On the Road to Improved Scheduling

Reducing the Effects of Variation in Duration

Lindhard, Søren Munch; Wandahl, Søren

Published in:
Proceedings of ICCREM 2013: International Conference on Construction and Real Estate Management

Publication date:
2013

Document Version
Accepted author manuscript, peer reviewed version

This is a pre-published version

Lindhard, S., Wandahl, S. 2014 "On the Road to Improved Scheduling: Reducing the Effects of Variation in Duration", Proceedings of ICCREM 2013: International Conference on Construction and Real Estate Management. Wang, Y., Lennerts, K., Shen, G. Q. P. & Bai, Y. (red.). American Society of Civil Engineers, **https://doi.org/10.1061/9780784413135.012**

On the Road to Improved Scheduling: Reducing the Effects of variation in Duration

Søren LINDHARD[1] and Søren WANDAHL[2]

[1]Ph.D. Candidate, Department of Mechanical and Manufacturing Engineering, Aalborg University, Denmark; PH (45) 21848004; Email: lindhard@m-tech.aau.dk
[2]Professor, Department of Engineering, Aarhus University, Denmark; PH (45) 41893216; Email: swa@iha.dk

ABSTRACT

Scheduling in onsite construction is based on commitments. Not kept commitments are resulting in non-completions which lead to waste. Moreover, it is important that commitments are made realistic to avoid both positive and negative variation in duration. Negative variation is destructive to plans and schedules, and is resulting in delays; while positive variation is destructive to productivity by creating unexploited gap between activities and thus inducing unexploited capacity. By registering non-completion at three construction sites, the magnitude of activities inducing negative variation has been mapped. In total 5424 activities has been registered whereof 1450 activities ended up as non-completions; thus, did 27 % of the scheduled activities not finish on scheduled. Both positive and negative variation can be minimized by improving the quality of the commitments. Moreover, positive variation can be exploited by A) ensuring that the crew finishing an activity to early can continue their work and B) ensuring that any connecting activity can start as fast as possible.

Key words: Variation, Scheduling, Waste, Construction management

INTRODUCTION

Production control is an essential part of every construction project and it is a necessity in the attempt to be able to handle the complexity of the project. In construction, production is characterized by being on-site and fixed position manufacturing, unique designs and one-of-a-kind production. Moreover, the projects are completed by a temporary organization of competing contractors which have to complete highly interrelated, interacting, and overlapping activities with limited space, multiple components, and a lack of standardization (Salem *et al.* 2006;

Lindhard, S., Wandahl, S. 2014 "On the Road to Improved Scheduling: Reducing the Effects of Variation in Duration", Proceedings of ICCREM 2013: International Conference on Construction and Real Estate Management. Wang, Y., Lennerts, K., Shen, G. Q. P. & Bai, Y. (red.). American Society of Civil Engineers, **https://doi.org/10.1061/9780784413135.012**

Bertelsen 2003a; Ballard 1998; Schmenner 1993). In this complex, dynamic, and uncertain context the schedule is trying to create order by adding structure to the process. It is a tool to keep track of the production so expenses in time and resources are kept under control. The objective of production control is thus to identify problems or negative variations, after which corrective actions can be taken (Ballard 2000).

In the Last Planner System (LPS) control is divided into three main tasks: planning, scheduling, and monitoring (Ballard 2000). The planning specifies what to be conducted and in which sequence. Scheduling determines the actual timing and duration of activities, while monitoring to keep track on the production provides feedback. Feedback is provided by comparing the actual progress with the conducted plans.

In LPS control is handled through four main schedules and a follow-up process (Cho and Ballard 2011; Salem *et al.* 2005). 1) The Master schedule, which cover the entire construction process and establishes overview by including important milestones. 2) The Phase schedule which, optimize the sequence of the construction project. 3) The Look-ahead plan, which contains a making ready process. In the making ready process the preconditions for production of upcoming activities are fulfilled. 4) The Weekly Work plan, which is a one week plan containing the activities which in the following week will be conducted. The plan is based on mutual commitments between the subcontractors. Ensuring that only ready activities enters the Weekly Work plans increases the success rate of completed tasks and increasing the reliability of the schedules (Ballard and Howell 1995). The four schedules are followed by a follow-up process, where the quality of the schedule is measured through the Percent Planned Completed (PPC) measurement. If low PPC is measured root causes are investigated and eliminated in order to increase productivity (Ballard 1994; Howell and Ballard 1994). This way, the PPC measurement serves both as a feedback system and as a learning system.

METHODS

Three construction sites are followed to observe and register causes for non-completed activities. Collection of qualitative data made it possible to get an apprehension to extend but also the causes to non-completion in onsite construction.

To ensure high quality of the collected data, the cases were selected based on three basic requirements: Last Planner Systems had to be applied, and PPC calculation had to be conducted. Furthermore, since most data are collected from archives, reasons for non-completion or non sound activities had to be described. To secure consistency in how the registration is carried out all three construction

Lindhard, S., Wandahl, S. 2014 "On the Road to Improved Scheduling: Reducing the Effects of Variation in Duration", Proceedings of ICCREM 2013: International Conference on Construction and Real Estate Management. Wang, Y., Lennerts, K., Shen, G. Q. P. & Bai, Y. (red.). American Society of Civil Engineers, **https://doi.org/10.1061/9780784413135.012**

projects followed have the same site manager in charge. In the selection process, mail correspondences and phone conversations with site managers and company consultants secured the fulfillment of the mentioned requirements.

Collection of data is carried out through either the LPS meetings or archived summaries from the LPS meetings. The LPS meetings are at focus because the PPC calculation and collection of reasons for non-completion take place at the LPS meetings. Furthermore, the LPS meetings includes the Look-ahead planning and the scheduling of the next weeks plans which in relation to LPS-theory are completed in collaboration between site-mangers and foremen. The use of archives enables collection of data from the entire construction period.

The archived data are supplemented with onsite observations to get an insight to how the meeting actually proceeded and how non-completions were recorded. Besides participating in the meetings the cases studies were supplemented with on-site observations and semi and unstructured interviews. These supplementing studies were carried out to increase the insight to how non-completions were handled and registered on-site. Even though these supplementing methods only were applied at one of the three construction cases the results were generalized. The generalization is based on the fact that all construction cases had the same site-manger in charge.

The data analysis started by categorizing the recorded causes to non-completions into main categories. This is done to get an overview to causes to non-completion and to simplify the problem. Data collection from the cases is listed in **Fejl! Henvisningskilde ikke fundet.**.

Table 1: Data collection from the three case studies

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

RESULTS

Lindhard, S., Wandahl, S. 2014 "On the Road to Improved Scheduling: Reducing the Effects of Variation in Duration", Proceedings of ICCREM 2013: International Conference on Construction and Real Estate Management. Wang, Y., Lennerts, K., Shen, G. Q. P. & Bai, Y. (red.). American Society of Civil Engineers, **https://doi.org/10.1061/9780784413135.012**

In total 5424 activities has been registered whereof 1450 activities ended up as non-completions. This entail that the average PPC for all construction projects is 73,27 %. Thus, is the likelihood of completing two connected activities without delay only (73,27^2) 53,68 %. Moreover, the likelihood of, without delay completing every activity in a construction project including only 100 activities is approximately zero. Thus, external elements such as slack and management adjustments are necessary to avoid accumulated delay between interrelated activities.

At the three construction projects the cause to every non-completion has been registered. The results are presented in Table 2. The causes to non-completions has besides an "unknown" category, been divided into 11 categories. Nine categories are non-completions caused by not-ready activities which cannot be completed. Six of these categories are corresponding to the preconditions presented by Koskela (1999), while the last three categories are an expansion of Koskela's (1999) external conditions. This expansion is presented in Lindhard and Wandahl (2012b) and includes the categories: Weather conditions, unexpected conditions, and safety. The remaining two categories are containing non-completions caused by changes made in the schedule or activities where rework is required.

The "unknown" category contains non-completions where the reasons have not been identified. It contains, among others, non-completions where the completion duration exceeded the scheduled. The remaining registrations, if any, could be caused by A) the "unknown" category can be caused by not identified categories or sources to non-completions. B) The "unknown" category could be non-completions related to a single or few categories were the registrations have not been correct completed. C) The unknown category is common mistakes in the registration process, and should be equally distributed between all the identified categories. D) Finally, the "unknown" category could be caused by a combination A), B) and C).

Table 2: Deviation of non-completions

	Registration of occurrences	Registrations pr. 100 planned activities
Unknown	612	11,28
Connecting works	250	4,60
Change in work plans	147	2,71
Work force	134	2,47
Weather conditions	92	1,70
Materials	87	1,60
Construction design	76	1,40
Space	21	0,39
Equipment	13	0,24

Lindhard, S., Wandahl, S. 2014 "On the Road to Improved Scheduling: Reducing the Effects of Variation in Duration", Proceedings of ICCREM 2013: International Conference on Construction and Real Estate Management. Wang, Y., Lennerts, K., Shen, G. Q. P. & Bai, Y. (red.). American Society of Civil Engineers, **https://doi.org/10.1061/9780784413135.012**

Rework	8	0,15
Unexpected conditions	6	0,11
Safety	4	0,07
Total	1450	26,7

From Table 2 it can be concluded that approximately 27 % of all activities is delayed due to negative variation in the execution process. From this follows that the remaining 73 % of the activities theoretically will be completed on time or before scheduled. Assuming that the duration of an activity is normally distributed then the negative variation should in theory be more than counterbalanced with the positive variation of subsequent activities.

DISCUSSION

Scheduling is based on commitments. Non-completions are activities not completed according to schedule, and thus not kept commitments made at the weekly LPS meetings. Therefore, in order to improve onsite scheduling the number of non-completed activities must be minimized. This increases the schedules robustness and reduces the risk of delay.

In construction both positive and negative variation is undesirable (Lindhard and Wandahl 2012d). Negative variation is destructive to plans and schedules, and is resulting in delays (Howell and Ballard 1994). This was clear illustrated in the Parade of Trades simulation by Tommelein et al. (1999). Most often the positive variation does only create unexploited gap between activities. The wasted gaps are an effect of multiple trades completing highly interdependent activities (Bertelsen and Koskela 2004; Bertelsen 2003b). Interdependencies between the multiple trades on site make it difficult to adjust the sequence because the next trade is often occupied elsewhere, not-aware of the gap, or simply not ready to start the conduction of the following activity. Moreover, onsite construction is dominated by long changeover times caused by the complexity and the fact that onsite production is not following a straight assembly line. In construction different trade’s does simultaneous work at interacting and overlapping activities (Lindhard and Wandahl 2012d). This makes it difficult to keep a sense of perspective and complicates the management and communication at site.

The average PPC is way below the theoretical 100 percentage level. One reason to the high number of non-completions is that non-sound activities are able to enter the Weekly Work Plans. Despite the making ready process at the Look-ahead level in LPS removes constraints, resurrections are still possible. To detect the resurrections Lindhard and Wandahl (2011) suggested to implement a health check just before an activity enters the weekly work plan.

Lindhard, S., Wandahl, S. 2014 "On the Road to Improved Scheduling: Reducing the Effects of Variation in Duration", Proceedings of ICCREM 2013: International Conference on Construction and Real Estate Management. Wang, Y., Lennerts, K., Shen, G. Q. P. & Bai, Y. (red.). American Society of Civil Engineers, **https://doi.org/10.1061/9780784413135.012**

When disregarding the "unknown" category, approximately 15 % of all activities entering the Weekly Work Plans end up as non-completions due to problems with at least one of the 9 mentioned preconditions. The remaining 2-3 percentage is caused by rework and changes in work plans. Though, the triggers to changes in work plans, besides just bad scheduling, can be related to delay, non-sound work activities, or to rework.

There seems to be two roads to achieve increased robustness in the schedule. A) Exploiting the positive variation in an attempt to counterbalance the effect of non-completions including negative variation. B) Minimizing the number of non-completions to raise the PPC level above the 70 percentage level.

Exploiting positive variation

The positive variation is exploited if the utilization of the capabilities in the production system is kept high. This includes high utilization of the present work force, equipment and machinery, and space etc. It is important to notice that even though lowering the manning will result in high utilization of the remaining work force the capabilities in the production system is not exploited.

Thus, the first step is to ensure that the crew finishing an activity to early can continue their work while the second step is to ensure that any connecting activities are able to start as fast as possible. One approach to fulfill the two steps would be by buffering activities or workforce, respectively. Because of the associated cost buffering is not the ideal solution to handle variation and should therefore be minimized (Ballard and Howell 1995; Howell and Ballard 1994). Of course the need for buffering will decrease as variation an uncertainty is removed from the schedule (Ballard 1999).

The needs of buffering will decrease if the complexity of the construction process is reduced. This can be achieved by reducing the number of activities and trades on site (Lindhard and Wandahl 2012c). Moving activities away from the construction site could be achieved by increased prefabrication, preassembly and modularization. Fewer activities and fewer trades equal less interactions and interdependencies between the present trades (Lindhard and Wandahl 2012c). Moreover, modularization will ideologically simplify the assembly process at site leading to less complex work activities. If task complexity is reduced the need of a specialized work force is reduced. Thus, the remaining activities could be completed by more general skilled craftsmen. This increase the flexibility and adaptability in the assembly process (Lindhard and Wandahl 2012c). Furthermore, general skilled craftsmen will be capable of completing the same buffered activity reducing both buffer size and the related waste.

Lindhard, S., Wandahl, S. 2014 "On the Road to Improved Scheduling: Reducing the Effects of Variation in Duration", Proceedings of ICCREM 2013: International Conference on Construction and Real Estate Management. Wang, Y., Lennerts, K., Shen, G. Q. P. & Bai, Y. (red.). American Society of Civil Engineers, **https://doi.org/10.1061/9780784413135.012**

Minimizing the number of non-completions

To raise the PPC level non-ready work activities should be prevented from occurring in the Weekly Work Plans. Thus, the quality of the making ready process should be improved. Non-ready activities emerge in the Weekly Work Plans because of the varying nature of the preconditions (Lindhard and Wandahl 2011). If possible the ideal solution would be to avoid or at least reduce the variation in the individual precondition. By finding the root cause to variation and prevent that from reoccurring variation in the preconditions can be avoided. Thus, non-ready activities will not occur in the Weekly Work Plans.

It will be impossible to stop all variation in the preconditions. Unexpected and undiscovered changes can evolve affecting the soundness of an activity. Since soundness cannot be guaranteed Lindhard and Wandahl (2013b; 2011) suggest a weekly health check of all buffered activities to prevent non-sound activities from entering the Weekly Work Plans. Moreover, Lindhard and Wandahl (2013b) also suggests to briefly checking up on the soundness of the scheduled activities at a daily basis. The daily health check will help in detecting conflicts earlier while the still is time enough to make small adjustments in the schedule and thus avoiding interruptions in the workflow.

Reducing the risk of varying preconditions and avoiding non-ready activities from entering the Weekly Work Plans will increase the quality of the making ready process. By not only trying to fulfilling the basic requirements in the preconditions, but attempting to secure optimal production conditions, productivity will increase because the risk of negative variation is reduced (Lindhard and Wandahl 2013a).

Not all changes can be stopped by improving the making ready process itself. For instance does changes in the construction design emerge outside the construction site and therefore without control from site management. In an attempt to improve the design procedures, to design not only for present but also future needs Lindhard and Wandahl (2012a) suggested that the owner should complete a *"lifecycle"* plan of the expected usage in the buildings lifetime. By designing for the future, fewer changes are expected to occur within the construction process itself. Naturally, everything cannot be planned on beforehand. Therefore, is it also expected that unforeseen work activities emerge as the projects proceeds. The earlier these activities are discovered the more time is there to handle and avoid interruptions in the scheduled work flow.

The presence of labor is important in construction because every activity needs labor to be completed. Moreover, the output quality is depending of the labors performance. Therefore, the skill and motivation is in particular important. While

Lindhard, S., Wandahl, S. 2014 "On the Road to Improved Scheduling: Reducing the Effects of Variation in Duration", Proceedings of ICCREM 2013: International Conference on Construction and Real Estate Management. Wang, Y., Lennerts, K., Shen, G. Q. P. & Bai, Y. (red.). American Society of Civil Engineers, **https://doi.org/10.1061/9780784413135.012**

skill is a constant motivation is changeable and is affected by the surrounding working environment, supported by ethical values and leadership, it should ideally provide comfort and mutual trust (Lindhard and Wandahl 2012). Besides increased output quality increased motivation will lead to increased accountability and productivity (Singh 1996; Olomolaiye 1988). Accountability raises the likelihood of observing the commitments within the schedule and thus increases the schedules robustness (Lindhard and Wandahl 2012).

CONCLUSION

Time overruns is an everyday experience in today's construction projects. By increasing the robustness of the schedule the risk of time overruns can be decreased. Two roads to increased schedule robustness were identified. A) Exploiting the positive variation in an attempt to counterbalance the effect of non-completions including negative variation. B) Reducing negative variation. This is achieved by minimizing the number of non-completions to raise the PPC level above the 70 percentage level.

Positive variation is exploited if the utilization of the capabilities in the production system is kept high. This is achieved by ensuring that a) that the crew finishing an activity to early can continue their work and b) that any connecting activities are able to start as fast as possible. Several initiatives exists i.e. simplification of the production which can be achieved by reducing the number of tasks and trades on-site.

Negative variation is reduced if activities are ensured to be "ready" at the time of execution. Too minimize the risk of non-ready activities in the Work Plans; it is proposed to implement a weekly health check together with daily health updates and a soundness awareness among all project participants. Moreover, repeating non-completions can be avoided by detecting root causes and eliminating them. Avoiding repetitions is a part of LPS's learning process.

REFERENCES

Ballard, G., (2000). *The Last Planner System of Production Control*, University of Birmingham,.

Ballard, G., (1999), Improving Work Flow Reliability *Proceedings for the 7th annual conference of the International Group for Lean Construction*, Berkeley, USA, , pp. 275-286.

Ballard, G., (1998), What kind of production is construction? *Proceedings for the 6th annual conference of the International Group for Lean Construction*, Guaruja, Brazil, .

Lindhard, S., Wandahl, S. 2014 "On the Road to Improved Scheduling: Reducing the Effects of Variation in Duration", Proceedings of ICCREM 2013: International Conference on Construction and Real Estate Management. Wang, Y., Lennerts, K., Shen, G. Q. P. & Bai, Y. (red.). American Society of Civil Engineers, **https://doi.org/10.1061/9780784413135.012**

Ballard, G., (1994), Implementing Lean Construction: Stabilizing Work Flow, *Proceedings for the 2nd annual conference of the International Group for Lean Construction*28-30 September, Santiego, Chile, , pp. 101-110.

Ballard, G., Howell, G., (1995), Towards construction JIT, *Proceedings of the 3rd annual conference of the International Group for Lean Construction*, Albuquerque, New Mexico, .

Bertelsen, S., (2003a), Construction as a Complex System, *Proceedings for the 11th annual conference of the International Group for Lean Construction*, Virginia, USA, .

Bertelsen, S., (2003b), Construction as a Complex System, *Proceedings for the 11th annual conference of the International Group for Lean Construction*, Virginia, USA, .

Bertelsen, S., Koskela, L., (2004), Construction Beyond Lean: A New Understanding of Construction Management, *Proceedings for the 12th annual conference of the International Group for Lean Construction*25-27 July, Copenhagen, Denmark, , pp. 1-11.

Cho, S. and Ballard, G., (2011), Last Planner and Integrated Project Delivery, *Lean Construction Journal*, **7** (1), pp. 67-78.

Howell, G., Ballard, G., (1994), Implementing lean construction: reducing inflow variation *Proceedings for the 2nd annual conference of the International Group for Lean Construction*, Santiego, Chile, .

Koskela, L., (1999), Management of Production in Construction: A Theoretical View, *Proceedings for the 8th annual conference of the International Group for Lean Construction*26-28 July, Berkeley, USA, , pp. 241-252.

Lindhard, S., Wandahl, S., (2012), Adding production value through application of value based scheduling, *COBRA 2012-RICS International Research Conference*, Las Vegas, USA, .

Lindhard, S. and Wandahl, S., (2013a), Improving Onsite Scheduling - Looking into the Limits of Last Planner System, *The Built & Human Environment Review*, .

Lindhard, S. and Wandahl, S., (2013b), Learning From Constraints – On the Road to Increased Productivity in Onsite Production, *Construction Management & Economics*, -- (--), pp. --.

Lindhard, S., Wandahl, S., (2012a), Designing for Second Generation Value – Future Proofing Constructions, *COBRA 2012-RICS International Research Conference*.

Lindhard, S., Wandahl, S., (2012b), Improving the Making Ready Process - Exploring the Preconditions to Work Tasks in Construction,
Proceedings for the 20th annual conference of the International Group for Lean Construction, San Diego, USA 17th-22nd July.

Lindhard, S., Wandahl, S., (2012c), On the Road to Improved Scheduling – Fitting Activities to Capacity, *COBRA 2012-RICS International Research Conference*.

Lindhard, S., Wandahl, S. 2014 "On the Road to Improved Scheduling: Reducing the Effects of Variation in Duration", Proceedings of ICCREM 2013: International Conference on Construction and Real Estate Management. Wang, Y., Lennerts, K., Shen, G. Q. P. & Bai, Y. (red.). American Society of Civil Engineers, **https://doi.org/10.1061/9780784413135.012**

Lindhard, S. and Wandahl, S., (2012d), Scheduling of Large, Complex, and Constrained Construction Projects - An Exploration of LPS Application, *International Journal of Project Organisation and Management (IJPOM)*, .

Lindhard, S., Wandahl, S., (2011), Handling Soundness and Quality to Improve Relaibility in LPS – A Case Study of an Offshore Construction Site in Denmark, *COBRA 2011-RICS International Research Conference*September 11-12.

Olomolaiye, P.O., (1988). *An evaluation of bricklayers' motivation and productivity*, Loughborough University,.

Salem, O., Solomon, J., Genaidy, A. and Luegring, M., (2005), Site Implementation and Assessment of Lean Construction Techniques, *Lean Construction Journal*, **2** (2), pp. 1-21.

Salem, O., Solomon, J., Genaidy, A. and Minkarah, I., (2006), Lean Construction: From Theory to Implementation, *Journal of Management in Engineering*, **22** (4), pp. 168-175.

Schmenner, R.W., (1993). *Production / operations management: From the inside out.* Macmillan,.

Singh, J., (1996), Health, Comfort and Productivity in the Indoor Environment, *Indoor and Built Environment*, **5** (1), pp. 22-33.

Tommelein, I.D., Riley, D.R. and Howell, G.A., (1999), Parade Game: Impact of Work Flow Variability on Trade Performance *Journal of Construction Engineering and Management*, **125** (5), pp. 304-310.