A COMPARISON OF TAKT TIME AND LBMS PLANNING METHODS

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ABSTRACT

Takt time and LBMS are getting increased attention from practitioners of Lean Construction. The takt time approach focusses on designing work locations with similar quantities and plans on the same duration for each task without any buffers. To achieve level resource utilization takt time projects require substantial work backlog tasks or locations to absorb periods of low production demand. The LBMS approach plans on using consistent resources through all the locations. Buffers are added to absorb the risk of deviations and durations are allowed to vary based on quantity of work. This results in significantly longer schedules but decreases the need for workable backlog areas and the risk of demobilizations.

To compare these two methods, three schedules planned with LBMS methodology were reformed into takt time schedules by forcing each task to have the same duration in each location. This was achieved by changing the crew size in each location to achieve a duration shorter than or equal to the takt time. The resulting schedules were compared in terms of total project duration, total project manhours and the risk of duration and manhours evaluated using Monte Carlo simulation.

The results indicate that takt time achieves substantially shorter schedules but the manhours required in work backlog areas are much higher than in LBMS approach. In projects where quantities are similar between locations, takt time performs well if the resources are not demobilized when they run out of work. If the resources demobilize, the risk of return delays makes takt time a risky strategy.

KEYWORDS

LBMS, takt time, variability, buffers

INTRODUCTION

Takt time is originally a lean manufacturing concept where the goal is to make sure that the customer demand rate is met. It is the division of available work time per shift by the customer demand rate per shift (Rother and Shook 1998). Takt time requires balancing the production rates of different workstations to ensure that product does not accumulate between workstations and workstations do not starve waiting for work (Hopp and Spearman 2008). In recent IGLC conferences, several case studies of production system design using takt time in construction projects have been presented (Fiallo and Howell 2012, Frandson et al. 2013, Linnik et al. 2013). In building construction applications, takt time has been defined as the maximum number of days allowed to complete work in each location. (Frandson et al. 2013)

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Location-Based Management System (LBMS) is the latest generation of location-based planning techniques. Earlier related approaches include Line-of-Balance (Lumsden 1968) which was limited to exactly repetitive work. Flowline technique (Mohr 1979) removed the requirement of exactly repetitive work and used locations, rather than quantity of elements, but did not consider flexible location breakdown structures. Other location-based techniques include Arditi et al.'s (2002) integration of line-of-balance and CPM and Russell and Wong's RepCon (1993). LBMS is rooted in all of these methods and especially on extensive action research done in Finland since 1989. These results were originally published in Finnish but have been summarized in English (Kankainen & Seppänen 2003, Kenley & Seppänen 2010). The main contribution of LBMS over these previous techniques is the use of a flexible location breakdown structure, combining CPM algorithm to location-based techniques through layered logic, having a cost and risk model considering workflow continuity and buffers between locations, and a production control system forecasting future progress based on past production rates (Kenley & Seppänen 2010).

Linnik et al. (2013) wrote that the priority of LBMS is to maintain labor utilization and the priority of takt time is to have work flowing continuously without stopping. Both systems would in ideal case to eliminate workers waiting on work and work waiting on workers. LBMS allows durations of a task to vary when quantities are not the same between locations. Takt time requires durations to be the same. The LBMS approach plans for the same crew to work continuously through the project, maximizing learning benefits, and making progress easier to forecast. It has been argued that providing a continuous work path for a consistent work crew will reduce the complexity of projects (Kenley 2005). Furthermore, LBMS attempts to prevent the risk of cascading delays by taking corrective actions when two crews are forecast to interfere with each other. Buffers allow time for corrective action (Seppänen 2009).

The takt time is determined based on the production rate of the bottleneck task or based on project requirements (Frandson et al. 2013). The approach allows for continuous workflow but has a risk of capacity loss for faster trades following the bottleneck trade. Reducing the variability in production rates and workable backlog have been proposed as possible ways to reduce this capacity loss (Linnik et al. 2013). Takt time approach should reduce overall project duration by increasing concurrency (Linnik et al. 2013). Both approaches will increase predictability of work releases; takt time by forcing everyone to the same rhythm and LBMS by explicitly focusing production control on interference between trades.

In IGLC 2013 conference in Fortaleza, a discussion about differences and similarities between LBMS and takt time arose. The research described in this paper is an attempt to quantify these differences to enable better understanding of the similarities and differences. The questions addressed in this research are:

- What is the duration difference between a takt time and optimized LBMS schedule?
- How large of a workable backlog is required in takt time versus LBMS schedules? How does risk impact the results?
- Do the results differ between repetitive and non-repetitive projects?

METHOD

Three location-based schedules which had been optimized with LBMS principles were selected for comparison. The projects were selected to represent different project types – a highly non-repetitive race track tower, a highly repetitive office building, and a moderately repetitive medical office building. The selected schedules were all resource-based with subcontractor-provided labor consumption values and were quantity-loaded by location for each task. The analysis focused on the interior rough-in and finishes stage of each project.

Table 1 summarizes the project details. Repetition in the table refers to how similar the quantities were in each location. It should be noted that the project teams had participated in optimizing the LBMS schedules, and identification of bottlenecks and resource requirements, but they did not participate in the creation of comparison takt time schedules. The project teams had used the optimized LBMS schedule for production control. This comparison uses the same data but for the purpose of theoretical comparison.

Table 1: Summary of three selected projects

	Project 1	**Project 2**	**Project 3**
Building type	Sprint Tower	Office building	Medical Office Building
Gross m2	83293	14856	28350
Number of tasks	27	50	23
Number of locations	17	14	20
Repetition	Low	High	High
Areas outside of takt	Not included	First floor, Basement, Plant	Not included

The existing LBMS schedules were converted into takt time schedules by using the following approach. First, any buffers in the LBMS schedule were removed. Second, dummy “takt line” flowlines were added to the schedule based on the production rate of the slowest “bottleneck” task. Bottleneck tasks were identified based on the LBMS schedule which also synchronizes all production rates to bottleneck tasks. Therefore, the production rate of the slowest task of the LBMS schedule was equal to production rate of the “takt line”. To achieve consistent takt time, the total duration of the bottleneck task was divided by the number of locations and rounded to the closest full day. The takt time was allowed to change between locations if the majority of tasks had larger quantities in one specific location. Third, the actual production tasks were tied to these takt lines with a Start-to-Start link and planned to start as early as possible. This ensures that even if the preceding location finishes early, the work in the next location will not start before dictated by takt. Fourth, the number of crews in each location was adjusted to change the duration to be equal or shorter than takt time.

The two schedules of each project were compared based on total duration and amount of waiting hours. Figure 1 shows the difference between LBMS and takt time schedules for three tasks from Project 3. LBMS duration is longer but the takt time schedule experiences periods of downtime. Total duration was observed visually from the schedule. Waiting hours are automatically calculated in Schedule Planner

Standard 2013 (Trimble Navigation Limited 2013) software by filling in any valleys in the resource graph as illustrated in Figure 2. This waiting time could be actual waiting time and lost productivity or it could be spent on workable backlog in tasks not included in the takt time or LBMS schedule.

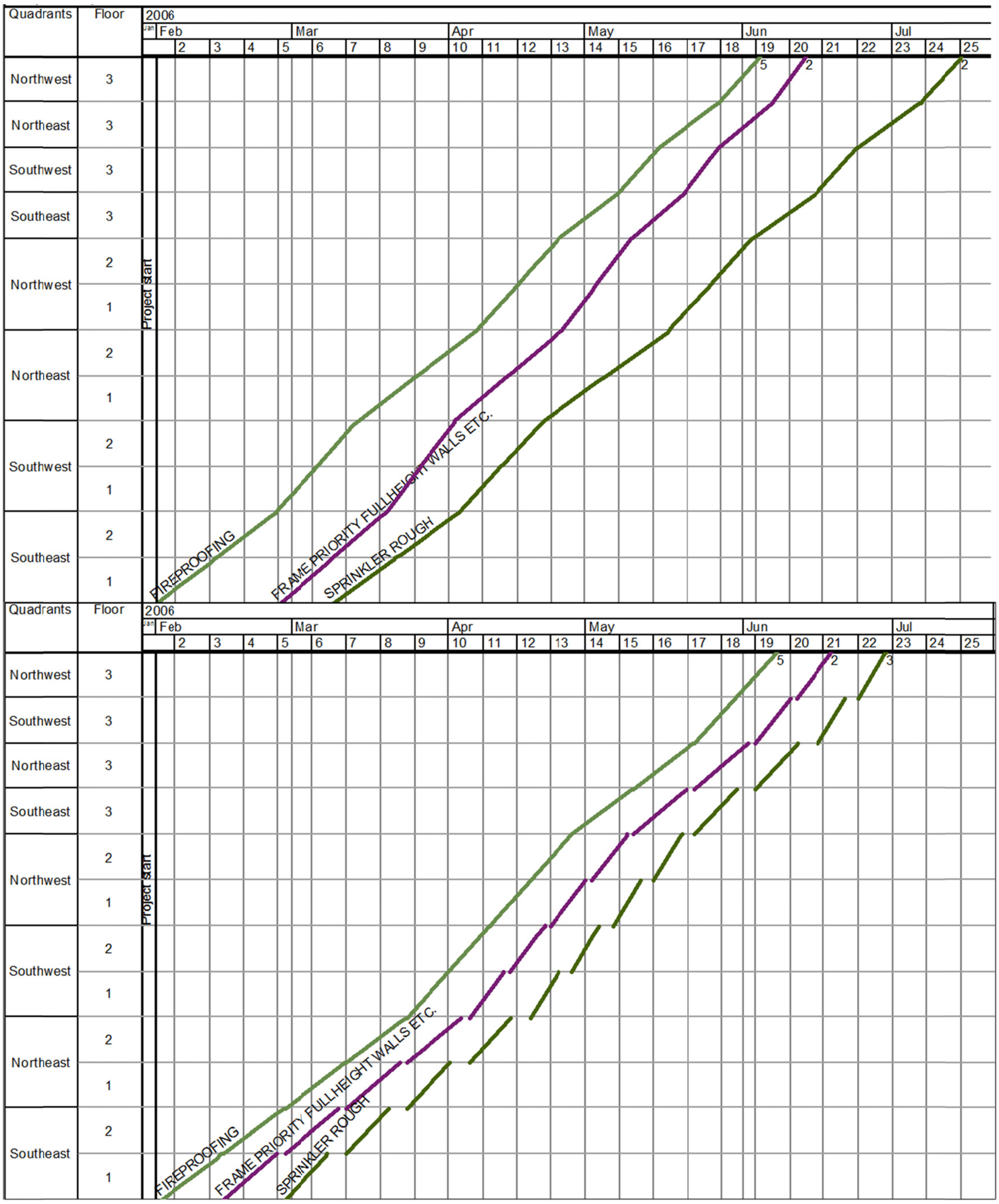

Figure 1: LBMS (top part) vs. Takt (bottom part). Takt time version compresses the schedule by two weeks but has starts and stops for tasks which are faster than the bottleneck.

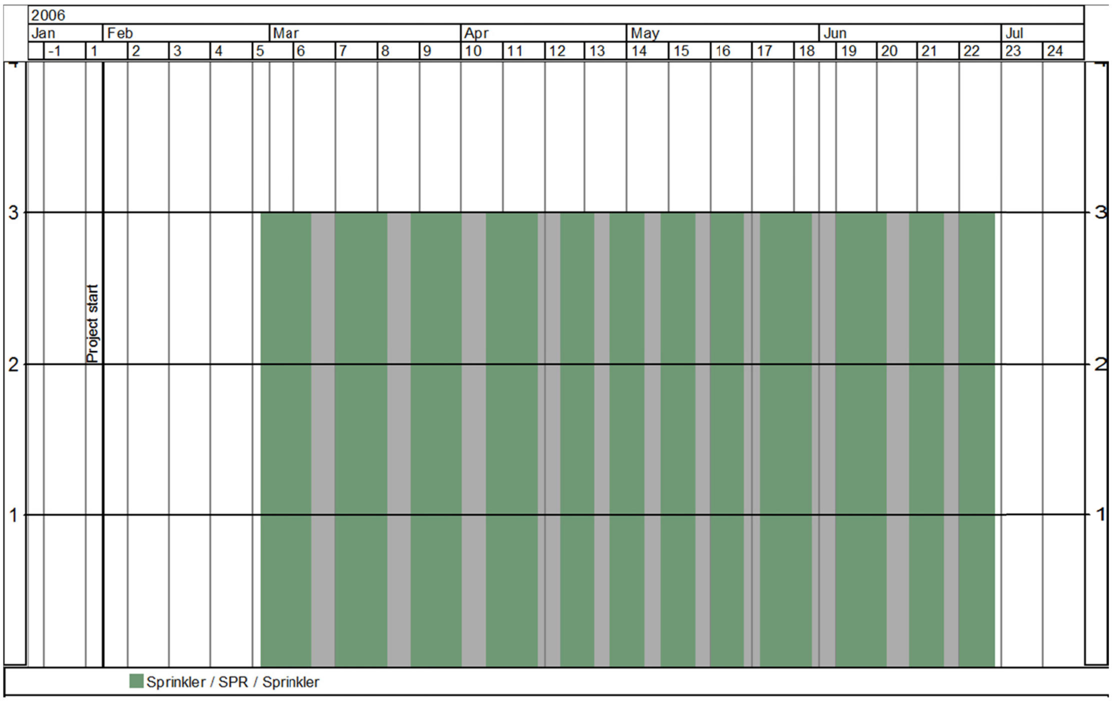

Figure 2: Waiting time calculation graphically. Sprinkler contractor of Figure 1 has downtime after each location. The downtime is graphically represented as the grey area in the resource graph.

The comparison of LBMS and takt time was done deterministically based on the planned schedule and stochastically based on risk analysis simulation performed in Schedule Planner 2013 software (Trimble Navigation Limited 2013). The risk simulation considers the following types of risks (Kenley & Seppänen 2010):

- Starting risk
- Duration risk
- Resource mobilization risk
- Resource return delay risk
- Production rate risk

Starting risk considers uncertainty related to starting the task based on any factors which are not included in the schedule as tasks. Duration risk is random variation of duration which is independently sampled for each location. Production rate risk is similar but it is sampled once for each trade and thus the risk impacts all locations. Resource mobilization risk is the delay associated with mobilizing new resources and is sampled for each mobilization event. Resource return delay risk is the risk related to resources not returning to site immediately when they are needed if they have had to demobilize. This risk type increases the risk of schedules without time buffers. Table 2 shows the risk values used for low, medium and high variability scenarios by risk type. All distributions were beta distributions with minimum, expected and maximum parameters.

Table 2: Risk values in low, medium and high variability scenarios

	Variability	Minimum	Expected	Maximum
Starting risk (days)	Low	-2	0	5
	Medium	-5	0	10
	High	-10	0	15
Duration risk (%)	Low	90%	100%	120%
	Medium	80%	100%	150%
	High	50%	100%	200%
Resource mob. risk (days)	Low	0	0	2.5
	Medium	0	2.5	5
	High	0	5	10
Resource return delay risk (days)	Low	0	2.5	5
	Medium	0	5	10
	High	0	5	15
Production rate risk (%)	Low	90%	100%	110%
	Medium	70%	100%	130%
	High	50%	100%	150%

The risk analysis for each schedule in each project was run with 1,000 iterations using three different sets of risk values based on low, medium and high variability. Additional variables included whether the resources waited on site (incurring waiting hours but no return delay risk or mobilization risks) or demobilized (not incurring waiting hours but including risks of return delay and mobilization). In risk analysis, the maximum amount of resources for each subcontractor were constrained to the same level in both takt time and LBMS schedules based on the maximum required level in either schedule. In the stochastic case, schedules and strategies were compared by looking at the minimum, expected and maximum durations and waiting hours and their variance.

RESULTS

Generation of the takt time schedules was more complicated than anticipated. Selecting the appropriate takt time was straightforward only in Project 3 where very few unique tasks existed. Both Projects 1 and 2 had special circumstances that needed to be taken into account. Project 1 had a very slow flooring task in the end of the project which was clearly a bottleneck and could not be accelerated because of resource constraints. However, if all tasks had been aligned to this bottleneck task, project duration would have increased substantially. A decision was made to allow more time for that task in locations where resource constraint was reached. This caused some extra empty space in the schedule which functioned as a buffer. Project 2 had an opportunity to increase the pace substantially in the latter half of the project. However, Level 1 of the building had unique tasks and constraints, and was was on the critical path. It could not follow takt time because it was accessible much later than other locations. Therefore, the benefit of takt time strategy was limited in Project 2.

Visual comparison of the resulting schedules show that takt time production has all the flowlines going at the same slope in clean progression but LBMS schedule has a lot of kinks in flowlines caused by quantity variation. There is also a lot more empty space in LBMS schedules because task start dates are delayed to achieve workflow continuity based on the most constrained location of each task. Buffers are also represented by empty space. Figure 3 shows the comparison of LBMS schedules (top part of figure) and takt time schedule (bottom part of figure) of Project 3. Takt time approach compresses the project duration from 51 weeks to 48 weeks by removing all empty space from the schedule.

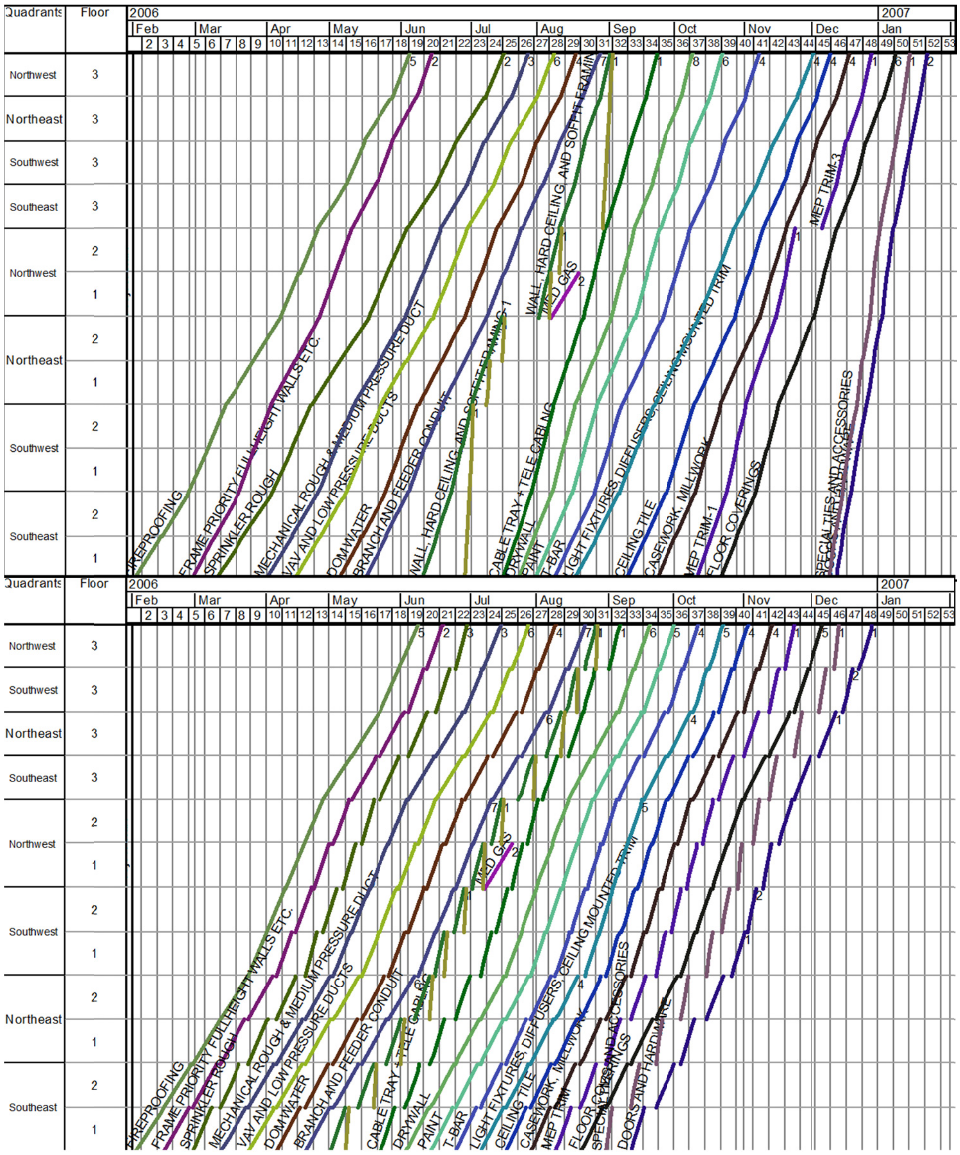

Figure 3: Visual comparison of LBMS (top) and takt time (bottom) schedules. Takt time compresses all empty space from the schedule. Small numbers on top of lines or line segments denote the number of crews.

Table 3 shows the deterministic duration in weeks and waiting hours (as a percentage of total hours scheduled) by project and by scheduling method. For example, 54% in project 1 is based on 24,358 waiting hours divided by 45,528 working hours. Working hours are the same in both schedules. Projects 2 and 3 are close in duration but in non-repetitive Project 1 takt time approach achieves a duration saving of 33% (20 weeks). Waiting hours in Projects 1 and 3 are substantially higher for takt time scenario and almost identical for Project 2.

Table 3: Duration and % of waiting time for LBMS and takt time schedules

		Project 1	Project 2	Project 3
LBMS	Duration	60	64	52
	% of waiting hours	14%	43%	3%
Takt time	Duration	40	63	49
	% of waiting hours	54%	42%	15%

In the stochastic scenario, waiting hours are incurred only when resources wait rather than demobilize. If resources demobilize, duration risk increases due to return delay risks. Figure 4 shows project duration in the case when resources demobilize in both strategies. Deterministic duration is based on the plan without risk simulation. Minimum (maximum) duration is the shortest (longest) duration found during 1,000 simulation rounds. Expected duration is the mean project duration over all simulation rounds. Project 1 results show that LBMS is very close to deterministic duration in all cases. Takt time schedules are shorter but under medium and high variability they deviate significantly from deterministic duration. Project 2 has virtually identical results for takt time and LBMS scenarios. Project 3 takt time schedules have longer durations than LBMS schedules even though the deterministic schedule was three weeks shorter.

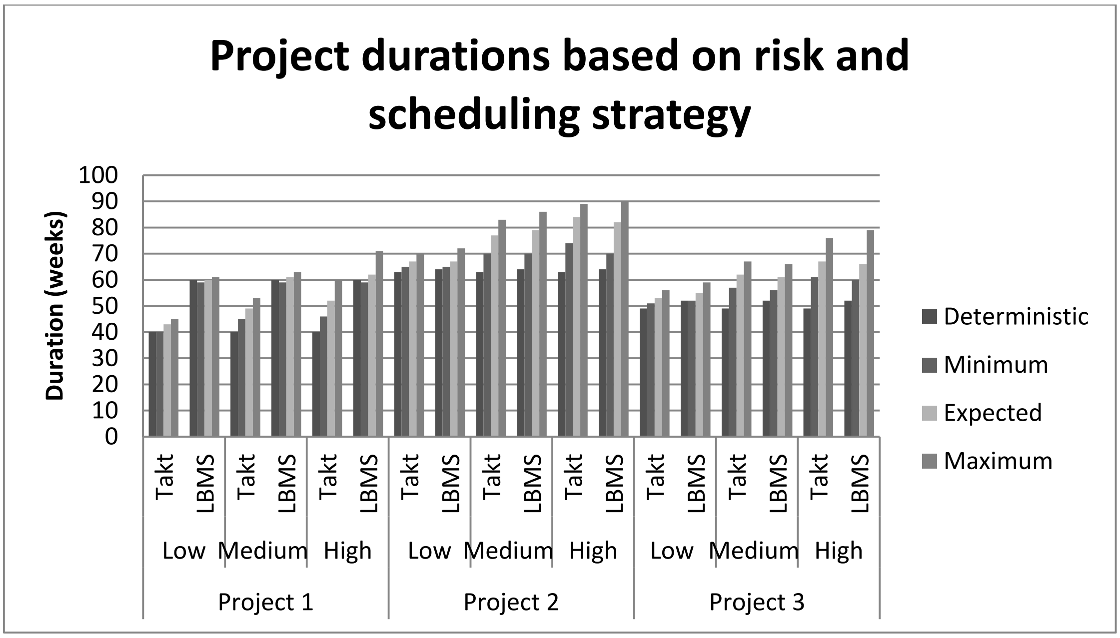

Figure 4: Comparison of takt time and LBMS durations when resources are allowed to demobilize

In takt time projects it is more likely that resources would be assigned to workable backlog rather than be allowed to leave the site. Figure 5 shows the overall durations when resources are not allowed to leave the site and work is prioritized in the locations following takt time. LBMS results are also shown for comparison purposes. Both schedules are very close to deterministic duration when resources are not allowed to demobilize except when variability is high, where projects 2 and 3 show minor delays of expected results to deterministic duration.

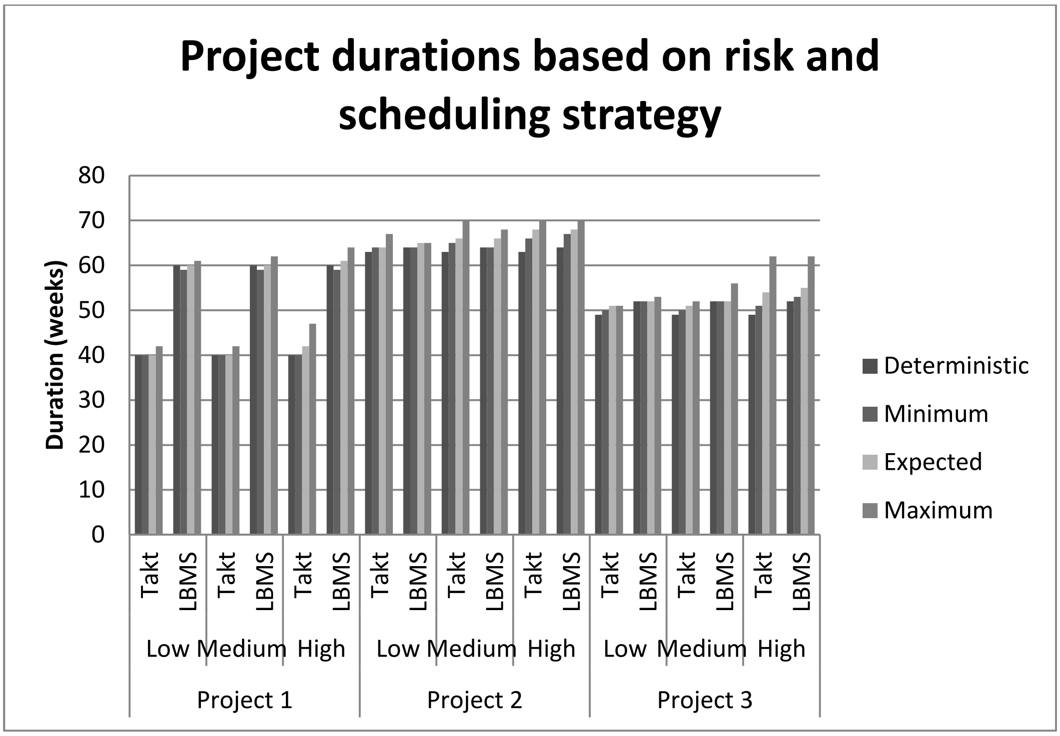

Figure 5: Comparison of takt time and LBMS durations when resources wait

The downside of achieving a more reliable duration by having resources wait is the requirement to have either a large workable backlog or have resources idle doing non-productive work. The size of the workable backlog was evaluated in the waiting scenario as a percentage of planned production manhours. For example, a 100% workable backlog would require as many hours outside of takt time production as within takt time production tasks. Figure 6 shows these results by project and by scheduling strategy comparing to deterministic scenario in each project. Waiting hours in takt time strategy are (in all projects) larger than with LBMS strategy. The difference is most evident in project 1. Project 2 also shows differences in simulation even though the deterministic values were identical.

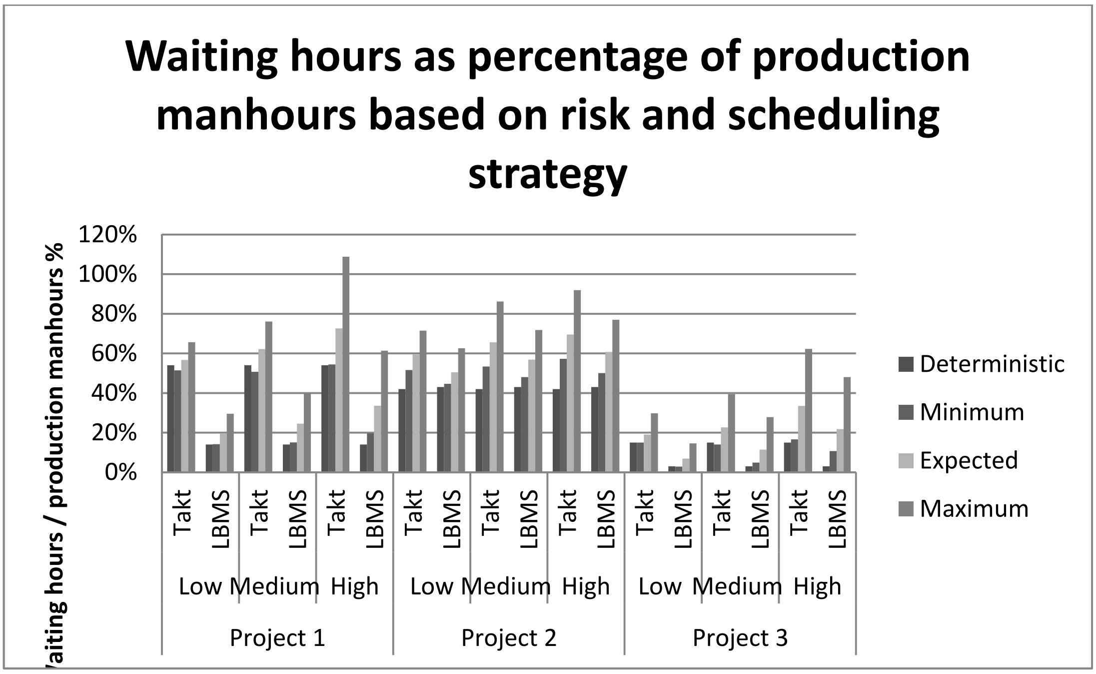

Figure 6: Comparison of waiting hours in takt time and LBMS schedules

DISCUSSION

Results were very different for each project. The trade-off between waiting time and duration was clearly demonstrated in the non-repetitive Project 1 (the sprint tower) where crews needed to be adjusted for each floor due to varying quantities of work. Project 2 had critical path flowing through areas which were not part of the repetitive sequence amenable to takt time sequencing. In this project takt time brought no additional duration benefit but still used more manhours to achieve the same duration. Project 3 saved three weeks by using the takt time method but the benefits disappeared under the high variability scenario and waiting hours were substantially higher on all risk levels.

These results indicate that the right scheduling strategy is dependent on project variability, repetitiveness, availability of workable backlog, and cost considerations of keeping crews waiting. When quantities are highly variable between locations, takt time is able to achieve much shorter schedules but at the cost of managing large amounts of workable backlog. Since it is not realistic to manage a workable backlog of 80% of takt time hours, the required backlog in Project 1, takt time may not be suitable for these types of projects. In repetitive projects both the duration savings and waiting time cost are much smaller. In these projects LBMS strategy is very close to takt time because the production slopes are the same between locations. The differences arise from the LBMS requirement of continuously working optimal crews which causes small slope differences and requires some additional buffers.

It should be noted that the best practices of takt time planning include designing work areas so that the quantities are similar between locations (Frandson et al. 2013). This research did not consider changing locations to achieve takt. Additionally takt time provides a management benefit which is not apparent from the simulation study. Committing to the same duration in each location makes schedules easier to implement because they are very easy to understand and communicate. It can also drive continuous improvement because the takt time must be met week after week (Frandson, et al. 2013, Linnik et al. 2013). In CPM methodology controlling is essentially an after-the-fact process limited to reacting to problems after they have happened. In LBMS, control actions are targeted at tasks which are about to cause production problems (Seppänen 2009). In the takt time approach, control actions need to be even more "real-time" and problems occur immediately if takt time is not met by a task. Any deviations are mitigated by assigning resources to workable backlog tasks rather thanleaving the site whenever takt time work is not available.

Simulation results show that although buffers are not included in takt time schedules, the time used on workable backlog tasks operates as a kind of buffer. Resources cannot be allowed to leave the site or duration benefits will not be gained. The use of takt time approach requires careful consideration of how much workable backlog is available for each trade. Reducing the variability of production using other lean approaches will also help to mitigate the impact.

FUTURE RESEARCH

The results presented here open up many different additional avenues for exploration. One of the more important future research questions is related to how much workable backlog outside of takt time work is available for each trade. How much workable backlog is realistic as percentage of total manhours? How does the burden to manage workable backlog in the takt time approach compare to the management of buffer in the LBMS approach?This number can be used to estimate the feasibility of using takt time versus other management strategies.

It was also found that if locations are sufficiently similar, the required workable backlog size decreases along with the duration benefit over standard LBMS approach. How much can locations be standardized in a complex construction project? Will location boundaries which are not obvious (e.g. non-linear shapes rather than floors and quadrants) negate the benefit of having a clear, repeating target for each week? Can location boundaries be made more obvious by visual management techniques?

CONCLUSIONS

This research compared the LBMS and takt time scheduling methodologies. A method to create a takt time schedule within LBMS framework was introduced. In the deterministic case, takt time was found to decrease project durations if the project's critical path went through the locations and tasks following takt time. The effect was most evident when the quantities of work differed by location. In these cases the slopes of LBMS schedules were allowed to change between locations resulting in empty space between tasks. However, the gain in time was offset by the requirement to have large workable backlogs. In more repetitive projects, takt time schedules were somewhat faster than LBMS schedules but also required more workable backlog. It can be said that the workable backlog takes the place of LBMS buffer in takt time scheduling and control.

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