Seppänen, Olli; Evinger, Jake; Mouflard, Christopher

Comparison of LBMS schedule forecasts to actual progress

Published in:
Proceedings of the 21st Ann. Conf. of the Int'l Group for Lean Construction

Published: 01/01/2013

Document Version
Publisher's PDF, also known as Version of record

COMPARISON OF LBMS SCHEDULE FORECASTS TO ACTUAL PROGRESS

Olli Seppänen[1], Jake Evinger[2] and Christopher Mouflard[3]

ABSTRACT

Location-based Management System (LBMS) uses actual progress, resource, and productivity data to calculate schedule forecasts. The forecasting method has been developed by using empirical results from real construction projects and these forecasts are intended to be used as early warnings to highlight production problems and interference before they occur. It is expected that control actions are taken in response to adverse forecasts to prevent the forecasted problems from happening on site. The updated forecasting system based on earlier research has been used in several projects and now there is enough data to evaluate how well the forecasts reflect reality.

In this research, forecasts from two hospital construction projects were evaluated for accuracy. Tasks were selected for analysis based on their manhour count, availability of accurate resource data and full completion of the operation. Forecasts were reviewed at four dates during performance of each task. The forecast on each date was compared to actual progress on these four dates. Results show that certain deviations such as working out of sequence, not finishing locations or working in several locations at the same time severely impact the forecasting ability of LBMS and make the project schedules unpredictable. Forecasting is accurate in the short term if there are no special circumstances and the work proceeds continuously.

KEYWORDS

Location-Based Management Systems, CPM, flowline, Production Control.

INTRODUCTION

Location-based Management System (LBMS) calculates schedule forecasts based on actual progress and original schedule (Kenley & Seppänen 2010). Forecasts in Critical Path Method (CPM) are based on manually providing remaining durations for any ongoing activities, adjusting for logic changes and then recalculating the network and re-planning to achieve the original contract duration (Galloway 2006). LBMS forecasts are different from those in CPM because the forecast is a technical calculation based on quantities produced and resources used (Seppänen 2009). Forecast is also a separate "stage of information". The original plan remains until replanning is necessary and the forecast is used to manage production to that plan and to alarm of upcoming production problems (Kenley & Seppänen 2010).

[1] Postdoctoral Researcher, Aalto University and Director of VDC Services, Trimble Navigation Limited, olli_seppanen@trimble.com

[2]. Senior Project Manager, Trimble VDC Services, jake_evinger@trimble.com

[3] Project Engineer, Trimble VDC Services, chris_mouflard@trimble.com

LBMS forecasts are used primarily to predict upcoming problems and to allow management to take early action when actual production rates do not meet the target rate. Forecasts do not become the new plan or the new target. Instead, production managers should take control actions to beat the forecasts and prevent them from becoming reality (Seppänen 2009). LBMS forecasts are based on actual resource consumption (manhours / unit) achieved close to the time of calculating the forecast (recent events are given more weight). This resource consumption is combined with forecasted resource information (either from the plan or from the control plan if one has been used). The duration of all upcoming locations of the same type of work is calculated by using this resource consumption value. Impacts to other tasks are calculated using the logic network. Seppänen (2009) has described these calculations in detail.

There has been some debate in Lean Construction community about the stability of workflow. Bertelsen and Koskela (2003) argued that construction is a turbulent kind of production. Kenley (2005) disagreed and argued that similar work in previous locations can be used to forecast progress of the same type of work in upcoming locations. These studies did not present any empirical evidence. Seppänen (2009) tested the forecasts and alarms using three case projects. It was found that the forecasting system gave good information about upcoming production problems which could be used for management (but often was not because an adequate social process was missing). However, the accuracy of forecasting was not evaluated numerically.

Forecasts can be used to provide support to look-ahead and weekly planning functions of the Last Planner System™. Seppänen, Ballard and Pesonen (2010) proposed that the forecasts would be used to select the tasks for the look-ahead window and discussed weekly in a superintendent meeting devoted to look-ahead planning. The look-ahead plans and weekly work plans would use LBMS forecasts as one information source. LBMS forecasts which have been updated with any agreed-on control actions can be used by Last Planners to compare weekly plan commitments to what should be happening based on the forecast (Seppänen, Ballard & Pesonen 2010). If Last Planners use the forecast as proposed, they should know how accurate forecasting is and what its limitations are. The goal of this research is to provide insight to the accuracy and limitations of forecasting.

In this research, we evaluated the accuracy of LBMS forecasts by analyzing two hospital construction projects and comparing forecasts to actual progress. Our hypothesis was that the forecasts would be more accurate in the short term for continuous production of similar work. We expected the forecasts to fail if there were a lot of problems with starting constraints, if there were a lot of starts and stops, if work was performed out of sequence or if work was not fully completed before moving to the next location. Forecasts were evaluated in terms of total quantity completed, manhours consumed and sequence of work.

METHOD

The schedule forecasts were evaluated for tasks at four time points looking forward one, two, three and four weeks. These forecasts were compared to actuals of the same time intervals. The tasks were selected from production tasks of two hospital projects based on the following requirements:

- Production task of more than 1,000 man-hours of work
- Task duration calculated based on quantities and resources
- Actual progress data entered weekly
- Task included in superintendent production reports

The project file of the week of question was opened and the following data was collected from the forecast for each task for the next four weeks:

- Predicted labor consumption (mh/unit)
- Predicted production rate (units/day)
- Predicted resources (mh/day/ 8)
- Predicted no. of locations completed
- Predicted locations with work

Corresponding actual data was collected at the same time steps and compared to the forecast:

- Actual labor consumption
- Actual production rate
- Actual resources
- Number of locations completed
- Percentage of correct locations completed
- Percentage of correct locations worked

RESULTS

Introduction of data

The two case study projects followed a different management philosophy. One of the projects (Project 1) tried to use LBMS, forecasts and the Last Planner System™ to improve production. The other one (Project 2) used LBMS for Owner reporting only and did not utilize the forecasts for decision making managing the project conventionally without the use of lean tools. Because of these differences, the results will be reported separately for each project. Both projects were hospital construction projects in California and the number and scope of tasks was similar between the projects. A total of 52 tasks were analyzed in Project 1 and 49 tasks in Project 2. The tasks in each project and time step were similar in scope. For example the task "Ductwork Horiz Mains + Seismic" was analyzed on all four time steps of Project 1 and the task "Remaining HVAC duct mains" was analyzed on all four time steps of Project 2.

Aggregate results

The results were analyzed based on actual variable as percentage of forecast variable. This makes it possible to combine several tasks with different quantities and units into the same analysis. Many outliers were found in the data. For example, in several cases actual resource consumption could be 25% of forecast or 10 times higher than forecast. To prevent these outliers from affecting the results too much, the median was used instead of mean to aggregate results.

Table 1 shows the aggregate results for Project 1. Time step results are the median for that time step over all tasks for all forecasts. Forecast results show the median result over all tasks for that forecast.

Table 1: Project 1 aggregate results

	Dur.	Qty	Hrs	Mh /unit	Res.	Locs compl ete	% of corr. locs comp	% of corr. locs worked
TIME STEP 1	**100%**	**103%**	**73%**	**80%**	**72%**	**100%**	**50%**	**75%**
FORECAST 1	100%	81%	67%	94%	67%	58%	33%	55%
FORECAST 2	100%	104%	74%	72%	67%	100%	55%	71%
FORECAST 3	100%	98%	70%	75%	74%	100%	54%	79%
FORECAST 4	104%	120%	86%	80%	74%	100%	63%	78%
TIME STEP 2	**86%**	**56%**	**52%**	**147%**	**79%**	**50%**	**21%**	**33%**
FORECAST 1	86%	36%	67%	147%	76%	50%	0%	47%
FORECAST 2	88%	80%	64%	162%	88%	50%	0%	33%
FORECAST 3	76%	56%	42%	152%	84%	58%	33%	29%
FORECAST 4	70%	47%	40%	135%	84%	50%	25%	30%
TIME STEP 3	**100%**	**61%**	**55%**	**73%**	**70%**	**0%**	**0%**	**25%**
FORECAST 1	100%	24%	29%	64%	91%	0%	0%	17%
FORECAST 2	100%	42%	57%	79%	72%	0%	0%	25%
FORECAST 3	100%	84%	58%	73%	70%	33%	0%	33%
FORECAST 4	90%	63%	46%	73%	51%	25%	17%	33%
TIME STEP 4	**58%**	**44%**	**70%**	**118%**	**140%**	**17%**	**0%**	**22%**
FORECAST 1	54%	44%	66%	118%	140%	0%	0%	0%
FORECAST 2	59%	54%	70%	117%	168%	0%	0%	26%
FORECAST 3	54%	33%	60%	132%	133%	50%	0%	42%
FORECAST 4	56%	41%	57%	131%	99%	20%	20%	33%

In Project 1, median numbers are close to the forecast for tasks analyzed in time step 1. Forecast accuracy improves over the four week period. Locations are being completed at the same rate as forecast although not exactly the same locations as forecast. In later time steps forecast accuracy appears to degrade. Work is being performed in incorrect locations, fewer locations and quantities are being completed, and work is often less productive (higher consumption in time steps 2 and 4) than forecast and/or fewer resources are mobilized (time steps 2-4). In all cases fewer manhours are spent on work than forecast. In time step 4 larger crew sizes are mobilized (resources over 100%) but resources experience starts and stops (duration less than 100%).

Table 2 shows the same results for Project 2. Similar to Project 1, manhours worked were much lower than forecast. Crew sizes were smaller in the first two time steps but increased in time steps 3 and 4. There were many starts and stops in all time steps except one. An interesting difference in data is the inability to finish locations; the median task finished zero locations in time step 1. The data show that work was ongoing in several locations (% of correct locations worked) but these locations were not being finished. The percent of correct locations worked went down as function of time. Labor consumption was poor (over 100%) on three of the four time steps and production rate improvement (quantity) was achieved by adding more resources (time steps 3 and 4).

Table 2: Project 2 aggregate results

	Dur.	Qty	Hrs	MH/ unit	Res.	Locs complete	% of corr. locs comp	% of corr. locs worked
TIME STEP 1	**100%**	**41%**	**71%**	**176%**	**81%**	**0%**	**0%**	**67%**
FORECAST 1	100%	46%	107%	205%	97%	0%	0%	50%
FORECAST 2	100%	30%	71%	202%	85%	0%	0%	50%
FORECAST 3	100%	30%	86%	208%	81%	0%	0%	67%
FORECAST 4	100%	38%	107%	216%	91%	0%	0%	67%
TIME STEP 2	**80%**	**45%**	**50%**	**84%**	**66%**	**0%**	**0%**	**40%**
FORECAST 1	80%	31%	36%	65%	67%	0%	0%	11%
FORECAST 2	80%	33%	50%	85%	64%	0%	0%	33%
FORECAST 3	87%	50%	45%	84%	62%	20%	14%	70%
FORECAST 4	93%	95%	71%	86%	75%	29%	23%	75%
TIME STEP 3	**83%**	**47%**	**88%**	**177%**	**120%**	**0%**	**0%**	**27%**
FORECAST 1	70%	17%	47%	187%	51%	0%	0%	0%
FORECAST 2	67%	34%	73%	117%	94%	0%	0%	17%
FORECAST 3	86%	62%	82%	177%	103%	20%	10%	31%
FORECAST 4	70%	62%	107%	150%	141%	25%	20%	39%
TIME STEP 4	**59%**	**58%**	**57%**	**114%**	**123%**	**25%**	**13%**	**33%**
FORECAST 1	50%	31%	34%	215%	57%	0%	0%	12%
FORECAST 2	55%	46%	31%	122%	105%	17%	0%	33%
FORECAST 3	52%	69%	65%	108%	135%	23%	6%	47%
FORECAST 4	69%	79%	80%	100%	123%	39%	33%	60%

To determine the possible causes for successful or poor forecasting data each task was reviewed in detail. Three tasks where forecasting worked well on Project 1 are shown in numbers in table 3 and in Flowline in figure 1.

Table 3: Project 1 tasks with good forecasting results

	Dur.	Qty	Hrs	MH/ unit	Res.	Locs complete	% of corr. locs comp	% of corr. locs worked
INSTALL TOP TRACK								
FORECAST 1	100%	81%	77%	95%	77%	50%	0%	60%
FORECAST 2	100%	104%	74%	72%	74%	80%	60%	67%
FORECAST 3	100%	109%	72%	66%	72%	86%	57%	75%
FORECAST 4	100%	120%	77%	64%	77%	100%	75%	73%
FIRE-PROOFING								
FORECAST 1	100%	61%	66%	108%	66%	67%	33%	100%
FORECAST 2	100%	73%	60%	82%	60%	100%	75%	80%
FORECAST 3	100%	74%	60%	82%	60%	100%	80%	71%
FORECAST 4	100%	73%	68%	94%	68%	63%	63%	82%
FIRE SPRINKLER								
FORECAST 1	100%	82%	77%	94%	77%	100%	100%	75%
FORECAST 2	100%	103%	97%	95%	97%	133%	67%	75%
FORECAST 3	100%	88%	101%	115%	101%	120%	60%	83%
FORECAST 4	100%	96%	101%	105%	101%	100%	71%	70%

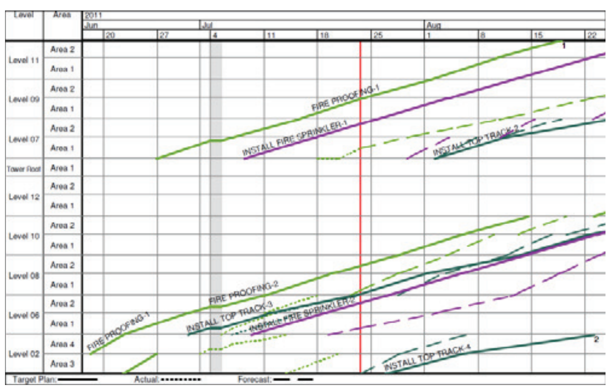

Figure 1: Forecast of Fireproofing, Fire Sprinkler and Top Track

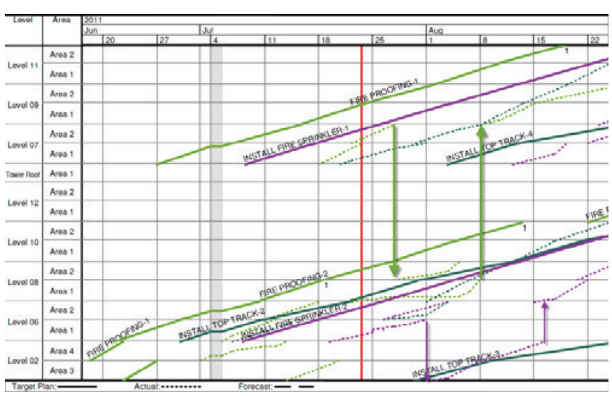

Figure 2: Actual progress of Fireproofing, Fire Sprinkler and Top Track

By looking at the numbers and figures together it is possible to understand the sequence of events. Instead of two planned crews for fireproofing (figure 1, overlapping forecast lines), one crew was working and alternating between locations (figure 2, green arrows). This resulted in a slower production rate. However, better productivity on level 7 made it possible to stay close to the forecast. Fire Sprinkler was able to maintain continuous production even though Fireproofing was delayed by moving crews to level 2. Install Top Track was able to beat the forecast by working ahead of fireproofing. A clear learning effect can be seen on higher floors, as steeper slope of actuals, and labor consumption fell to 64% of forecast. Despite working out of sequence the forecasted quantity was completed for most tasks and a large percentage of planned work was completed over the four week time period.

Investigation into an example where the forecast worked poorly is even more important. 73% of tasks in the first time step of Project 2 achieved less than 80% of forecast quantity. Most tasks did not finish any locations during the four week analysis period. Table 4 shows three tasks in numbers and figures 3 and 4 show the Flowline forecasts and actuals.

Table 4: Project 2 tasks with poor forecasting results

	Dur.	Qty	Hrs	MH/ unit	Res.	Locs comp lete	% of corr. locs comp	% of corr. locs worked
DRYWALL TOP OF RATED WALLS								
FORECAST 1	100%	51%	105%	205%	105%	0%	0%	50%
FORECAST 2	67%	30%	71%	235%	106%	0%	0%	50%
FORECAST 3	50%	24%	58%	239%	117%	33%	33%	75%
FORECAST 4	42%	15%	47%	322%	113%	67%	33%	80%
INSTALL BACKING/PICK-UP FRAMING								
FORECAST 1	50%	30%	21%	71%	42%	0%	0%	29%
FORECAST 2	33%	19%	17%	89%	52%	0%	0%	43%
FORECAST 3	57%	30%	41%	136%	72%	40%	40%	71%
FORECAST 4	68%	38%	62%	165%	91%	33%	33%	86%
REMAINING HVAC DUCT MAINS								
FORECAST 1	222%	77%	199%	258%	90%	0%	0%	222%
FORECAST 2	500%	187%	425%	227%	85%	25%	0%	500%
FORECAST 3	483%	221%	390%	176%	81%	20%	0%	483%
FORECAST 4	655%	283%	573%	202%	87%	40%	20%	655%

It can be seen from Figure 3 that at the time of the forecast multiple locations were ongoing for each trade. In this case LBMS forecasting logic distributes the same production rate into open locations. In practice, work did not continue in most of the open locations and actual quantity produced fell behind forecasted production (figure 4) On the other hand, “Remaining HVAC Duct Mains” task started in several locations well ahead of forecast and achieved much bigger quantity than forecasted. It can be argued that figures 3 and 4 represent a project which has become chaotic.

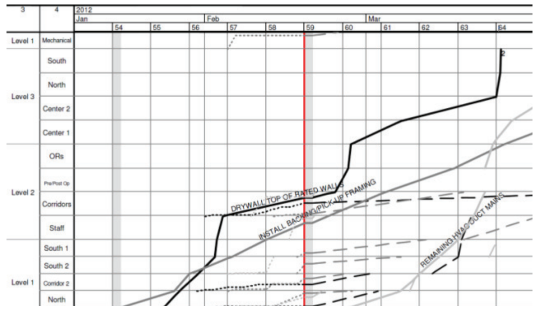

Figure 3: Flowline forecasts for Project 2

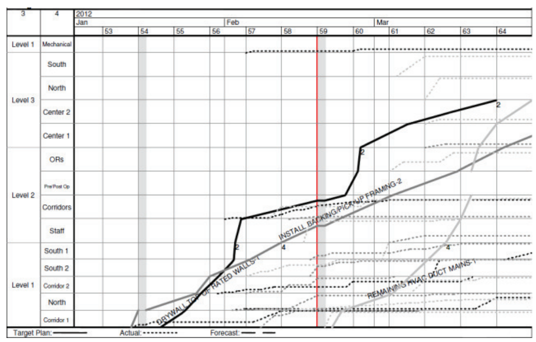

Figure 4: Flowline actuals for Project 2

Analysis by task type

Based on these findings a secondary analysis was run. Tasks were divided into four classes: continuous tasks, tasks with starts and stops, tasks starting before forecasted start date, and tasks starting after forecasted start date. The median value of the cumulative four week forecast is reported in table 5 for these task groups.

Table 5: Median of week 4 forecast for task groups

	Dur	Qty	Hrs	Mh /unit	Res.	Locs complete	% of corr. locs comp	% of corr. locs worked
Project 1								
Continuous	100%	78%	82%	97%	74%	76%	44%	71%
Starts and stops	59%	67%	39%	94%	77%	45%	25%	33%
Ahead of f.cast	98%	101%	196%	155%	81%	100%	33%	50%
After forecast	57%	33%	35%	80%	75%	20%	20%	42%
Project 2								
Continuous	120%	120%	149%	176%	113%	33%	20%	74%
Starts and stops	68%	69%	66%	100%	99%	29%	25%	50%
Ahead of f.cast	111%	106%	556%	526%	500%	125%	100%	100%
After forecast	52%	33%	66%	141%	92%	0%	0%	29%

Continuous tasks and those tasks starting before forecast achieved the best results compared to forecasted quantity in both projects. However, resource consumption of tasks which started early was much higher than forecasted. Continuously performed tasks were able to complete more locations overall and more correct locations than those tasks which had starts and stops.

CONCLUSIONS

LBMS forecasts were evaluated based on actual results of two projects. Forecasts were found to work well in some circumstances, and poorly in others. Tasks with continuous workflow were best forecasted by LBMS forecasting method. LBMS forecast had difficulties with tasks that happened out-of-sequence, had starts and stops or that started ahead or after forecast. This increased predictability is a less documented benefit of continuous workflow.

LBMS forecasts use actual resource consumption as the basis of forecasts. Forecasts are inaccurate if labor consumption is highly variable, resources are not mobilized according to plan, or work happens out of sequence. In Project 1, fewer resources were consistently mobilized. In Project 2, the same result was found earlier in the project. Larger crews that were deployed later were mobilized possibly because the project was getting delayed and resources were added to finish the project on time. Similar findings have been reported in earlier research when resource use was compared to the original plan (Kala, Mouflard & Seppänen 2012). More research is needed to find out why subcontractors do not mobilize committed resources.

Technical forecast of LBMS worked better in longer term (cumulative 4 weeks) than in short term. This finding may be important because the Last Planner System™ (Ballard 2000) aims to improve the reliability of weekly work plans, targeting the next week in particular. The combination of these two methods may be able to improve both short-term and longer term forecasting on projects (Seppänen, Ballard, Pesonen 2010).

This research effort increased understanding of circumstances where technical forecasting works well and where forecasts are likely to fail. In a project implementing Lean Construction, like Project 1, LBMS forecasts worked well initially when most of the tasks were continuous. Later on in the project work started happening out of sequence and forecast performance decreased. Forecasts were too optimistic in the conventionally managed Project 2 where the focus was on starting as early as possible instead of focusing on finishing work. It can be argued that Project 2 had reached a chaotic, unpredictable state where continuous workflow could not be recovered without radical re-planning.

Based on these results, forecasts can be used by Last Planners as a tool for look-ahead and weekly planning purposes in projects where workflow is still predictable and work is mainly continuous. Other tools should be implemented in projects which have already reached a chaotic state with unpredictable workflow. Bertelsen and Koskela (2003) highlighted the importance of describing the symptoms of a chaotic project. The data from LBMS seems promising for this purpose. Signs of chaotic projects where forecasts are no longer reliable seem to include actual flowline patterns which have little or no resemblance to the plan and a large number of suspended locations. However, more research is needed to establish actual best practices of recognizing these projects based on actual data and to propose alternative tools for look-ahead planning to bring such projects back on track.

In future research, it would also be interesting to compare LBMS forecasts to Plan Percentage Complete (PPC) results and to compare LBMS forecasts to CPM forecasts. Our hypothesis is that PPC would correlate with LBMS "% of correct locations finished" metric and CPM forecasts would show overly optimistic results compared to LBMS.

REFERENCES

Ballard, G. (2000). *The Last Planner(tm) System of Production Control.* Doctoral thesis, University of Birmingham, School of Civil Engineering. Birmingham, U.K

Bertelsen, S. & Koskela, L. (2003). Avoiding and Managing Chaos in Projects. Proceedings of the 11th Annual Conference of the International Group for Lean Construction, July 22-24, Blacksburg, Virginia

Galloway, P. (2006). CPM Scheduling – How Industry Views Its Use. *Cost Engineering,* Vol. 48, No. 1, pp. 24-29

Kala, T, Mouflard, C. & Seppänen, O. (2012). Production Control Using Location-Based Management System on a Hospital Construction Project. Proceedings of the 20th Annual Conference of the International Group for Lean Construction, July 18-20, San Diego, California

Kenley, R. (2005). Dispelling the Complexity Myth: Founding Lean Construction on Location-based Planning. Proceedings of the 13th Annual Conference of the International Group for Lean Construction, July 19-21, Sydney, Australia

Kenley, R. and Seppänen, O. (2010). *Location-based Management for Construction. Planning, scheduling and control.* Spon Press. London and New York.

Seppänen, O. (2009). "Empirical Research on the Success of Production Control in Building Construction Projects." Ph.D. Diss. Helsinki University of Technology, Finland, 187 pp. (available at http://lib.tkk.fi/Diss/).

Seppänen, O., Ballard, G. & Pesonen, S. (2010). The Combination of Last Planner System and Location-Based Management System. *Lean Construction Journal*, 6 (1) 43-54, 2010 issue