PRODUCTION CONTROL USING LOCATION-BASED MANAGEMENT SYSTEM ON A HOSPITAL CONSTRUCTION PROJECT

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ABSTRACT

Critical Path Method (CPM) scheduling is currently the dominant scheduling system in use in construction. Location Based Management System (LBMS) is increasingly being used as an alternative in the US, particularly in hospital construction. The goal of this paper is to provide a critical evaluation of one such LBMS implementation by comparing it to a CPM implementation run in parallel.

Three hypotheses drove this research. First, LBMS requires more person-hours than CPM to manage the schedule. Second, LBMS provides real-time information to make educated decisions about production control. Third, the subcontractors' start dates are controlled better than their production rates.

Both systems are currently being used on a 1 million GSF OSHPD hospital in Northern California. Standard task lists were used to compare the different scheduling time requirements. CPM and LBMS reports were then compared to analyze the different deliverables. Finally, LBMS production data was reviewed against CPM actuals and planned start dates to evaluate the most effective method of subcontractor scope management.

The results indicate that more time is required to update the CPM compared to the LBMS schedule on the standard task list. However, CPM supports many legacy processes such as change management. Production rates were controlled better than start dates in this project, contrary to our hypothesis.

KEYWORDS

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

INTRODUCTION

Production control in CPM focuses on the critical path. CPM forecasting is based on planned logic and durations (Kelly & Walker 1959; O'Brien & Plotnick 2009). LBMS plans production in more detail by considering quantities, productivity data, and a location breakdown structure. Detailed production data is then collected from observations in the field to provide real-time forecasting against the target plan. (Kenley & Seppänen 2010).

One of the goals of Lean Construction is the application of production control throughout the life of the project (Howell 1999). This paper presents a case study on

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the application of parallel CPM and LBMS processes for production control on a large hospital construction project.

The LBMS and CPM processes were implemented on The Kaiser Permanente Oakland Medical Centre Replacement Project, Phase II. The project is approximately 1,000,000 ft^2 (93,000 m^2) with a 12-story and basement hospital tower, speciality medical office building, and a central utility plant. This paper is a continuation of the research that focussed on the planning stage of LBMS for the project. This planning case study captured discontinuity and variable resource demand within the CPM (Kala, Seppänen & Stein 2010). After the planning process, the focus was shifted to implementation of LBMS for production control, which is covered in this paper.

Critical Path Method

Critical Path Method (CPM) is a construction scheduling system visually portrayed in a Gantt chart. The critical path is the sequence of project network activities that add up to the longest overall duration (Kelly & Walker 1959). Durations and resources are then estimated based on experience or subcontractor negotiations (O'Brien & Plotnick 2009).

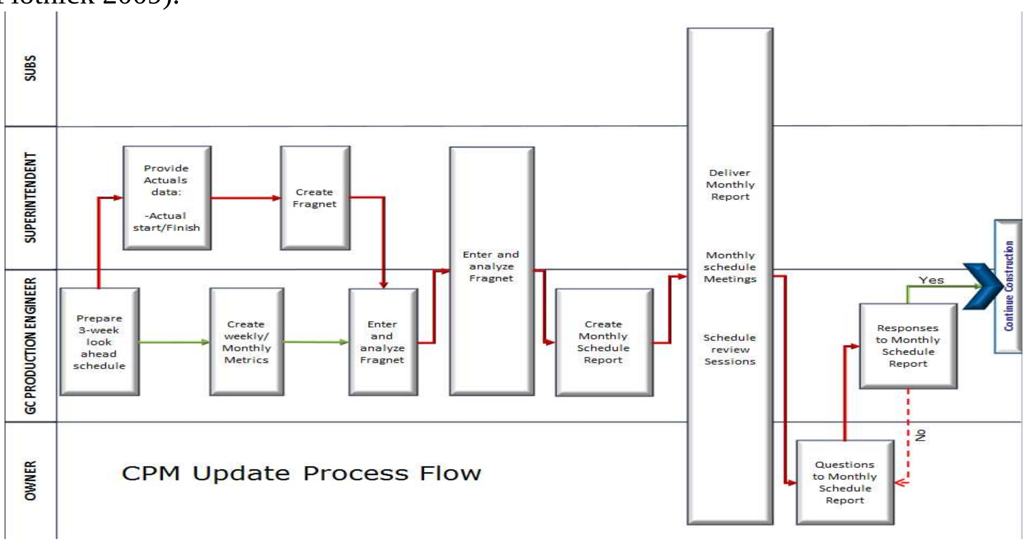

Figure 1: The process flow for the CPM updating process used on the hospital project

On the Hospital project, the CPM schedule is the contractual document and owner-reporting tool. Actuals are collected on a weekly basis from superintendents. The CPM scheduler reviews the schedule updates from the different project teams weekly. Analysis of the actuals and schedule updates form the monthly report. Each week the CPM scheduler must produce a 3-week look ahead for the project teams and owner weekly metrics; this includes Early Start Date analysis and twenty-one days within critical path analysis. (Figure 1)

Location Based Management System

Location Based Management System (LBMS) is a construction planning and production control system most often visualized as a flowline. Project quantities (by scope), productivity data, and geometrically defined locations (using a Location Breakdown Structure) form the calculation to define trade durations and resource requirements for tasks by location (Kenley & Seppänen 2010).

LBMS production control compares the actual quantities installed over time to that of the target quantity-time relationship (Kenley & Seppänen 2010). Forecasts are calculated from historical performance. LBMS production quality data is tracked weekly and includes:

- Actual start date of task
- Actual finish date of task
- % Complete or quantities progress update on data date
- Number of resources per task per location
- Days not worked for a task per location

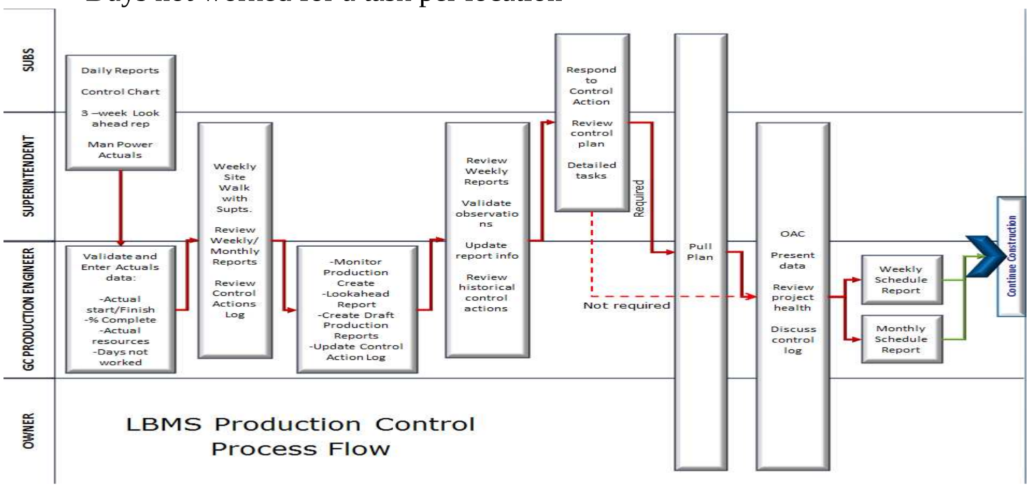

Figure 2: The LBMS process flow for production control on the hospital project

Ballard, Pesonen & Seppänen (2010) conclude that Last Planner™ System (LPS) and LBMS are complimentary. LPS focuses on the social process of planning and commitment, while LBMS is a technical system used to structure information to improve the planning process and calculate progress metrics and forecasts. LPS weekly plans and look-ahead reports can utilize LBMS progress and forecast data as an early warning system to evaluate total project effects of production deviations (Ballard, Pesonen & Seppänen 2010).

On the Hospital project, LBMS is on a weekly reporting cycle. Weekly production reports focus on tasks and monthly reports focus on phase analysis. Production actuals are collected from superintendents and subcontractors and are validated on site walks. The schedule is reviewed in live work sessions where Control Planning enables the team to determine the most appropriate correction to the deviations. Control Actions are implemented based on the team decisions and commitments. All observation and actions are recorded.

Research Questions and Hypotheses

Answers were sought for the following research questions:

1. What is the time commitment required to manage the CPM and the LBMS processes?

Our hypothesis was that updating and schedule analysis in LBMS takes longer than CPM because of greater data tracking requirements.

2. Does LBMS provide real-time information to make educated decisions about production control?

We assumed that LBMS is able to provide better information to superintendents than CPM and help them in real-time decision-making.

3. How reliable was the planning process?

Based on earlier empirical research (Seppänen 2009), we assumed that the interior rough-in and finishes schedule would have big variations from planned production rates and planned resource amounts, but planned start dates would be well controlled.

RESULTS

Results of the case study are presented below by research question. For each research question the research method is first presented, followed by the results.

RESEARCH QUESTION 1: WHAT IS THE TIME REQUIRED TO UPDATE LBMS VS. CPM?

Research Method

To normalize the data collection a standard task list was created so each scheduler could tally their daily hours for each task over the course of a month. In addition to the standard task lists, the scheduler recorded non-comparative tasks and daily hours. Please refer to table (1) for the standard task list. The non-comparative CPM tasks include owner deliverables, change order time impact analysis, and Fragnet schedule re-sequencing. The LBMS non-comparative tasks include Owner production reporting and internal meetings with relative project teams. In order to make a comparison, the results will compare schedule management tasks for each system.

Standard Task List

Actuals collection for CPM is the distribution of the 3-week look ahead to project superintendents and the retrieval of the look ahead with the updated start and finish dates. The actuals are then reviewed to ensure the data is there. Analysis of the actuals consisted of entering the data into the CPM system. Schedule analysis is the preparation of numerous reports from add-on CPM software programs and reviewing the impact to the critical path. Schedule review meetings include time spent with individual project team members and owner meetings. Weekly reporting is the generation of owner metrics and Fragnet review. Monthly reporting is the analysis of the critical paths and schedule changes. Metric reporting focuses on early start data reached for owner weekly review.

LBMS actuals collection includes gathering production data from subcontractors and superintendents and validating that data on site walks. The data is reviewed to ensure that it is complete. The analysis of the actuals included time for entering the data and reviewing the forecasts. Review sessions highlight the major observations made in the analysis. From here monthly and weekly reports are generated and revised with the project team members before distribution to the project team. Metrics focus on production/consumption data for all phases for GC review.

The deliverables for each methodology are inherently different because of their base theory. However, the standard task list reflects deliverables that parallel one another.

Results Analysis

Table (1) compares the hours per week required to manage the CPM and LBMS schedules. Table (2) shows the overall time to manage the standard task list. In CPM updating the bulk of the time is spent creating reports based on schedule changes. The LBMS actuals process takes significantly longer, however the reports are automatically generated based on the data – analysis is only needed to explain the findings. The process for LBMS report generation uses a group environment to generate reports with active feedback. The CPM process does not include site walks. The LBMS process mandates actuals validation and site walks with superintendents.

Table 1: CPM and LBMS standard task list with average weekly hours, calculated hours per day and cumulative hours per week

Standard Task List (hours/week)	CPM AVG (hours)	LBMS AVG (hours)	Task List Δ
Collect Actuals	5	7.85	-2.85
Review Actuals	2	1.4	0.6
Analyze Actuals	2	13.8	-11.8
Schedule Analysis	10	3.55	6.45
Schedule Review Meetings	4	1.77	2.23
Weekly Reporting	5.25	1.95	3.3
Monthly Report	7.25	1.45	5.8
Metrics Reporting	3	0.6	2.4

Table 2: The delta between CPM and LBMS average management hours per week, day and month

Task List Totals	CPM	LBMS	Δ
Daily average hours	7.7	6.5	1.2
Total weekly hours	38.5	32.4	6.1
Monthly average hours	169.4	142.4	27.0

RESEARCH QUESTION 2: DOES LBMS PROVIDE REAL-TIME INFORMATION TO MAKE EDUCATED DECISIONS ABOUT PRODUCTION CONTROL?

Based on the data entered into the LBMS system, a weekly production report is generated. The report has two parts: first a completion report that contains planned vs. actual quantities, production rates and man-power per task (see figure 5 below) thereby providing the project status. The second part is a flowline view showing actual progress vs. planned progress and the forecast for the activities (see figure 3 below) provides project throughput and where the project is heading.

CPM also collects the data on a weekly basis, but the reports are released on a monthly basis. In addition the focus is on actual start and actual finish dates and their impact on successor activities providing project status (Abdelhamid 2004).

Two examples, one from the foundations phase and the other from the superstructure phase, were selected from the Kaiser Oakland hospital project to illustrate production control using the LBMS system.

Example 1: Foundations

During planning and schedule optimization of the foundations phase of the Kaiser Oakland Hospital project, the determining tasks (long duration and high resource tasks) were identified and tracked closely on a weekly basis. The determining tasks for the foundations phase were drilled piers, structural excavation, waterproofing, and reinforcing. All efforts were made to keep the determining tasks on track.

After a few weeks of production tracking it became apparent that waterproofing was not meeting its targets. Because both the waterproofing activity and the successor pier cap reinforcing activity were able to start on schedule, no red flags were raised in the CPM schedule. The LBMS weekly production report was showing that the slow production rate of the waterproofing task will lead to starts and stops in reinforcing and an overall delay to foundation phase work. Please see figure (3) which shows the resulting delay in grade beam/sub-slab reinforcing for foundation area 3(A) caused by slower-than-planned waterproofing production.

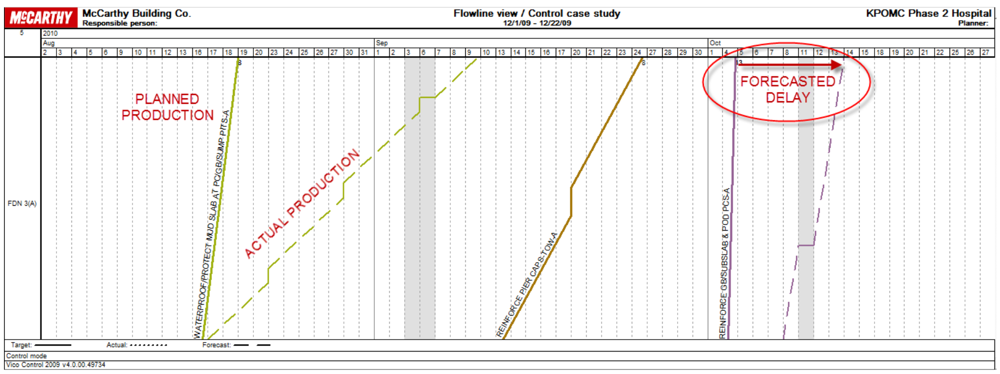

Figure 3: The forecasted delay of reinforcing due to staging conflicts between pier cap rebar and waterproofing

This issue was investigated with the superintendent. It was found that the field conditions required the pier cap rebar be staged on the sub-slab/grade beam area. This was preventing the waterproofing from being complete in the area. The waterproofing subcontractor was not working in the GB/Sub-slab area in order to prevent rework.

The superintendent and subcontractors made a decision to restructure the waterproofing workflow to represent the staging constraints. The quantities for waterproofing were split in the BIM model, isolating waterproofing below grade beams/sub-slab and waterproofing below pier caps to match the rebar activities. The manpower was adjusted to bring the completion back to the original target date. The schedule was executed through weekly pull scheduling sessions and daily check-ins to track the subcontractor progress.

Figure (4) shows the resulting plan dividing and re-sequencing the waterproofing workflow. Based on actual production seen on the jobsite, it was possible to calculate the resource requirements to re-align these tasks with the foundation phase schedule. Manpower for the pier caps waterproofing activity was reduced to one fourth of the original crew size and manpower was more than doubled for the grade beams/sub-slab waterproofing task in order to meet the required reinforcing completion date.

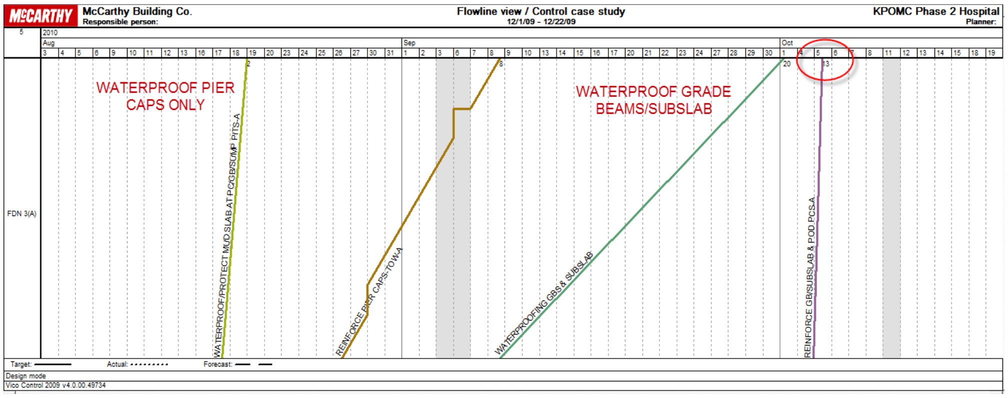

Figure 4: The additional waterproofing activity for grade beam/sub-slab between reinforcing for pier caps and reinforcing for grade beams/sub-slab

Example 2: Superstructure

Timely completion of the structural steel was the driver for the project and was monitored closely. Figure (5) is a weekly completion report for the structural steel. This metric exemplifies the man-power and production discrepancies between plan and actual. By comparing target versus actual production rates, trends can be observed enabling the project team to have educated conversations about production with subcontractors. Figure (6) shows the flowline forecast (thin flowlines) based on actual field productivity (rather than planned productivity rates (thick flowlines).

KPOMC Phase 2 - Tower and Podium								
		Target/Estimated						
Code	Name	Quantity	Unit	Production rate units/day	units	by Progress	Manpower	Start time
HOS__-150	ERECT STEEL	[illegible]	EA	57.7	ea/day	[illegible]	12	10/23/2010
HOS__-200	WELDING STRUCTURAL STEEL	[illegible]	EA	11.6	ea/day	[illegible]	13	10/28/2010
		Actual					Versus	
HOS__-150	ERECT STEEL	[illegible]	EA	61.9	ea/day	[illegible]	38	10/15/2010
HOS__-200	WELDING STRUCTURAL STEEL	[illegible]	EA	10.9	ea/day	[illegible]	18	10/25/2010

Figure 5: Completion report highlighting the differences between the originally planned manpower requirements versus the actual

Several weeks of tracking steel production also showed that the steel welding was happening on multiple floors which was different from the plan. However, the cumulative production rate was low and the forecasts showed that if the trends were to continue, there would be 3.5 months of projected delay (see figure 6). On the other hand, the CPM updates illustrated the welding starting on multiple floors, but was interpreted as beating the start dates and thus no delays were projected.

Based on the data from the location-based schedule the steel subcontractor was requested to increase manpower to exceed planned production so as to finish welding on time. The steel subcontractor was able to respond to the requests and welding manpower was increased from an average of 14 welders to 18 welders. This action also resulted in reducing the structural steel welding delay to 1.5 weeks from 3.5 months and no impact to follow-on critical path activities. Please see figure (7) showing the actual versus taget flowline view of steel welding.

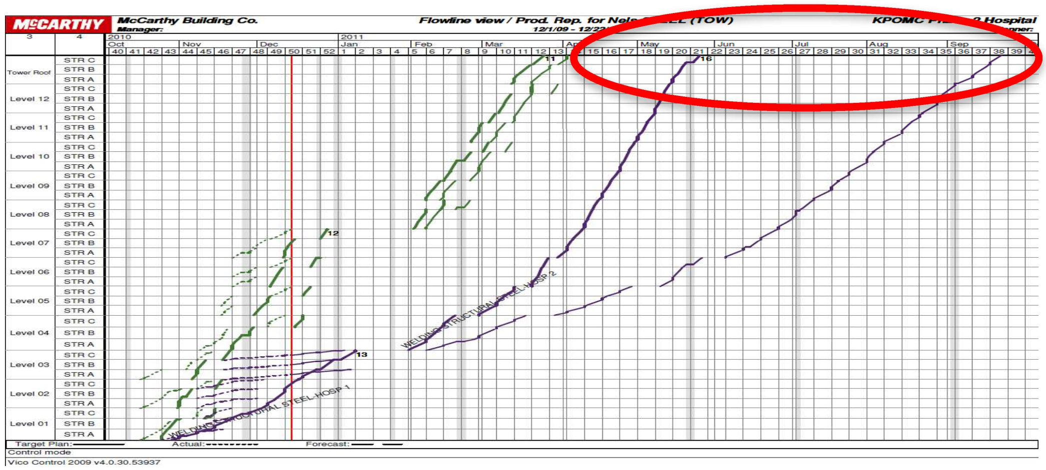

Figure 6: The flowline on 12/2012 showing 3.5 months delay in welding completion based on current production rates

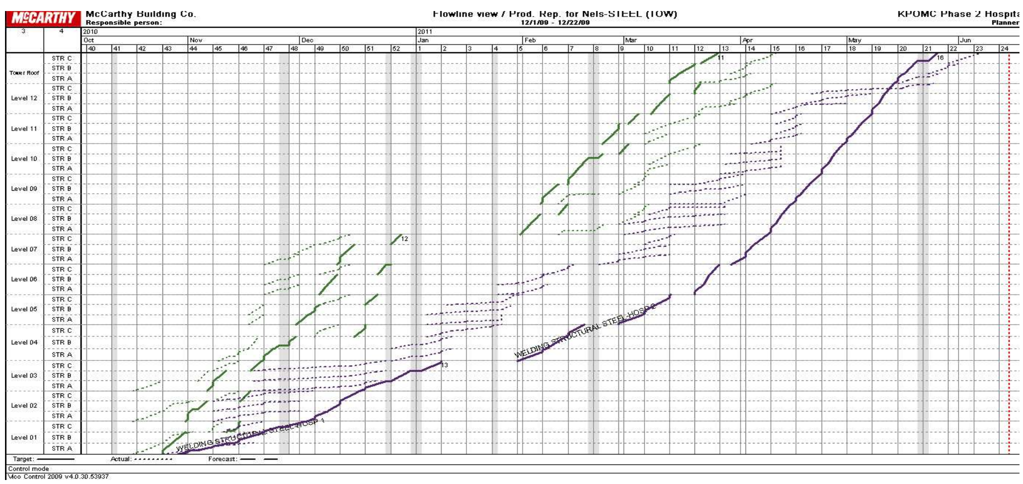

Figure 7: Final structural steel welding actual versus target production

RESEARCH QUESTION 3: HOW RELIABLE WAS THE PLANNING PROCESS?

In LBMS, the baseline plan is not updated automatically during the progress update. Actual and forecast information exist as separate sources of information (Kenley & Seppänen 2010). The plan should be updated only if it is impossible to get back on track (Seppänen, Ballard, Pesonen 2010). The reliability of schedules can be evaluated by comparing planned values to actual values (Seppänen 2009).

Research Method

The reliability of the planning process was investigated by comparing planned data related to a task at several time points to actual data at the end of the task. The tasks were selected from production tasks from interior schedules and included more than 1,000 man-hours of work. Tasks were over 80% completed at the time of this research.

For each of the tasks information about quantities, start and finish dates, production rates and average crew sizes and resource consumptions was collected for five time points of plans and for the actuals. The plans were collected two months before, one month before, one week before, one month after, and two months after the actual start of production. These time points were selected because there was no formal schedule approval process by trade. The assumption was that the schedule would have been reviewed with the subcontractor before starting production.

Results

Nineteen tasks were analyzed. Most of the tasks (16 or 84%) were initially based on man-hour assumptions without a physical quantity. Real quantities were added in the planning process to twelve of the nineteen tasks (63%). The other tasks remained based on man-hour estimates. All of the tasks were eventually resource-loaded. Planned task durations from all locations varied from eight days (Slab-on-Grade) to 181 days (Electrical Rough-Ins above Duct).

In terms of start dates, the average variance for plans two months before the start date was sixteen days delayed. One month before start date this dropped to fifteen days and one week before start date to six days. This shows that the plans were updated to some extent to correspond with actual reality.

Production rates were investigated by dividing the actual production rate by the planned production rate to get a production rate multiplier (Seppänen 2009). This could be done only for time points where the tasks were quantity-loaded. To get data for non-quantity-loaded tasks, the planned quantity of a later quantity-based time period was divided by the duration of the current time period. Table (3) shows that the planned production rates were reliable overall.

Table 3: Actual production rates as percentage of planned production rate

Actual Production Rates / Planned Production Rate					
	Pre Start - 2 Months	**Pre Start - 1 Month**	**Pre Start - 1 week**	**Post Start - 1 Month**	**Post Start - 2 Months**
Tasks	94%	101%	95%	98%	101%

Man-hours and crew sizes had the biggest variances between plans and actuals (table 4). Planned man-hours were based on information provided by the subcontractor. In 74% of tasks, actual man-hours measured based on production control data were smaller than any plans planned with subcontractor data. Thus it was possible to achieve the planned production rate with smaller than planned crew size.

Table 4: Actual man-hours and actual crew sizes compared to planned

Actual Man-Hours / Planned Man-Hours					
	Pre Start - 2 Months	**Pre Start - 1 Month**	**Pre Start - 1 week**	**Post Start - 1 Month**	**Post Start - 2 Months**
Tasks	66%	67%	71%	61%	73%
Actual Crew Sizes / Planned Crew Sizes					
	Pre Start - 2 Months	**Pre Start - 1 Month**	**Pre Start - 1 week**	**Post Start - 1 Month**	**Post Start - 2 Months**
Tasks	64%	66%	62%	59%	65%

CONCLUSIONS

On this project the CPM schedule required more person-hours to operate than the LBMS. This is because the process for CPM operates largely in a silo, reporting outwards on a monthly basis as the owner requests the information. The LBMS process is based on a group approach to analyzing data and finding solutions to production deviations on a weekly basis. This offers a proactive problem-solving environment at the expense of the time-required commitment from project stakeholders.

LBMS was able to provide better real-time information for superintendents for decision-making. Two examples were presented in this paper, but there were many more examples where LBMS was able to show more relevant information than CPM. The two examples covered in this paper were able to showcase the advantage of the forecasting mechanism in LBMS allowing for issues being eliminated proactively.

The start dates varied by three weeks from plans, but production rates were very close to planned. This is different from the results reported by Seppänen (2009). It is possible that the better implementation of the LBMS controlling practices focusing on production rates has kept the production rates better in check. Variation of planned consumptions and man-hours is also interesting. It appears that resource-loading based on subcontractor data is typically off by 30-40%. This indicates quite a bit of safety buffer in subcontractor numbers or unexpectedly high production on field.

While it is still too early to determine which production control methodology holds the advantage, it is clear from the results of the case study that additional research about the benefits of LBMS is needed. LBMS provides useful information which is not available from CPM and indicates that production rates can be better managed. We look forward to additional research in this area.

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