Evinger, Jake; Mouflard, Christopher; Seppänen, Olli

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PRODUCTIVITY EFFECTS OF STARTING AS EARLY AS POSSIBLE IN HOSPITAL CONSTRUCTION

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

ABSTRACT

Critical Path Method (CPM) is the standard scheduling methodology for building construction in the US. The objective of this research is to determine the effect of management strategies focusing on early starts (ASAP strategy) on the production and productivity rates of "critical path" tasks in a construction schedule.

In this study, two healthcare projects were followed over the course of construction to document the effects of field management decisions on production. On project one, a CPM schedule and ASAP strategy was used exclusively to manage subcontractor resources. On project two, both CPM/ASAP and Location Based Management System (LBMS) strategies were used in parallel, on similar location groups, enabling direct comparison. Actual activity start dates, finish dates, demobilizations and remobilizations, productivity and production rates, and manpower were recorded weekly for analysis. On project one, the actual dates and rates are compared against the CPM plan to determine how reliably the tasks could be completed using the ASAP "work in place" management strategy. Results show that certain deviations from the CPM plan, such as starting early, relocating resources before completing a location, and deploying resources to multiple locations at a time cause unpredictable dates of completion and frequent changes to the "critical path". On project two, actual productivity and production rates for selected tasks are compared between the CPM/ASAP and LBMS location groups. Results show that deploying resources to a location as soon as it is available can have a negative effect on the productivity and overall production rates of critical tasks.

KEYWORDS

Continuous, CPM, flow, LBMS, process, production, variability.

INTRODUCTION

CONCEPTS

Critical Path Method (CPM) of scheduling uses algorithms that force activity dependency relationship to start as soon as the preceding task is complete – assuming a finish to start relationship (O'Brien & Plotnick 2009). Standard practice in CPM project management advocates a similar approach when managing locations of work on a construction project (Abdelhamid 2004). The authors propose that this can be

[1] Senior Project Manager, Trimble VDC Services, jake_evinger@trimble.com
[2] Project Engineer, Trimble VDC Services, chris_mouflard@trimble.com
[3] Postdoctoral Researcher, Aalto University and Director of VDC Services, Trimble Navigation Limited, olli_seppanen@trimble.com

referred to as "ASAP" management and this mindset is often carried into the field by the General Contractor (GC) as a strategy for managing resources onsite. In CPM, if an activity suffers a delay to the start date, caused by a late predecessor, the balance of the plan will adjust accordingly to start as soon as the delayed location becomes available (O'Brien & Plotnick 2009). Industry standard practice requires monthly updates (Galloway 2006). Schedule updates help the contractor to understand when the critical path changes and re-planning is required.

It is not uncommon for ASAP management to be adopted to "maximize" empty locations on a project site before they are planned to become available. In this case it is also common practice to begin the successor task as soon as possible. In many cases starting a location early has advantages for the GC in that learning curve can be overcome sooner and potential problems may be identified earlier. It is also beneficial to show "work in place" ahead of schedule to build owner confidence and support early billings for cash flow. Arcuri (2007) suggests that this type of site management style also plays into legacy metrics such as percentage of early starts achieved. In CPM updates starting early will never hurt the schedule forecast and reporting only late starts or extended duration can have a detrimental effect on finish date (Lowe et al. 2012).

Howell (1999) highlights that Lean construction goals should align with managing the resource flow to maximize production while maintaining an acceptable amount of exposure to project risk. The authors argue that ASAP management does not meet the Lean goals established by Howell (1999) and other Lean authors. Meredith and Mantel (1995) describe this as management by exception. While this is better than no control at all, CPM is essentially an "after-the-fact" approach (Meredith & Mantel, 1995). Managers should be more interested in preventing problems than curing them. Koskela and Howell (2001) call this the thermostat model of control – managing by deviation from critical path rather than using more proactive means.

The Location Based Management System is an alternative way to plan, schedule and control projects. LBMS focusses on providing continuous workflow, completing locations in sequence, and promoting balanced and optimal production for work crews (Kenley & Seppänen 2010). LBMS schedule updating and reporting is a weekly or daily process (Kala, Mouflard & Seppänen 2012). Site managers are provided with transparency in project schedule management as they have the benefit of proactive forecasting which leverages metrics and Flowline diagrams (Kala, Mouflard & Seppänen 2012). During LBMS updates, which typically happen weekly or even daily, starting early is a benefit to the forecast only if work can be performed continuously and if production rates can meet the target. Thus the LBMS approach penalizes starting too early before work is ready to be started. In some cases this strategy requires waiting to start a task until continuous production can be achieved for all locations of the task or until a harmonious production rate can be achieved with adjacent trades. (Lowe et al. 2012). This can be a difficult concept for the field team to buy into, because it is contrary to the common ASAP management approach.

In this research we look to understand the potential impacts of the ASAP management strategy on production and consumption rates of field resources. Our hypothesis is that the "starts and stops" and task suspensions introduced by starting a location before it could be completed continuously would have a detrimental effect on production. This hypothesis is familiar to Lean practitioners and the Last Planner

System™ of production control has been designed to improve productivity by only allowing assignments which have been "made ready" to weekly work plans (Ballard & Howell 1994). To test this hypothesis we analysed actual production data from two healthcare construction projects: one that was being managed using only the CPM/ASAP strategy and another that employed both CPM/ASAP and LBMS strategies in different locations of the same project.

INTRODUCTION TO PROJECTS

Two active hospital construction projects were used in the statistical pool to complete this research. Both projects are located in California, USA. On each of these projects LBMS methodology has been used to record and analyze production in the field, however, both projects are contractually bound to a CPM schedule.

- **QVMC** 72,000 SF acute care facility added to an existing medical center in Napa, California. Includes six Smart Operating Rooms, 20 private intensive care rooms, clinical and pathology laboratories.
- **KPOMC** 684,000 SF replacement hospital on a new medical center campus in Oakland, California. Includes 350 patient beds, 16 operating rooms and 2 hybrid ORs.

On the KPOMC project we had a unique opportunity to compare both management strategies on the same scope in the same project. There are 14 stories of construction on the KPOMC hospital tower. The same subcontractors were used throughout the project on all locations. The CPM management strategy was employed on the Lower Level through Level 3 and LBMS strategy on Levels 5-12. Level 4, a mechanical level, and the roof level were not included in this study.

CASE STUDY 1 QVMC

METHOD

The impact of ASAP management on the production schedule was measured by comparing the actual performance of tasks that were executed continuously with those that experienced starts and stops or suspensions during production. It was assumed that tasks which were suspended before completion of a location had either been started before all prerequisite tasks had been completed or had enough float to be suspended without impacting the critical path. Production tasks which had been quantity and resource-loaded, and had been calculated at 500 manhours of work or more, were used as the basis for analysis if they had been completed and actualized at the time of research. For analysis the following data were collected for each task:

- Actual production rate (units/day)
- Actual labor consumption (manhours/unit)
- Actual start and end dates at each location
- Actual duration of task (number of workdays)

From the collected actuals the following data was calculated for each task:

- Calendar days that a task was in progress (excluding non-workable days)

- Suspended work days (calendar days minus actual work days)
- Measure of labor consumption by area relative to best consumption by task (%)
- Measure of production rate by area relative to best production rate by task (%)

By measuring the labor consumption and production rates by location, relative to the consumption and production rates for the best location of each task, it is possible to look for location-specific factors which may have prevented optimal performance.

Although the contractual CPM schedule was updated throughout the project, the LBMS schedule used for production tracking was frozen in February 2012 to ensure accurate resource tracking against the baseline. The data for this research were collected during the time period February – December 2012 and the scope is focused on interior rough-in and finishes tasks.

RESULTS

Thirteen tasks fit the criteria for data analysis with data points compiled from 185 progress actuals collected over 17 project locations. The results were analyzed based on actual task performance by location as a percentage of performance in the best location. This allows for comparison between tasks in isolation of task-specific factors such as quantity, units, or manpower.

The original data set contained many outliers. Some project locations which were less important or had higher amounts of float were started early and suspended more often when more important work became available. These locations were often kept as "backlog" and would be worked on when delays to other locations put work continuity at risk. To prevent the outlier data from skewing the results, and to emphasize the impact of ASAP management on the performance of critical tasks, the results were filtered to only those locations with zero total float; those on the critical path.

Table 1 shows the actual and calculated values for three of the thirteen analyzed tasks. Each task has been filtered to only those locations which fell on the critical path at the time that the actuals were collected. Higher "% Best Consumption" values are a result of the task requiring more manhours per unit to install in a particular location than the best location for that task. Lower "% Best Production" values are a result of the task producing lower output per day in a particular location than the best location for that task. As an example, the results show that the task Hang Drywall Side 2 in location Lvl 1->South 2 required only 12 working days to complete but spanned 105 calendar days from start to finish. Ninety-three (93) of those calendar days were suspended. It required 640% of the manhours/unit at this location, relative to the best location, and the output/day was a relative 26%.

Table 1: Results of calculated rates, suspended days, and performance for a sample of analyzed tasks along the critical path.

TASK NAME	**Cons Rate**	**Prod Rate**	**Work Days**	**Cal. Days**	**Susp Days**	**% Best Cons.**	**% Best Prod.**
Hang Drywall Side 2							
Lvl 1->South 2	3.20	6.7	12	105	93	640%	26%
Lvl 2->Corridors	0.50	26.2	11	78	67	100%	100%
Lvl 2->Pre/Post Op	0.67	20.0	12	39	27	133%	76%
Lvl 2->ORs	1.50	9.6	10	52	42	300%	37%
Lvl 3->Center 1	1.27	12.0	20	30	10	253%	46%
Lvl 3->Center 2	1.00	15.0	16	17	1	200%	57%
Lvl 3->North	1.50	9.6	10	44	34	300%	37%
Lvl 3->South	1.83	8.0	12	80	68	367%	31%
In-Wall Electrical							
Lvl 2->Pre/Post Op	1.87	7.50	32	61	29	327%	40%
Lvl 2->ORs	2.32	8.20	49	144	95	406%	44%
Lvl 3->Center 1	1.35	8.40	19	83	64	236%	45%
Lvl 3->Center 2	5.10	3.10	52	160	108	893%	17%
Lvl 3->North	2.40	7.10	34	51	17	420%	38%
Lvl 3->South	1.90	8.90	27	42	15	333%	48%
Top-Down Drywall							
Lvl 1->Corridor 1	7.00	2.00	8	41	33	2800%	3%
Lvl 1->North	1.00	10.70	9	87	78	400%	17%
Lvl 3->Center 1	2.50	5.60	17	166	149	1000%	9%
Lvl 1->Corridor 2	0.88	12.80	10	36	26	350%	20%
Lvl 3->Center 2	0.78	16.00	18	144	126	311%	25%
Lvl 1->South 2	0.25	64.00	1	1	0	100%	100%
Lvl 1->South 1	1.75	7.10	9	99	90	700%	11%

To identify whether a relationship exists between the downtime of a location and the performance of resources the “% Best Consumption” and “% Best Production” values were compared to the number of suspended days at each location. The relationship of suspended days to labor consumption was strong within many tasks but inconsistent across all analyzed tasks. For example, the task “Hang Drywall Side 2” showed a very significant 0.79 correlation between suspended days and “% Best Consumption” while the task “Top-Down Drywall” showed a statistically insignificant -0.02 correlation. Correlation between these two values for all critical tasks was 0.26. The relationship of suspended days to production, however, was consistent both within each location and across all data points. Figures 1-2 show the relationship between suspended days and “% Best Production” for all 52 data points along the critical path. Further numerical analysis shows a strong inverse correlation (-0.51) between suspended days and production rate of critical tasks.

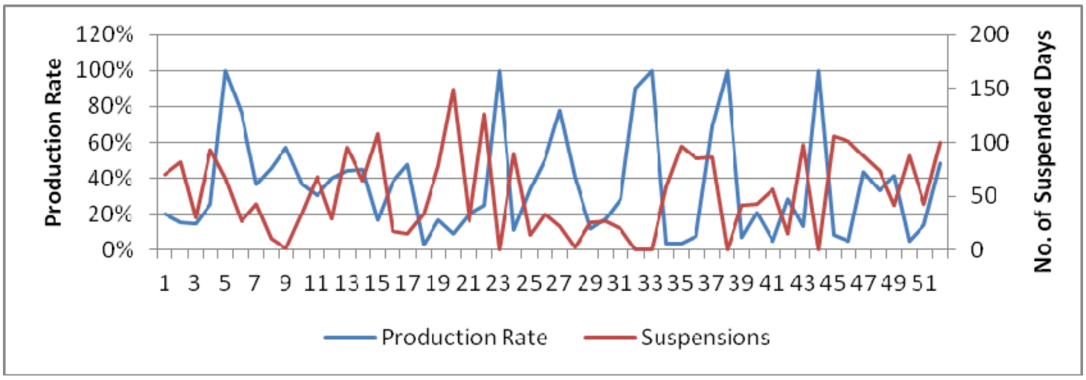

Figure 1: Relative change in production rates compared to number of suspended days where the change in production is calculated as actual production rate of a location divided by the best production rate of the task.

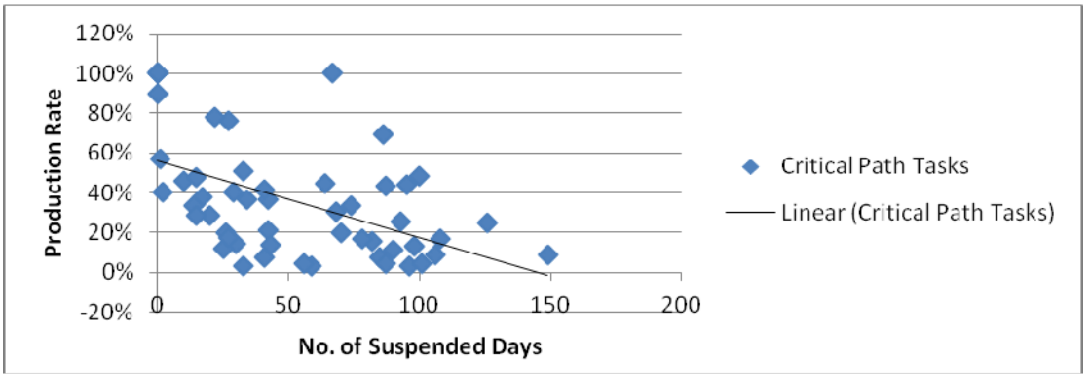

Figure 2: Scatter plot illustrates a -0.51 correlation between number of suspended days by location and production rate (relative to the best production of each task).

CASE STUDY 2 KPOMC

METHOD

The KPOMC project presented a unique opportunity where both the CPM/ASAP and LBMS management strategies were used in the same project, subject to similar resource constraints and environmental factors. Some of the superintendents managed work using CPM/ASAP methodology while others used LBMS. Superintendent scope was divided by area and the same trades worked in both environments with roughly similar scope. This makes it possible to compare performance between CPM/ASAP and LBMS location groups.

The actual production rates and labor consumption rates were compared between these two location groups for each task that had been completed at the time of research and had at least 1,000 man-hours. Actuals were collected from weekly interviews with field superintendents, subcontractor daily reports and daily site walk inspections. Although the floors were managed using different methodologies the entire project was scheduled and tracked in both CPM and LBMS.

RESULTS

To test the methodology, a selection of 56 interiors construction tasks were evaluated. Tasks were selected based on occurrence on both CPM and LBMS floors with similar scope, and tested to determine which methodology achieved better productivity and production rates.

Actual consumption of CPM floors was compared to actual consumption of the same task in LBMS floors. The average result was 18% higher labor consumption on CPM floors. CPM strategy resulted in a better consumption rate on 26 tasks and LBMS resulted in a better consumption rate on 30 tasks. Many of the instances where CPM results were better than LBMS they were close to equal productivity. Figure 3 shows the distribution. There are some tasks which are well below 100% (i.e. better consumption on CPM floors) but most of the tasks where CPM has better consumption are close to 100%. In contrast, there are many tasks where LBMS floors achieved much better productivity. For example, Fireproofing, which is a bulk production task with little potential for scope variation between locations, required twice the labor consumption on CPM floors compared to LBMS floors.

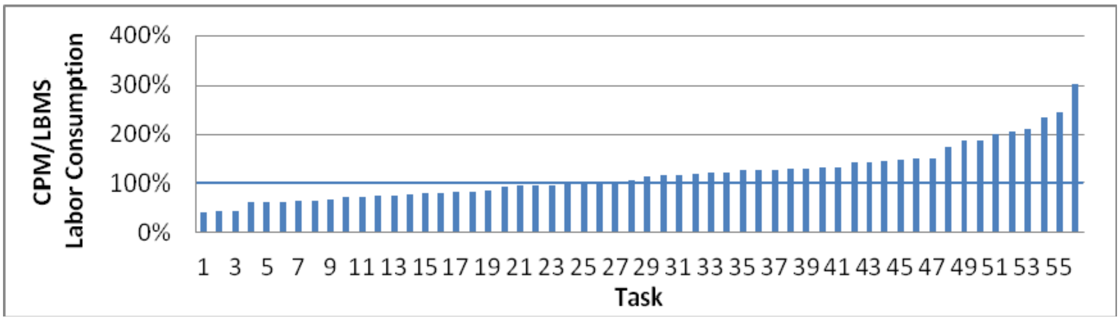

Figure 3: Labor consumption comparison by task. LBMS floor productivity was better for tasks with values greater than 100%.

In terms of production rates, LBMS floors were able to achieve better production in 69% of the tasks. LBMS had 39 tasks with high production compared CPM 17 tasks with higher production. On average, CPM tasks had 10% lower production rates than LBMS tasks. Figure 4 shows the results graphically. For example, Fireproofing achieved the average production rate of 1,174 square feet/day on CPM floors and 2,479 square feet/day on LBMS floors.

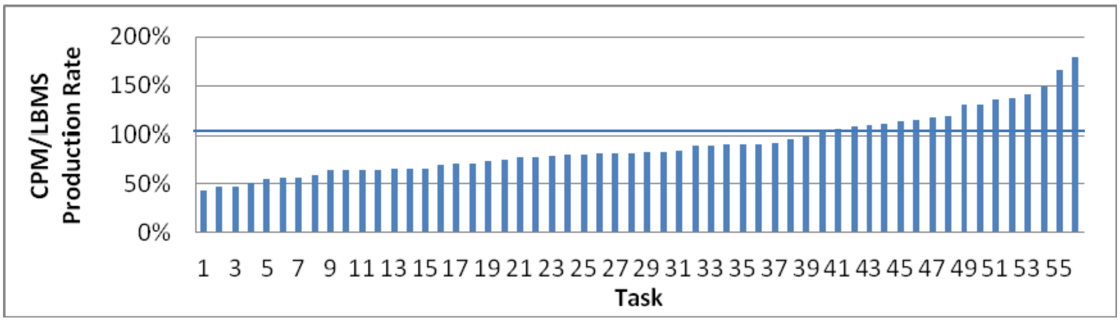

Figure 4: Production rate comparison by task. LBMS floor production was better for tasks with values less than 100%.

Figure 5 is a Flowline diagram of the In-wall Plumbing task on CPM floors. This task was originally planned with two crews: crew 1 (levels 1 and 3) and crew 2 (levels 2 and lower level). The actual progression of the task is shown with a dotted line and indicates that there was, in fact, only one In-wall Plumbing crew on the CPM floors. Level 1 started five weeks early and Area 2 was completed out of sequence. There was a seven-week demobilization between Levels 3 and 1 and after that the work continued in a different sequence than planned. Levels 2 and Lower Level experienced multiple starts/stops, suspensions, and "stacking" of locations resulting in lower than planned production rates. Overall, In-wall Plumbing on the CPM floors was completed 23 weeks later than planned.

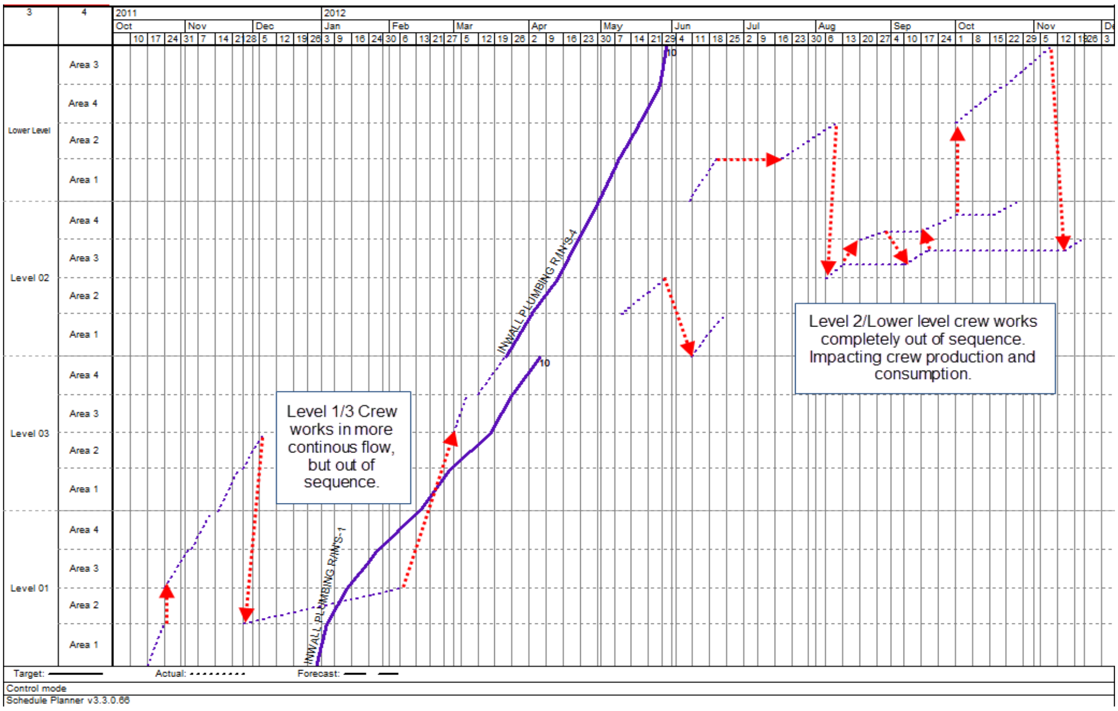

Figure 5: Flowline view of In-wall Plumbing task on CPM floors. The bold line represents the planned production while the dotted line is the actual production.

Figure 6 is a Flowline diagram of the In-wall Plumbing task on LBMS floors. This task was also originally planned with two crews: crew 1 (even floors) and crew 2 (odd floors). In this example the work was installed with two crews as planned and with the exception of some minor "stacking" between Areas 1-2 on Level 8 (week of March 5th) all location were completed according to the planned sequence. Both crews started earlier than planned and as a result appear to have suffered some starts and stops in production. Production rates met or exceeded the plan in all locations except Level 6 Area 2 and Level 7 Area 2. Overall, In-wall Plumbing on the LBMS floors was completed 2.5 weeks later than planned.

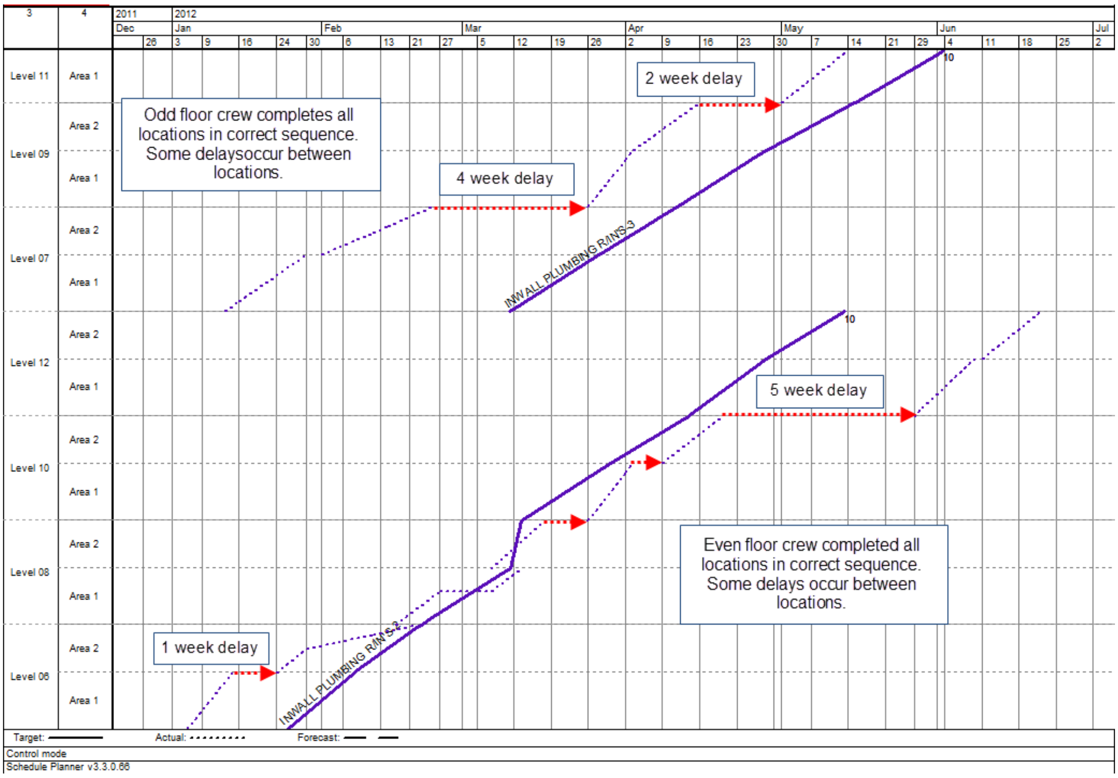

Figure 6: Flowline view of In-wall Plumbing task on LBMS floors. The bold line represents the planned production while the dotted line is the actual production.

CONCLUSIONS

This research brings more evidence about the detrimental effects of starting as early as possible and the benefits of continuous workflow. Starting too early often leads to work suspensions and a strong negative correlation between suspensions and production rate was found empirically in this research. This is interesting because production rate monitoring is focused on tracking working days. These results show that the downtime between periods of work in a discontinuous task correlates with slower production during those days when the work was actually done. This empirical result lends support to the theory of LBMS which states that continuous production enables faster production and shorter project durations. More emphasis should be placed on protecting continuous workflow rather than working on the basis of discrete activities or assignment.

In a direct comparison under the same site conditions, with the same labor resources, floors managed with “ASAP” methodology showed both lower productivity and lower production rates compared to floors which were managed with LBMS methodology. The average productivity difference was 18% in favor of LBMS, and the average production rate difference was 10%. Production rate difference was smaller than productivity difference because fewer resources were used on LBMS floors to achieve more production.

To our knowledge, this is the first time when both management approaches have been used in the same project but monitored consistently with the same method. Liu & Ballard (2008) have previously found a positive correlation between the use of Last

Planner System™ and productivity. It would be an interesting future research question to evaluate how much better results can be achieved by combining the technical system of LBMS to the social process of LPS as suggested by Seppänen, Ballard & Pesonen (2010).

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