INTEGRATION OF LAST PLANNER SYSTEM AND LOCATION-BASED MANAGEMENT SYSTEM

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ABSTRACT

The Last Planner System (LPS) and Location-Based Management System (LBMS) are both lean planning and controlling tools. A combination of these systems would bring much greater benefits than stand-alone implementations. However, previous research attempting to combine these methods has not been on sufficient level of detail for actual implementation.

The goal of this research is to develop a combined workflow for master planning, phase planning, look-ahead planning and weekly planning. The workflow is demonstrated through the use of a simple example from a case study project. Master scheduling clearly belongs to the domain of LBMS; time and weekly planning is clearly within the domain of LPS. Phase scheduling can include components from both systems but integration is straightforward. The biggest opportunities for improvement exist in progress tracking, forecasting, control action and look-ahead planning phase where LBMS and LPS both have important independent contributions and their combination is not trivial. The paper attempts to better define the inputs and outputs of each system in each phase to come up with a unified solution. A case study example will help practitioners implement the combined method.

KEYWORDS

Last planner system, Location-based management, production planning, production control

INTRODUCTION

The Last Planner System® (LPS) and Location-Based Management System (LBMS) are complementary lean production planning and controlling tools which aim to decrease waste, increase transparency, improve predictability and improve flow. LPS does so by focusing on the social process of collaborative planning and by improving the reliability of commitments (Ballard, 2000). LBMS is primarily a technical system which optimizes work continuity based on quantity and productivity information and forecasts future performance (Kenley and Seppänen, 2010). The systems complement

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each other well because they have no technical overlap. For example, the LPS process of phase scheduling could be implemented using various scheduling formats, including LBMS. The proposed integration uses the social process of LPS with the technical tools of LBMS. The combination of these systems has been proposed previously (Seppänen, Ballard and Pesonen, 2010) but the research was exploratory in nature and the description of the process did not contain sufficient detail for empirical research or industry application. The goal of this paper is to update and add more detail to the proposed combination of the two systems.

The proposed process is divided into two parts: production planning and production controlling. Production planning is understood to include master scheduling and phase scheduling. Master schedules in LPS are limited to milestones and long lead items (Ballard, et al., 2002, pp. 227-229). More detail is added collaboratively in phase schedules where planning starts from the milestone and works backwards so that each task releases work to the next task (Ballard and Howell, 2003). In terms of control, project and production control can be distinguished. The job of project control is to determine if the project is moving toward its objectives. The job of production control is to proactively move the project to achieve those objectives. From this perspective LPS works mostly on production control while LBMS has tools for both project control and production control.

A key requirement for lean production planning and control methods is to make problems visible as early as possible and subject them to root cause analysis, problem solving and continuous improvement according to the Plan-Do-Check-Act cycle (Deming, 1986). LPS and LBMS both aim to uncover these problems. The discussion in this paper focuses on how more problems can be identified earlier by combining the two methods.

CASE STUDY

A case study will be used throughout the paper to illustrate the concepts in a real project. Webcor Builders, a large general contractor operating mainly in the West Coast region of the United States, is the prime contractor. The client is a private company with headquarters in South San Francisco. The client has a new construction expansion plan of their facilities. The plan consists of two phases, an office building of 23,690 m2 (255,000 sqft) in the first phase and an employee center with fitness club in the second phase. The contract type is Highly Collaborative Project Delivery, which is similar to IPD but does not include the three party agreement. However, working in a big room, performance incentives and collaborative planning were core requirements used to select the project team. The project was discussed related to social aspects of LBMS implementation in IGLC 2014 (Freeman and Seppänen, 2014). After that study, LBMS and LPS were implemented together with a contractual CPM schedule.

PRODUCTION PLANNING

MASTER SCHEDULE

Production planning in Last Planner System is divided into Master Schedule and Phase Schedules. Master schedules of LPS are typically limited to phase milestones

and long lead time items (Ballard, et al., 2002, pp. 227-229). However, Last Planner principles do not prohibit producing a detailed master schedule (Ballard, Hammond and Nickerson, 2009). Seppänen, Ballard and Pesonen (2010) proposed that LBMS could add more definition to the master scheduling phase by defining the overall Location Breakdown Structure (e.g. project divided first to separate buildings, then to floors, then to zones) and to evaluate the required production rates. In LBMS, Location Breakdown Structure specifies the physical locations where work will be done. Different phases can follow different LBS's but all work within a phase is planned and controlled using the same locations. Locations can be hierarchical and logical relationships can be automatically created based on levels of hierarchy (e.g. all work of predecessor needs to be finished in a building before the successor can start in the same building) (Kenley and Seppänen, 2010). Master schedules were recommended to have 20-30 tasks, using available quantities and resource information where possible.

In master scheduling phase, there is generally limited availability of information about design. However, in almost all cases the main trades and main tasks to be carried out are known. It is also possible to know or reasonably assume many key quantities based on schematic design and building function. Location-Breakdown Structure on rough level (Buildings and Floors) can be designed, as well as overall production flow. How can we get into good phase milestones by using all this available information but not going into too much detail?

We propose that the focus should be on tasks with mandatory technical hand-offs to other trades and on tasks which require a lot of space for laydown areas and work. Tightly interrelated tasks such as form-rebar-pour sequences and overhead MEP can be lumped into one task. Additional buffers should be reserved for tasks which contain work of multiple subcontractors.

The overall strategy of the master schedule will likely have to be followed because it will be used to pull design and schedule long lead time deliveries and to discuss with subcontractors during buy-out phase. However, any dates and task names will likely change during the phase scheduling process. The exact dates of the master schedule should never be used to push production to start on a given date. Rather, it gives preliminary information for any phases which have not yet gone through collaborative phase scheduling exercise.

In the case study project, Webcor's project team developed an LBS which was broken down by buildings, level and for interiors to five zones on each floor. The team developed a master schedule based on an internal pull scheduling meeting before subcontractor buy out using experience gained from past similar office buildings. The plan was based on continuous workflow with one crew flowing from the first floor to the seventh floor for each main task. The plan was optimized for flow using LBMS and visualized with flowline diagrams (not shown here because of space constraints). The extended project team got the schedule in Gantt Chart format.

PHASE SCHEDULE

Phase scheduling using pull planning principles has been discussed extensively (see for example Tsao and Hammons, 2014 for a great practical case study). When combining LBMS and LPS, Seppänen, Ballard and Pesonen (2010) proposed having two workshops, one for location-breakdown structure and task and logic definition and second for schedule optimization with a homework assignment in between where

all the parties collect quantity and productivity data for each task. We recommend the same process but try to go into more practical detail in this paper.

First, a common Location Breakdown Structure should be defined. The goal should be to achieve similar quantities of work in each location with each trade able to finish work in one location completely before moving to the next location. One of the key decisions at this stage is location size. Large locations mean implicit buffers because if locations are large, it typically would be possible to have several subcontractors work in the same area. Very small locations can be hard to define so that they work for all or most of the subcontractors and it may not be possible to stage all the materials within the location.

In practice, defining the Location Breakdown Structure is easiest with printed floor plans. The facilitator of the meeting needs to make sure that each participant understands that a location must be able to be fully completed before moving to the next location. Subcontractors often request their own custom locations to locally optimize productivity but can be persuaded to adopt a common location breakdown structure when they understand that they will be able to own the location.

Pull scheduling can then be done using sticky notes, focusing first on standard work for each location type. For example, an office building could have different pull plans for cafeteria, office rooms, corridors and elevator lobbies. Different pull plans are not required for minor location-based exceptions. They can be handled with additional location-based sticky notes. If a location has a lot of exceptions, a separate pull plan should be considered. Durations should not be discussed at this time because the goal of the exercise is to get tasks and logic. Durations will be an outcome of the schedule optimization step (Seppänen, Ballard and Pesonen, 2010).

The first workshop results in a Location Breakdown Structure, a list of tasks and their logical relationships. The next step is to collect the remaining data required to create a location-based plan – quantities, labor consumption rates (manhours / unit) and resources. Quantities are required for each task and each location where the task exists. The same labor consumption is assumed to apply to each location, unless productivity is expected to be different due to changing difficulty. Resources and crews are based on optimum minimum crew size. For example, electricians can work productively alone (optimum crew = 1) but windows and doors require teams of two (optimum crew = 2). Additionally subcontractors can provide information of how many crews of optimum size they are planning to mobilize for each task. This information can be collected off-line by giving all participants an Excel spreadsheet template with task names in rows and labor consumption and quantities in locations in columns.

Before the schedule optimization workshop, the first location-based plan is created. This is strictly based on information collected in the workshop and based on quantity and labor consumption information provided by the subcontractors. The first schedule has continuous flow for all trades, logic based on pull scheduling workshop and resources based on subcontractor suggestions. In almost all cases, the first schedule significantly exceeds the master schedule milestone.

Schedule optimization is done collaboratively in the schedule optimization workshop. The best place to start is with tasks with largest empty spaces before them in the flowline diagram. For each task causing an alignment problem ways to improve productivity are discussed first. If it is not possible to improve productivity, more

resources are requested from the subcontractor. Additional resources are added until the slope of the task matches the predecessor. If it is impractical to add that many crews to work in one location, splitting the task into multiple workflows can be considered. If the subcontractor does not feel comfortable committing to required crew size, the first round of optimization goes up to the team size that is acceptable to the subcontractor. If the task is proceeding too fast, options include accepting discontinuous work, decreasing resources or adding more work to the scope. Issues are resolved in this manner one at a time until improvements can no longer be made within everyone's comfort zone.

If the target milestone cannot be reached during the first round, a second round is added where the team brainstorms about possible solutions. Because all the participants realize that targets could not be met within their comfort zones everyone should be more willing to make concessions after having gone through the process once. Often innovations, such as adding more prefabrication or removing any responsibility for logistics from bottleneck contractors, are proposed and can decrease resource requirements to balance the phase. The end result is a balanced flowline schedule which finishes before the master schedule milestone. Buffers can then be added within the phase to protect the flow of bottleneck operations. Once approved by all parties, the phase schedule replaces the corresponding part of the master schedule.

In the case study project, all trades involved in the phase were contacted prior to the pull planning meeting. The participants were asked to list their specific deliverables for this milestone and define the necessary steps they would need to achieve the deliverable. At the same time they were asked to develop their preferred LBS, sequence of locations, crew size and production rate for that crew size. The project team prepared for the meeting by having done a first draft schedule and production plan with a detailed LBS and production rates. In the pull planning meeting the LBS was first discussed and agreed on. After agreeing to the LBS the trades pulled from the milestone through one standard location. The results were analysed using LBMS. Optimization discussions were done as follow-up meetings with the impacted trades.

Figure 1 shows the interior rough-in phase schedule from the case study project for Building B. The schedule changed significantly from the master schedule based on the planning meetings. The phase was detailed out by adding several more tasks for each trade based on pull scheduling process. In the master schedule, each subcontractor had one crew flowing through floors in sequence. In the phase schedule, two crews working different floors were implemented for most trades (floors 2-4, floors 5-1). The special areas of the first floor were placed last in sequence and many trades have additional crews in that location. Most of the tasks are continuous but some have been planned to be. A few faster tasks flow continuously through floors 2-7 and do not have a separate crew for level 5-7.

PRODUCTION CONTROL

LOOK-AHEAD PLANNING

In the Last Planner System, lookahead planning (preparation) consists of constraints identification and removal, replanning when necessary, task breakdown to the level of

operations, and collaborative design of new operations (Hamzeh, Ballard and Tommelein, 2012). Operations consist of steps which are appropriate for assignment to individuals or sub-crews within a crew. Designing at operation level reveals different constraints, and having a tested design (virtual prototyping, physical prototyping, or thought experiment) increases the probability of reliable release of work downstream (Hamzeh, Ballard and Tommelein, 2012).
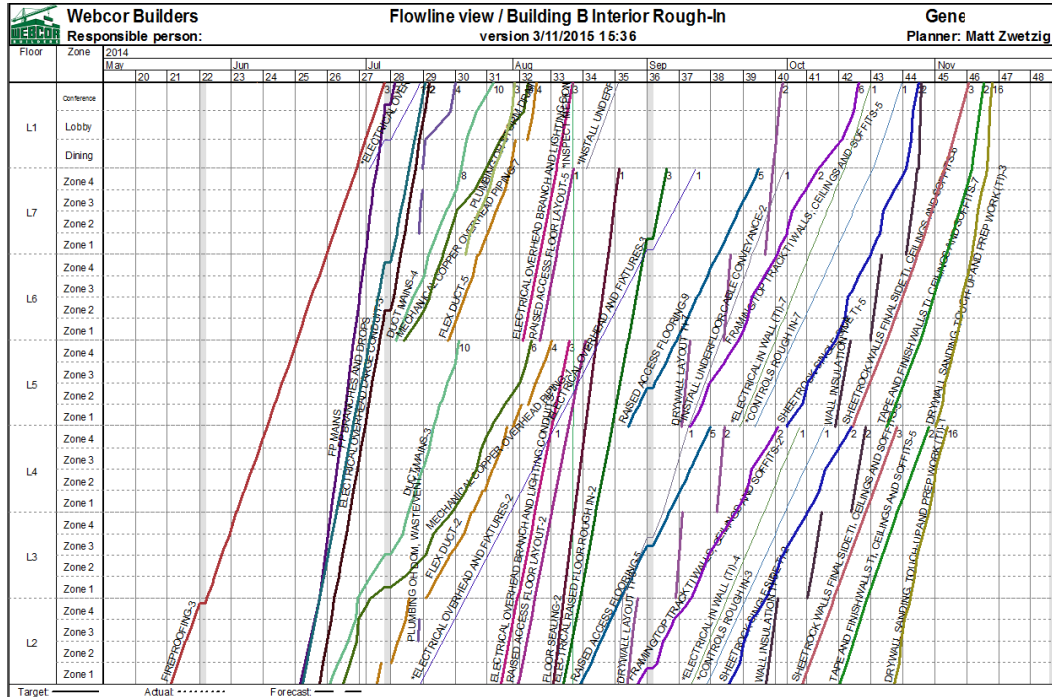

Figure 1: End result of phase scheduling optimization meeting for interior rough-in milestone in case study project

LBMS is concerned with cascading delays caused by interference between trades (Seppänen, 2009). The main control tools include systematic collection of progress data, forecasting future production based on actual production and alarming of upcoming interference. Constraints or operations level are typically not incorporated to the LBMS schedule because they could lead to cluttering and decrease of visual effectiveness of flowline diagrams (Seppänen, Ballard and Pesonen, 2010). However, constraints are critical to include in the analysis, or unplanned work stoppages or slowdowns may occur which have nothing to do with interference from other trades.

LPS and LBMS are very complementary with regard to look-ahead planning because they raise different problems for discussion. The LPS process exposes constraints which must be removed for production to continue according to the plan without interruptions. LBMS highlights problems related to capacity and production rates. All of these problems can be analyzed through root cause analysis and solved collaboratively.

Seppänen, Ballard and Pesonen (2010) proposed that the combined look-ahead process works by updating LBMS forecasts for discussion in a superintendent meeting devoted to lookahead planning. The complete weekly look-ahead process would thus include the following steps (not necessarily in the sequence below and allowing for some iteration):

- Identify tasks and locations in the look-ahead window
- Break down tasks and locations to operations
- Identify, assign and remove constraints
- Review actual production to identify ongoing production problems
- Review forecasts and alarms to identify future production problems
- Root cause analysis for problems
- Re-Plan to address current and upcoming problems
- Release constraint-free operations, tasks and locations to workable backlog
- Preparing for upcoming operations

These steps are elaborated below.

Identify Tasks and Locations in the Look-ahead Window

Tasks and locations in the look-ahead window are identified based on the LBMS phase schedule. This can be done graphically on production wall by drawing a line through the flowline diagram and listing all tasks and locations where flowlines are to the left, or intersecting with the look-ahead period line.

Break down tasks and locations to operations

Tasks in locations are broken down to operations level in a pull scheduling session with the team responsible for the task. The team needs to come up with the answer of what steps are required for the task to be finished in a location. This should be reviewed for both the task in general (what is common in all locations?) and by location (specific operations related to that location). For example, for a task called stud framing in phase schedule, operations could include layout, moving materials to the right location, installing bottom track, plumbing the top track, installing top track, installing bottom track, cutting studs to correct length, installing studs and installing backing. Different circumstances and their impact on operations should also be considered. For example, the attachment of top track depends on whether it is attached to concrete, metal deck or joists and any special circumstances may include different operations.

Identify, assign and remove constraints

Any missing constraints related to operations, tasks or locations are identified in meetings with the team responsible for doing the work and in weekly superintendent look-ahead meetings. A constraint can apply to the whole operation (for example, material not delivered) or a certain location (for example, open Request for Information on the fifth floor related to Drywall Framing). Identified constraints are assigned to team members who commit to their removal by a certain date. Currently active constraints are reviewed weekly and their status is updated. If a constraint cannot be removed before the LBMS forecast date, the constraint will be elevated into a problem.

Review actual production and forecasts to identify ongoing production problems

Progress data is collected and analysed with LBMS to identify start-up delays, production rate deviations and work interruptions. Forecast is calculated based on

actual labor consumption rate and current resources on site. Any alarms caused by current or future interference between trades are elevated to problems.

Root cause analysis and resolution for problems

Any problems identified through constraint identification, constraint removal or actual production are analysed for root causes (Ballard, 2000). LBMS will provide numerical support - such as actual production rate and actual labor consumption - for any discussions related to production deviations. Actions are agreed with the team to target these root causes. If the agreed on actions impact the crew size or anticipated future productivity of an operation, the forecasts are recalculated with these values to see if the actions are enough to prevent the problem.

Re-Plan to address current and upcoming problems

Re-planning can be initiated to address current or upcoming issues which cannot be dealt with by productivity improvements or crew adjustments, or if a better way to finish the phase has been proposed. Re-Planning can change any aspect of the phase schedule and can be organized in the same way.

Release constraint-free tasks and locations to workable backlog

When all constraints related to all operation of a task in a location have been removed, the location is released to workable backlog. The control chart is a good visual way to keep track of workable backlog. In control chart, the location-breakdown structure is shown on vertical axis and phase schedule tasks on horizontal axis. Tasks in a location are color-coded based on constraints and status. Any tasks with constraints in a location can be shown in grey color (Kenley and Seppänen 2010, p. 329). Although operations belonging to a task can also be constraint-free, they should generally not be started until all operations can be performed before handing off the location to the next trade. Starting individual operations would result in work-in-progress of no value to the downstream operation.

Designing upcoming operations

Before the start of an operation in the first location, the operation should be explicitly designed by those who are to execute the operation. The design of operations can be done using virtual prototyping, physical prototyping or first run studies. Standardization is appropriate for new, critical, and repetitive operations. Critical operations, such as heavy lifts, are those whose failure cannot be tolerated, and so warrant extensive planning and preparation. Planning and preparing for new operations, such as assembly and installation of light fixtures, helps avoid rework and work flow interruptions. Repetitive operations may benefit from virtual or physical prototyping (mock ups), but can also be refined over multiple iterations. That starts with a design session involving the craft workers who will do the first run (the first instance of the repetitive operation), documentation (videotaping, process maps, etc.) of the work as actually performed, and review with the craft workers to develop further improvements (Parker and Oglesby, 1972; Oglesby, Parker and Howell, 1989; Ballard, et al., 2002; Ballard and Howell, 2003).[4]

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[4] The expression "first run study" appears to have originated in the writings on Last Planner by Gregory Howell and Glenn Ballard, but the basic methodology was brought into the construction

Examples from the case study project

In one of the weekly meetings the electrical contractor complained of trade damage to his electrical under-floor installations, which required rework that caused delays. A root cause analysis of the problem found that the time between the electrical installation and the following trade putting in the raised access flooring was too long, and construction traffic and material transportation through the area damaged the completed electrical work. LBMS analysis showed that the electrician was installing faster than planned. The team decided to adjust the production rate of the electrician back to the initial planned rate to be almost at the same speed as the following accessed floor installation. In this case LBMS provided the tools for planning corrective actions to problems found with LPS tools.

Another example related to steel erection. The actual installation rate was significantly faster than the rate planned in phase scheduling. LBMS analysis showed that the steel erector would outpace welding and plumbing crews and cause a break in the flow of work. The decision was made to stop the steel erection to have the following operations catch up. The crew that continued work had a slower production rate than planned and failed the LPS commitments. The root cause analysis revealed that the first team was the "A-team" and the second crew was the "B-team" and they both deviated from the planned installation rate. In this case, LBMS highlighted the problem of going too fast and LPS highlighted the problem of going too slowly. With stand-alone implementation one of the problems would have been found much later if the project had been implemented LBMS or LPS alone.

WEEKLY PLANNING

The main strength of LPS is efficient execution based on commitments, collaboration and continuous improvement as a result of analysing plan failures. Root cause analysis is initiated for any assignments which were not completed as planned (Ballard, 2000). The proposed integration with LBMS on weekly planning level is to compare commitments to LBMS forecasts to highlight problems earlier. If commitments do not match or exceed the LBMS forecast, it is possible to know a week earlier that there will be issues. In the combined system, weekly planning highlights problems in the commitment phase through LBMS comparison and after execution through plan failures. Both the upcoming and actual problems should be subjected to root cause analysis and learning process.

CONCLUSIONS

In this paper, a process combining LPS and LBMS was described based on current best practices and using examples from a case study. With regards to production planning, the process described earlier by Seppänen et al. (2010) was elaborated in more detail. However, new ideas were presented particularly in relation to production controlling. A critical part of production control is highlighting as many problems as possible, as early as possible. It was found that the combined system looks at the production system from multiple different angles and is able to identify more

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industry by Parker and Oglesby (1972) and further elaborated by Oglesby, Parker and Howell (1989).

problems earlier than stand-alone implementation of either system. LPS constraint screening will reveal some problems, LBMS forecasts and actual data will reveal others. Finally, weekly planning will reveal problems if commitments do not match the required production rate and if the team fails to meet those commitments. These problems can then be subjected to root cause analysis and continuous improvement through Deming's PDCA-cycle. A few examples of problems were illustrated using a case study from Webcor. Previous research has reported the amount of problems found by LBMS (for example Seppänen, 2009; Seppänen, Evinger and Mouflard, 2014) and LPS (for example Ballard, 2000). Anecdotal evidence from the case study shows that the amount of problems identified increases and information from the combined system helps in solving the problems. This hypothesis needs to be tested in future empirical research.

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