A PRODUCTION CONTROL GAME FOR TEACHING OF LOCATION-BASED MANAGEMENT SYSTEM'S CONTROLLING METHODS

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ABSTRACT

Typical issues seen in the production data of projects which have implemented Location-Based Management System (LBMS) include subcontractors not finishing locations, working in random location sequences, working with smaller or large crew sizes than planned, and starting earlier than planned. LBMS control methods include delaying start dates until enough work is available and controlling production rates to prevent interference. These methods have been difficult to teach because any theoretical material is easily forgotten when actual production starts.

The research described in this paper tries to solve the teaching problem. A production control game was defined using a simple, repetitive building. Each subcontractor had a predetermined behavior modeled by variables including preferred crew size, how fast the subcontractor is able to adjust the crew size, and production rates for different crew sizes. The players of the game planned a schedule and implemented control actions when they wanted to influence subcontractors' behavior. Each group of players utilized the same subcontractors, so the effect of their decisions could be directly compared to other players in the same group. For comparison purposes, a purely heuristical game based on textbook LBMS method and textbook CPM method was also played with each group.

Game results show that total duration and total cost have a large variance depending on the control actions taken during the project. Purely theoretical LBMS outperformed all players in all groups. Purely theoretical CPM focusing on the critical path finished last or second to last both in terms of durations and total cost. All the players felt that they understood the impact of their decisions better after finishing the game and comparing the results with others in the same group.

KEYWORDS

Location-Based Management System, production planning, production control, variability, buffer, production system design

INTRODUCTION

The Location-based Management System (LBMS) is increasingly being used to plan and control production in construction projects. Better planning results have been reported in several case studies (Kenley & Seppänen 2010: 493-533, Kala, Seppänen

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& Stein 2010). However, plans have limited value if production is not controlled properly. Seppänen (2009) described three case studies where plans were far from actual progress and developed a new forecasting method to improve controlling parts of LBMS. Research in Lean Construction has focused on controlling production and the Last Planner System™ (LPS) has been developed as the controlling tool (Ballard 2009). Because LPS is primarily focused on social process and LBMS is primarily a technical system, ways to combine these systems have been proposed. (Seppänen, Ballard & Pesonen 2010).

LBMS controlling theory is based on calculating actual production and consumption rates and using those rates to forecast future durations. If the predecessor's forecast interferes with the successor, an alarm is generated. The goal of production management is to take control actions to remove the alarms. (Kenley & Seppänen 2010, Seppänen 2009).

The production control game was developed to train people using LBMS about how production works and what kind of control actions should be taken when. Earlier attempts of teaching production control have included classroom settings where teams get progress data from the instructor. These have always felt a bit too arbitrary. The Parade of Trades dice game (Tommelein, Riley & Howell 1999) teaches valuable lessons about variability but is based on luck and does not include decision-making by the players. The goal of this research was to develop a game where players would face the same subcontractors who behave somewhat realistically and where the players can be scored based on the plans and decisions they make. This was not originally meant to be an academic exercise but to be a training tool for people implementing LBMS to avoid frustration in real world implementations.

ASSUMPTIONS AND HYPOTHESES

Based on observations on projects, technical literature, and some empirical research, the author has developed a few fundamental hypotheses of how subcontractors behave in projects. The rules of the production control game assume that the following hypotheses are true.

Firstly, subcontractors follow their own schedule based on optimizing their cash flow and satisfying all their clients. These schedules are only loosely linked to the GC's master schedule and have almost nothing to do with the resource loading of GC's schedule. Subcontractors make decisions in a multi-project environment. They allocate limited resources to projects based on various criteria. One important principle is to optimize productivity of their people (Harel & Sacks 2006). From any individual project's point of view, this makes it difficult to increase the crew size because subcontractors have to withdraw those resources from other projects. Additionally, if production stops on one project, it is difficult to get the resources back on site because the resources are already working on other projects. Any demobilization from the site may result in return delays which are shown by a delay in mobilization after work becomes available again (Seppänen 2009).

Secondly, based on author's direct observations, General Contractors are not actively managing crews on site. Subcontractors tend to often work out-of-sequence or in parallel in multiple locations without being stopped by the General Contractor. They often leave unfinished work when they move to start work in other locations. Although some of this behaviour can be explained by lack of starting prerequisites, it often seems to be just a decision by the subcontractor to finish part of the scope in all locations first before coming back for the final part.

Thirdly, each subcontractor has a maximum amount of resources they are willing to allocate to a project. There is a maximum amount of resources which can work in a single location productively and a maximum amount of resources available for the project.

Although all these hypotheses make intuitive sense, managers making control actions do not seem to be aware of them. Most of the location-based schedules used in the field do not contain buffers. People implementing control actions get frustrated when subcontractors "play time" and do not agree to mobilize additional resources right away. They get even more frustrated when the subcontractors withdraw the additional resources after a few weeks of increased resource amounts. LBMS forecasting ability is compromised when subcontractors do not finish locations they started because production rates are based on the "easy" part of work. Also multiple open locations make it difficult to forecast where subcontractors will go next.

PRODUCTION CONTROL GAME

Players of the production control game were given a simple resource-loaded schedule with seven tasks flowing through six locations. Dependency relationships were predetermined. Players were told that durations and resources were based on subcontractor input. Their task was to optimize the schedule and then respond to progress data by control actions. They could optimize the schedule and change durations by increasing or decreasing resources. Instructions warned the players that any increase in resources may increase the risk of the project and make controlling more difficult.

For the production control part, players were told that each week they would get actuals including starting dates, finish dates, or % completed, any days when tasks were suspended, and information about future mobilization dates for each subcontractor. The players had to respond to that information by sending back an updated schedule file and a list of control actions. Control actions needed to be spelled out in the body of the e-mail response. Maximum of three control actions were allowed to model limited supervision time. Example actions such as increasing crew size were included in instructions.

Finally, players were informed of how assignments would be scored based on cost:

- $1,000 management cost / control action
- Labor cost based on man hours spent
- Mobilization / demobilization cost of 4 hours / person coming or leaving the site
- $1,000 overhead cost / day of project
- $2,000 bonus / week for early completion
- $3,000 penalty / week for late finish

PREDETERMINED PRODUCTION CONTROL DATA

To make the results within each group comparable, production control data was predetermined, along with rules how control actions would influence production. Each subcontractor had a few basic parameters and some unique special behavior. The main parameters for each subcontractor were:

- Preferred starting date for each task
- Optimal crew size
- Subcontractor preferred number of crews of optimal size
- How fast subcontractor would add resources (1-3 weeks)
- How many crews could be added each week (1-3 crews)
- How long control actions would remain effective (1-6 weeks)
- Return delay if the subcontractor had to leave the site
- Maximum resource availability
- Production rate (% / day) for each task in each location for subcontractors preferred crew

In addition to these basic parameters, subcontractors could have special behaviors. Special behaviors included:

- Predefined interruptions of work (open RFIs, weather delays etc.)
- Preference to work in multiple locations
- Preference to mobilize slowly
- Starting without request
- Overlap with other subcontractors (work in parallel with other trades)
- Working out of sequence
- Partially finishing locations

POSSIBLE CONTROL ACTIONS

Although subcontractor behavior and their production rates were predetermined, differences between players could arise based on their initial plan and their control action decisions. The following control actions were allowed:

- Crew size increase or decrease
- Sequence changes
- Logic changes
- Overtime work
- Force starting subcontractors

It should be noted that these control actions are not the only ones available in real construction. In fact, reducing variability by other means such as implementing the Last Planner System™ (Ballard 2000) or conducting First Run Studies (Howell & Ballard 1999) would in many cases be preferred because they improve productivity and can solve production rate issues while decreasing cost. However, implementing these approaches in this game would require an additional level of detail. Therefore control actions in this game influence only production rates, not productivity.

RULES OF THE GAME

What the players did not know, based upon the instructions given, was that each subcontractor had their own agenda which basically ignored the player's plan. They had their own preferred mobilization date and their own preferred crew size for each task and any special behaviors. To process the weekly production control data, the following steps were used:

1. Determine mobilization / return dates for subcontractors who are not on site
2. Determine resource amounts of each subcontractor for the week
3. Allocate resources of each subcontractor to tasks and locations in the beginning of the week
4. Calculate completed work for each task and location
5. Reallocate resources if location is completed or achieves the percentage completed target for each subcontractor who does not completely finish locations

Each one of the steps is described in detail below.

Mobilization / return dates for subcontractors

Subcontractors try to mobilize first on their preferred starting date. They inform of their intention to mobilize two weeks before the actual mobilization. Subcontractors who have the special behavior "Mobilize without instruction" try to mobilize automatically on that date. Subcontractors without the special behavior mobilize on that date only if instructed to do so by the player. Otherwise they shift to "standing by" mode. If a subcontractor is standing by, they can be requested to mobilize later but they will be able to show up on site only after their return delay parameter (1-3 weeks).

If the subcontractor has left the site, they try to mobilize after a location is available for work and their return delay duration has passed. Availability of work is defined by being at least 50% completed by any predecessors and suspended or 100% completed. Subcontractors who have the special behavior of "Overlapping with others" consider locations available when the predecessor work has started in the location or continued a previously suspended location.

Players can use a control action to force the subcontractor on site earlier than their preferred mobilization date or return delay allows. In this case, subcontractors mobilize two days after the control action with half of their normal crew size and half productivity. They will revert to standard behavior on their preferred mobilization date or after the return delay has passed.

Resource amounts of each subcontractor

Resource levels of each subcontractor depend on active control actions taken by the player. If no control actions have been taken or the subcontractor mobilizes for the first time, they will mobilize with their preferred crew size. If the subcontractor has been forced to mobilize (with a control action) before their preferred start date, they will mobilize with half their preferred crew size. Subcontractors with the special behavior “Slow mobilization” start with a smaller crew size and gradually increase to their preferred crew size.

If control actions have been taken, they will start to influence the resource levels after the time defined by subcontractor parameter “Time required to mobilize additional resources” has elapsed. Additional resources are added at the maximum of 1-3 crews per week (subcontractor parameter) until the crew size instructed by the control action or maximum resource amount has been reached. After this time the control action will remain effective for 1-6 weeks after which the subcontractor reverts to their standard crew size.

The result of this step is a crew size for each ongoing task.

Resource allocations in the beginning of the week

Subcontractors follow their predetermined behaviors when deciding where to allocate their resources for the week unless control actions have been taken. Resource allocations are affected by crew size, available locations, and special behaviors such as “Work in multiple locations,” “Work out-of-sequence,” and “Overlap with predecessors.” Subcontractors without any special behaviors allocate their resources to the first available location in the planned location sequence. Available locations are locations where predecessors are at least 50% complete and suspended or fully completed and the task has a smaller completion rate than the predecessor in the location. Only ten resources can work productively in the location, so if the crew size is more than ten, any additional resources are allocated to the next location in location sequence. If enough locations are not available in the task, the subcontractor allocates these resources to another task which has available locations (in location sequence). If no such locations exist, the subcontractor demobilizes resources which could not find an available location.

Subcontractors with the special behavior “Work in multiple locations” allocate their resources to multiple locations, if available. Resources are allocated evenly and any remainder is allocated to the first location in location sequence. Subcontractors with “Work out-of-sequence” work otherwise in the same way as other subcontractors but they select their location opposite to the planned location sequence. Subcontractors with “Overlap with predecessor” consider locations available when the predecessor has started in the location and has larger percentage completed in the location.

Players can affect resource allocations freely with control actions. Subcontractors always follow sequence instructions as long as locations are available and no more than ten resources are working in the location. Subcontractors follow sequence instructions for the duration of control action.

Calculate progress in each location

Progress calculations are based on predetermined production rates adjusted by crew size and any special circumstances. An increase or decrease from standard crew size is assumed to increase or decrease the production rate uniformly (i.e., 20% increase in crew size increases production rate by 20%).

The basic production rate is adjusted if multiple subcontractors work in the same location (50% penalty for each subcontractor), if overtime was used as control action (50% penalty for overtime hours), if work was done out-of-sequence (50% penalty for the task which was predecessor, for example if studs were installed before overhead MEP). If the location was completed or reached subcontractors' target completion rate during the week, resources are reallocated in step 5. Otherwise, the percentage completed at the end of the week was recorded for each task and each location and reported back to the player.

Reallocate resources after any completed locations

Resource reallocation would happen after locations were completed or reached their target completion rate or were suspended by special behavior. The same rules as for the initial allocation were followed, except that location availability was evaluated on the next day after location completion.

LBMS AND CPM THEORETICAL EXAMPLES

For comparison purposes, a set of data for each group was defined for LBMS and CPM theoretical cases. The behavior for these "players" was predefined based on LBMS and CPM literature. Main points of these behaviors are described below.

LBMS controlling behavior

An LBMS player optimized the schedule by synchronizing production rates and adding in buffers. During the production control phase, an LBMS player evaluated the forecasts at the end of each week based on resources currently on site. If alarms were calculated for the next two locations or the next two weeks, a control action was taken. For the last task ("Finishes"), a control action was taken if the forecast exceeded planned finish date. The first attempted control action was always to increase resources of the predecessor or decrease resources of the successor to remove the alarm. The LBMS player analyzed the production rate achieved with the current crew size and specified the number of resources required to remove the alarm. If the maximum resource limit had already been reached, overtime was implemented. If work was occurring out-of-sequence or if the subcontractor had not completed locations, sequence changes were additionally implemented but only if an alarm had been generated.

CPM controlling behavior

A CPM player did not optimize the schedule but used the original durations and logic. For controlling, the player looked at float and criticality of each task and each location at the end of each week. A standard CPM algorithm was used to calculate these values. Control action was taken if the project end date was delayed from contract end date after the update. Control actions always impacted critical activities first and then any activities with float less than five days. If the activity was already ongoing, maximum resources were required as a control action. Additionally, overtime was required if the activity was critical. If the activity was not ongoing but could start on the following week based on CPM update early dates, the activity was force-started; or if the subcontractor was already working in another task or location, a sequence change was implemented.

RESULTS

So far, three groups have completed the game. Each group had a different set of predetermined subcontractor information so the results are comparable only within the group. Table 1 shows the results of each group. The LBMS heuristic example got the best results in all groups. The CPM heuristic example finished last in groups one and three and second to last in group 2. Human players finished in the middle. The total durations and productivity had a big variance in all groups indicating that decisions about control actions have a big effect on the outcome. Interestingly, the CPM-based heuristic approach lost also in total duration, not just in cost measures as expected.

Table 1: Production control game results (3 groups)

PLAYER	COST	DURATION
Group 1		
LBMS	$ 690,560	185
Player 1	$ 749,700	176
Player 2	$ 768,340	247
CPM	$ 842,380	225
Group 2		
LBMS	$ 942,040	170
Player 1	$ 1,000,240	191
Player 2	$ 1,021,400	189
CPM	$ 1,040,800	180
Player 3	$ 1,214,040	213
Group 3		
LBMS	$ 667,600	160
Player 1	$ 697,440	156
Player 2	$ 729,765	148
Player 3	$ 740,380	171
CPM	$ 760,080	161

HOW DID HUMAN PLAYERS CONTROL THE PROJECT?

Analysis of player behavior revealed the following problems in their decision making:

- Too active or too passive controlling
- Push controlling based on the original plan instead of looking at the current situation on the field
- Inability to use the forecast

These problems are explored below.

Frequency of control actions

Players typically either took too many or too few control actions. Some players observed that the subcontractors are not following their instructions and gave up. This observation was based on the delay of mobilizing additional resources and by the fact that control actions had durations. Some players reacted to this by doing too many control actions – basically giving instructions to subcontractors every week and micromanaging their production. This strategy often got good results in terms of total duration but was penalized by the control action cost.

Push controlling based on original plan

Push controlling was very prevalent even though all the players had been exposed to LBMS management principles. Successors were started even if their predecessors were delayed which led to either bad productivity or return delays. Instead of looking at the actual production rate achieved, players looked at the pre-planned number of resources and tried to force the subcontractors to come on site with that crew size. Because production rates and productivity were almost always different from planned this led to either too many or too few resources. Some players were obsessed with finishing each subcontractor at their planned finish times even if their production was not impacting other subcontractors.

Inability to use the forecast

The forecast was typically not well used by players. Control actions were more often based on what had happened in the past compared to the master plan instead of focusing on what will happen in the future if control actions are not taken. Instead of calculating the forecast based on manpower currently on site, players decided in most cases to calculate the forecast based on their planned amount of manpower. During the closing meeting, many players were surprised that their plan was not followed. One of the key learnings for players was that the preplanned schedule is only a guideline and actual productivity values can only be measured on site.

WHY DID LBMS WIN?

The LBMS approach achieved good results because of these main reasons:

- The plan included buffers between tasks
- Focusing control actions on production rate instead of critical tasks enables longer-term decision making

Each of these main reasons is explored below.

Importance of buffers

In this game, the original plan had limited relevance. Regardless of the plan, subcontractors would mobilize with their preferred crew size and their production rate. However, players made decisions based on comparison of the plan to actuals. Plans which did not include buffers led to push controlling start dates and starting too early which led to return delays and overlapping work and therefore poor productivity.

Management based on production rates instead of critical path

Using the forecast instead of criticality information seemed to give better information for decision making. The CPM method forecasts the future based on originally planned durations. LBMS forecasts the future based on production trends. The benefit of buffered continuous flow is that even if there is a delay before a control action takes effect it is possible to prevent problems. The CPM approach suffered from the fact that any additional resources would often show up only after the critical location of a task had already been completed. If the critical path shifts between subcontractors, the tools to control production are severely limited.

CONCLUSIONS AND FUTURE RESEARCH

In this research a production control game was developed. The game included controlling subcontractors with predetermined production rates and behavior. Behaviors were based on typical behaviors observed in real LBMS projects. The goal was to motivate the players by comparing their results, thus making the game a competition where differences between players would arise based on their decisions. A secondary goal was to evaluate LBMS and CPM heuristic decision making rules.

From a teaching standpoint the game was a success for the first three groups. In closing meetings with each group, many of the players shared their frustrations with the subcontractors of the game. However, they could easily identify similar behavior from the real projects they were working on. Everyone was able to appreciate the importance of buffers and on-time control actions by comparing the results of the LBMS heuristic example to their own results. The fact that costs and durations could be affected by 20% by controlling was interesting to all players. The next step is to repeat the assignment again with different subcontractor data and see if the players can beat the heuristic LBMS solution by using their learnings from the first round.

The difference between LBMS and CPM heuristic results was interesting. The assumption was that LBMS would be much stronger in productivity and labor cost because of its focus on eliminating interference. Additionally, it was assumed that CPM would achieve the same or shorter duration because of its standard control action of mobilizing maximum resources and implementing overtime for any delayed critical activities. LBMS also outperformed CPM in terms of total duration. This was caused by return delays, lost productivity when force-starting activities, and also by controlling the wrong tasks. Short duration tasks often end up on the critical path but for any control action to be effective, the repetitive task needs to be longer than the subcontractor's ability to react. Any conclusions about LBMS vs. CPM cannot be drawn by these limited examples. However, it would be an interesting subject of future research to develop a simulation which is able to compare these decision making heuristics in hundreds of different scenarios using different assumptions.

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