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INTEGRATING LBMS, LPS AND CPM: A PRACTICAL PROCESS

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ABSTRACT

Despite the lean construction community criticism of Critical Path Method (CPM), it is impossible to ignore its widespread use. Furthermore, CPM is commonly considered a contractual requirement demanded by owners. On the other hand, Location-Based Management System (LBMS) and Last Planner System (LPS) have been successfully implemented in many construction projects. This article puts forward the proposition that there are synergies between these tools and their combined use could provide great benefits and fill some gaps.

The aim of this paper is to propose a practical process for integrating LBMS, LPS and CMP, in an attempt to improve planning and controlling processes in general, besides filling gaps related to delay analysis. A constructive research was developed through a case study, collecting data of a planning and controlling system used by a large construction company, which applies CPM and LPS tools. The processes and the main decisions of the project team were systematized in an integrated model, taking into consideration the project phases. Two additional propositions were formed to be validated in future case studies. Firstly, the integrated sources of data will help professionals to support decisions. Secondly, the schedules created with this integrated approach are better able to model workflow.

KEYWORDS

Location-based management, Last planner system, Critical path method, production, delays.

INTRODUCTION

There is a widespread use of Critical Path Method (CPM) in construction projects. In addition, in some countries such as Brazil or United States, this tool is commonly a contractual requirement demanded by owners. Furthermore, Galloway (2006) conducted a survey in the USA where 63% of the respondents indicated that they use CPM as a contractual requirement. In the same survey, 50% indicated that CPM helps to reduce delays and 46% believed that CPM minimizes the disputes between the contractor and owner. However, CPM has been criticized by the lean construction

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community, especially in relation to the lack of schedule workflow, the focus on project control instead the production control, the poor quality of constraints analysis, the inadequate daily management of activities and the use of highly detailed schedules, even in the projects' beginning, where a lot of definitions and details are unknown. Many papers published in IGLC conferences point out the need of adjustment of CPM for construction (Mendes Jr. and Heineck 1998; Kala et al. 2012; Koskela et al. 2014). Additionally, the lack of a theoretical basis for construction project management has been pointed out in the literature (Halpin 1993; Koskela and Howell 2002; Cicmil and Hodgson 2006).

The term CPM is ambiguous and can be understood as an algorithm for calculating the project's critical path or, in a more complex way, as a planning and controlling technique, which incorporates some concepts such as Gantt charts. In addition, this technique is mainly focused on helping the project team to manage the time in a long term. In this paper, CPM is defined as a planning and controlling technique.

Location-Based Management System (LBMS) and Last Planner System (LPS) are complementary lean production and controlling tools, getting increased attention from lean practioners and have been implemented in many construction projects (Seppänen et al. 2010). These tools aim to decrease waste, increase transparency, improve predictability and improve flow (Seppänen et al. 2015). However, based on the authors' experience, in Finland, where LBMS is widely adopted but there is no tradition of using CPM schedules, time-related disputes are common and there is a lack of accepted rules for the management of delays. On the other hand, in countries where CPM is a contractual requirement, it has been difficult to completely replace it with LBMS and LPS because of risks related to lack of experience of using the tools to justify time extension claims. The practical result has been that the two systems have co-existed in the same project, which has resulted in confusion about which information to use for which decisions. The use of LBMS and LPS for delay analysis and owner reporting purposes would be the best way; however, their use in this situation has not yet been addressed.

The aim of this paper is to propose a practical process for the integration of LBMS, LPS and CPM in an attempt to improve production planning and controlling processes in general and fulfill gaps related to delay analysis. Working together, the three systems can offer a viable solution, as one system tends to compensate the shortcomings of others.

In terms of systems complementarity, Seppänen et al. (2015) explore the integration benefits of LPS and LBMS in the production planning and controlling phases, mentioning that is possible to add more definition to the master scheduling phase by defining the overall Location Breakdown Structure (LBS), which defines locations in the work level. In addition, the integration of CPM and LPS has been analysed and implemented by lean practioners (e.g., Huber and Reiser 2003). On the other hand, previous research with focus on combining CPM and LBMS has not been detailed in a high level, but it is important to remember that LBMS calculations are based on a modified CPM algorithm (Kenley and Seppänen 2010). Despite the additional layers of logic, buffers and forecasting in LBMS being useful for production planning and control purposes, carrying out the delay analysis is a challenging task. Therefore, at least in the short term, there may be a role for traditional CPM for this important contractual aspect.

RESEARCH METHOD

This research can be classified as constructive research. This approach aims to generate scientific knowledge, developing an artefact to solve a real problem (Holmstrom et al. 2009). Despite their different underlying philosophies and controlling mechanism, the authors put forward the proposition that there are possible benefits of integrating LBMS, LPS and CPM in the course of all phases of the project. In addition, new process and best practices are required to support the project team decisions. An exploratory case study was developed to obtain a deep comprehension of the problem. The generated artefact is the proposed integrated model. Both artefact and proposition's development need to be tested in practice in future research.

The case study was carried out through data analysis of the main processes and tools used on planning and controlling system of a large Brazilian construction company, acting in the real estate market since 1980, with focus on construction projects for residential buildings, corporative and mixed use. The company has a matrix structure, where its projects apply the same processes, procedures and tools. The work of development and updating of planning tools is done by own teams. The company has a strong tradition in using LPS and CPM planning and controlling technique.

The main data were collected through electronical documents, considering procedures, schedules, spreadsheets and tools, used in a set of twenty already finished real projects. Furthermore, one of the authors of this work followed the performance of the projects on field. The unit of analysis used was the planning and controlling system. More than 100 documents were analysed during two months, considering the four main aspects of LBMS and LPS, i.e., (i) buffers, (ii) workflow, (iii) management of subcontractors and (iv) constraints. The main documents analysed were: CPM schedule, procurement schedule and EVA (earned value analysis), constraints meetings sheets, WWP (Weekly Work Plan), PPC (Percent Plan Completed), WBS (Work Breakdown Structure), measurements criteria, sequence patterns and attack plans.

After the case study analysis, the integrated model was developed. Firstly, the main processes related to scope and time were identified, for each project phase. Secondly, each process was classified in CPM schedule or LBMS schedule. Thirdly, the main decisions related to the project team were analysed. The processes and decisions were organized in a chart and were numbered from **[1]** to **[30]**, to facilitate following the model. Finally, the processes and decisions were described considering their main characteristics and an analysis of their impacts.

RESULTS

The case study shows that the main processes and tools of the company are strongly rooted on traditional project management principles. Thus, as a characteristic of project management, the focus is on project control and not on production control, trying to obtain the production goals indicated in the CPM and EVA. There is a clear lack of attention in items such as locations, labor, resources, buffers management and continuous flow. Table 2 shows the main results taking into consideration the planning and controlling phases.

Table 2: Case study main tools and processes

Planning phase	**Controlling phase**
CPM schedule - The CPM schedule is the basis of the system and has as end date that agreed with the managers, which is different from dates promised to the customer (usually at least two months earlier). - The schedule is structured according to WBS and usually has more than 5,000 activities, which are based on the divisions and on measurement criteria established. The company adopts pattern-sequencing models for the activities. **Attack plan** - This plan divides the project into small packages and defines the buildings' tasks sequence of infrastructure, foundations and concrete structure. **EVA** - The estimated cost for each task is inserted in the CPM schedule, generating information for the development of the EVA. **Procurement schedule** - A procurement schedule is defined based on the CPM dates and definitions of procurement time, mobilization of subcontractors and delivery time of materials.	**Updating of CPM schedule and EVA** - The updating process happens only once a month. The actual start and finish dates of each task are inserted, considering completed activities. The analysis is often limited to the month production and to the critical path. - Considering that there is no LBS applied, the level of detail of WBS is not enough to attend the production team needs. **Spreadsheet of production goals** - The link between CPM and production teams: besides the activities to be done in the period, each task' percentage share of costs are shown and it is highlighted if the task belongs to the construction critical path. **Look ahead planning** - There is no scheduling during the look ahead process. The look ahead meetings are used only to analyse the constraints. **WWP** - The PPC measurements are presented every week to the subcontractors and managers. There is a procedure, which indicates the meeting steps. New tasks divisions are done in the WWP.

BUFFERS

As the company only uses the CPM schedule, there is no formal buffer analysis, either in the planning phase or in the controlling phase. The critical path follows the general rule considering only zero float activities. Some floats are analysed only when the critical path indicates a time overrun during the tracking process. In these cases, the activities' durations are reviewed, new resources are planned or some activities are rescheduled to be parallel with the predecessors. Eventually, alerts are sent to the board of directors when the critical path cannot be reached or when the monthly EVA goals grow very high.

The average project duration is 24 months, without buffers. As a pattern for each project, the company adopts a project buffer of two months, inserted in the end of the project. This is basically a process to minimize delay risks of customers' dates. However, this buffer is "owned" by the organization. The project team's goals consider

the project end date without any buffer. Thus, there are two main dates to be considered: the team goal date and the customers date. These two dates are known by the whole team and subcontractors.

WORKFLOW

There is no formal workflow analysis, even during the planning phase. The managers prefer to work with the original pattern of CPM schedule and links defined by the company. The basic rule is to start tasks as soon as possible. Managers usually argue that there are a lot of uncertainties in the beginning of each task and, during this period, the crews work with a lower rate than their normal rhythm of production. Thus, no buffer analysis is formally applied and frequently there are no tasks with continuous workflow in the CPM schedule. After the concrete structure and masonry tasks, most of the activities are planned with the same duration, in a clear attempt to offer nonstop work to the subcontractors.

The company applies prerequisites sheets to start new tasks for the first time and to evaluate the conditions of work. When a task which cannot create value is identified, it is removed from the process, the work instruction is reviewed and the task is no more planned on the WWP. When the work instruction is modified, a formal instruction is given to the work team, in a short training managed by the quality team, in compliance with the quality procedures. No actions are formally registered in order to reduce processes' lead times and variations, but sometimes some instructions related to process improvement are verbally given directly to the production team. Some processes are simplified during the commitment planning, especially when the subcontractors are involved in the discussion.

MANAGEMENT OF SUBCONTRACTORS

The company usually works with a lot of subcontractors in its projects. Rather than using large subcontractors, the managers prefer a relationship with small subcontractors, specialized in each task, which frequently have less than thirty workers on the construction site. It is very common to find specialized subcontractors working in a lot of construction sites at the same time. The subcontractors are involved in the project scheduling discussions related to the WWP only. The majority of them have no ability to develop their own schedules or even discuss a long term plan. Usually, they follow the goals established in the CPM schedules, which are attached to their contracts. Each subcontractor's performance is monitored by the construction team, but delays are very common. On the other hand, claims are well controlled by contractual clauses.

There is a procurement schedule, which monitors around eighty main construction resources (such as steel bars, cement and waterproofing). This schedule considers the main tasks and the times required for the supply chain process, such as negotiation time, documental analysis and mobilization time. Procurement is weighted based on the representative budget of each resource. During controlling phase, the schedule is updated monthly and the needs are evaluated based on the constraints meetings. The schedule progress is monitored by the planners and engineers. The subcontractors' performance is analysed in the commitment plan and in a specific software.

CONSTRAINTS

Referring to LPS tools, the company uses spreadsheets for identification, following up and removal of constraints and WWP. Last Planner System has been implemented only

partially, for example, there is no phase scheduling involving the subcontractors. Constraint analysis meetings occur monthly, with a high emphasis on the correct identification of constraints. The meetings with production teams are weekly and their results are registered in spreadsheets. In these meetings the goals are informed and discussed, in addition to presenting PPC results from previous periods.

With the adoption of LPS, generally speaking, the company obtains good results with the monthly constraints analysis meeting, increasing the productivity and helping the team to discover bottlenecks in the production process. They usually analyse the tasks three months ahead and, in some cases, specific resources that will be needed in the future. The company applies a procedure which indicates the necessary steps to conduct the meetings, including a set of constraint groups, the documents required and the professionals who must participate. An indicator which shows the percentage of removed constraints is applied and analysed by the managers.

GAP ANALYSIS

There is a procedure where the subcontractors' performance is monthly evaluated, in aspects related to time, quality, safety and cleaning. In addition, the commitment plan process evaluates the subcontractors' performance, but only considering aspects related to short term. However, even with these actions, there is no formal analysis of delay impacts related to each subcontractor standing alone or working in an integrated way with other subcontractors. Thus, delay analysis is not done systematically.

Despite the adoption of some concepts, LPS is not completely implemented: there is no phase scheduling involving the subcontractors and there is no scheduling on the look ahead planning process, which is focused only in constraints analysis. Furthermore, due to the lack of continuous workflow, the resource use is discontinuous.

The case study company needs a system where flow can be planned and controlled (i.e. LBMS) and LPS is completely implemented without compromising the ability to perform delay analysis and integrate other company functions, such as procurement, using CPM.

MAIN PROCESS AND DECISIONS

Figure 1 shows the proposed integrated model divided into planning and controlling phases. In the following section, the main processes and decisions are described.

PLANNING PHASE

[1] The attack plan is developed based on an analysis of contractual phases (for example, three towers with different delivery dates), constraints of sequencing imposed by retaining walls and foundations, considerations and constraints of logistics, available resources and duration of tasks, weather conditions for each phase of the construction project (retaining walls, foundations, structure, façades and waterproofing) and safety conditions for each situation.

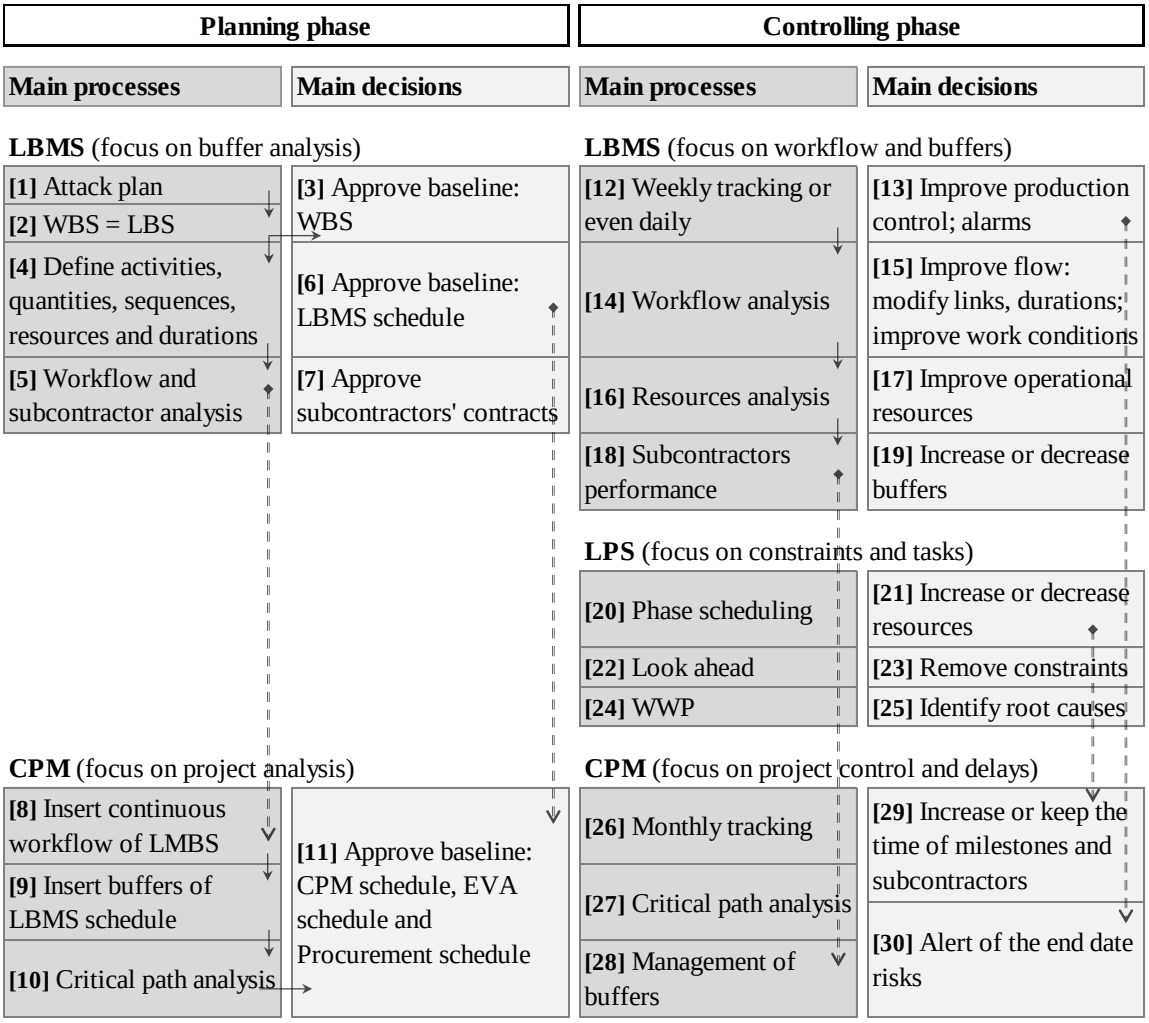

Figure 1: Proposed integrated model, divided into planning and controlling phases and considering the main process and decisions

[2] Both CPM and LBMS schedules need to start with a common WBS and LBS. This procedure seeks to improve the quality of the schedules and the integration between them. The companies usually work with a standard WBS for the development of construction plans. From WBS´s definition, a smaller division for locations is defined, called LBS, which is defined for each construction project, taking into consideration the number of towers, floors and apartments or commercial rooms, the area of each of the units and the technical constraints, such as for example, separation and division of façades in which the elevator is installed. LBS is a fundamental part of LBMS. **[3]** The baseline of WBS and LBS must be approved by the project manager.

[4] The LBMS scheduling process starts with the physical measurement criteria of the tasks, which is targeted at establishing the way the physical progress of the construction project will be measured. After that, quantities and the construction sequence are defined, considering the attack plan definitions. The analysis of resources and activities duration are determined simultaneously during schedule optimization. Finally, buffers are inserted mainly to protect the schedule against cascading delay chains. **[5]** A workflow and subcontractors' analysis is needed at this moment. **[6]** As a product of this step, adjustments in the costs and project schedule are made, followed

by a baseline LBMS schedule. **[7]** During the planning phase, some key subcontractors' contracts are approved by the project team.

The CPM schedule is prepared based on the LBMS schedule on the same level of detail. Firstly, it is necessary to configure both CPM and LBMS calendars on the same basis. Secondly, the activities, links, sequences and durations defined in the LBMS schedule must be inserted in CPM schedule. **[8]** To achieve the same set of initial planned dates as in LBMS schedule, the CPM schedule is adjusted by inserting activity lags to model buffers and continuous flow. **[9]** Buffers must be inserted preferably as a new task or as a lag between activities and contain the same duration as LBMS buffers. **[10]** An analysis of the critical path is made, taking into consideration the main project milestones, the period when the main tasks are occurring, the main subcontractors' tasks and the monthly production required. **[11]** Finally, the EVA and the procurement schedule are developed based on the CPM and both CPM, EVA and procurement baseline are approved.

CONTROLLING PHASE

The proposed integrated model uses LBMS, LPS and CPM systems simultaneously. **[12]** The LBMS schedule is monitored weekly, or even daily. The activities completed are collected in field and updated in the schedules, considering the real start and finish dates and actual resources and quantities. The forecasts are compared with plans to detect future problems. Any identified future problems are discussed and control actions are planned to prevent them.

[13] The LBMS controlling process can be connected with the LPS to guide production control decisions and to generate alarms about upcoming production problems. **[14]** A workflow analysis is done to achieve continuous flow of crews. **[15]** In attempt to improve flow, the main decisions during this process involve modifying links and durations and improving work conditions of the subcontractors. **[16]** A resource analysis is done to evaluate the **[17]** operational resources and the necessity of adjustments. **[18]** An analysis of the subcontractors' performance may help the project team to **[19]** increase or decrease buffers. **[20]** The phase scheduling process involves subcontractors in the definition of common plans and makes it easy to commit to **[21]** increasing or decreasing resources.

[22] Look ahead meetings are done based on the LBMS schedules' update. The aim is to analyse the tasks that will occur on few weeks, listing the constraints that may require changes to plans. **[23]** Every week the constraints must be followed up by the construction project team. From the constraints meetings, the prerequisites of production are monitored and prioritized, evaluating in this way the necessary resources for executing the tasks. **[24]** The WWP process divides the activities by team and by day of the week, who commit to the plan. The success of this WWP is measured by PPC and any plan failures are investigated allowing **[25]** the identification and treatment of root causes for not completing the activities.

[26] The CPM and Procurement schedules are usually updated monthly, based on the information generated by the updating of LBMS. The actual start and finish dates of LBMS are inserted in the CPM schedule. The LBMS forecasts are not inserted in CPM, which keeps the originally planned durations and sequences. If the CPM schedule starts to deviate a lot from LBMS schedule, a schedule revision may be submitted to the Owner based on the process defined in the scheduling specification.

With the tracking of CPM and EVA it is possible to evaluate the progress of the construction project, as well as compare with the established baseline. In the CPM schedule it is possible to monitor delays on the Critical Path and in EVA the percentage progress of tasks. Procurement schedule is updated considering the predicted and accomplished dates of main resources, allowing a follow up of results.

[27] With the insertion of the LBMS actual dates is possible to calculate in CPM the total amount of delays on critical path and evaluate the impact of any change orders and delays, such as weather delays and design delays. In CPM, the same actual start and finish dates will result in different dates because the CPM algorithm does not take into account continuous work or adjust durations based on forecasts. Therefore, it can be used to achieve the traditional project management objectives. The critical path and the main milestones are checked to evaluate the risks of delays. **[28]** The buffers' durations inserted in the planning phase can be modified if necessary. A subcontractors' analysis is applied in attempt to compare the original buffers and milestones with the forecasts.

[29] LBMS forecasts dates will be different from CPM activity dates. CPM will be used to evaluate the critical path and to supply enough information to the project team related to delay analysis and subcontractors' performance, increasing or decreasing the original time of buffers and subcontractors. On the other hand, LBMS is more appropriate to analyse continuous workflow, buffers, durations, forecasts and to determine control actions to recover delays and it is the operational schedule which can be connected with LPS constraints analysis and daily management of activities. **[30]** Both LBMS and CPM schedules can supply information to develop monthly reports to the owner and to the project team. CPM will provide information to analyse delays, and the performance of subcontractors and the project. LBMS will provide information related to production control and the necessary actions to improve flow and recover delays.

CONCLUSIONS

The integrated model systematizes the integration of three distinct, but complementary systems, which are LBMS, LPS and CPM. The processes and decisions were developed based on using LBMS and LPS to run operations but having an aligned CPM schedule which can be used for traditional project management purposes, such as delay analysis. Standing alone, each system is strong in some areas but requires improvements in others. Thus, it is expected that through further artefact implementation, the proposed integrated model can compensate the deficiencies of using the planning and controlling systems in an isolated manner or by running various systems in parallel with no integration. Two additional propositions were formulated and need to be validated in future research. Firstly, the integrated process will help professionals to choose the best set of data to support their decisions, including both project managers and operation team. Secondly, the schedules created with this integrated approach are better able to model workflow, help managers to analyse and communicate delays and to decide about the best approach to the critical path.

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