USING THE LINE OF BALANCE FOR PRODUCTION SYSTEM DESIGN

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ABSTRACT

The line of balance (LOB) is a tool for project planning and control that provides great visibility for the flows of work in a construction site. The LOB depicts information related to when, where and what activities are done at any time as well as activity batch size, pace, and buffers between different crews. Besides making work flows more transparent to those managing a project, this tool can serve as a means to simulate and discuss different alternatives and strategies to sequence activities in the long run. This paper presents a study carried out in a construction company in Fortaleza, Brazil in which the authors used the LOB in the initial planning phase of a high-rise residential project. Based on the information provided by different LOBs, representing different scenarios, the authors discussed with projects managers, superintendents, and crews the advantages and disadvantages of each scenario regarding the project's lead time, activities cycle time, gang sizes, batch sizes, buffers, sequencing, interferences between crews, learning effect and productivity. The paper presents the project's personnel views about the different scenarios and respective indicators, and discusses the implications of the group's chosen scenario for the project as whole. The LOB was developed in spreadsheet software (Microsoft® Excel) and had a high rate of success as the project's participants could easily understand the concepts used to develop each scenario, simulate, and evaluate the impacts they had on the project's performance. Based on other papers' conclusions about the topic, this paper aims at contributing to the discussion about production system design based on solid production indicators depicted through low-cost and low-level of abstraction tools such as the Line of Balance.

KEY WORDS

line of balance, lead time, flow, batch, buffer, negotiation

INTRODUCTION

The line of balance (LOB) has been studied markedly since Lumdsen's 1968 book. After this book, several papers were published about the topic (e.g., Mendes Jr and Heineck, 1999; Kankainen and Seppänen, 2003; Seppänen and Aalto 2005), some of them even tried to reconcile antagonist points of view such as the critical path method (CPM) and the concepts combined by the LOB (e.g., Lutz and Hijazi, 1993), others have more

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recently presented the LOB or its variations (graphs depicting activity pace) with a focus on variables such as cycle time, lead time, batches, and delays (Ioannou and Srisuwanrat, 2007). Many papers about the LOB can be criticized by the Lean Construction community for insisting that the method can be summarized into algorithms, mathematical functions, and graphical flows through the use of simplistic examples trying to emulate reality.

The discussion about LOB presented in previous IGLC conferences also have added more philosophical discussions to real life scheduling problems, including the use of LOB scheduling software. Some IGLC papers have even suggested that the LOB should be the preferred scheduling technique for repetitive and non-repetitive projects due to its emphasis on the location-based approach for scheduling projects (Kenley, 2004; 2005).

However, the difficulties in using the LOB for scheduling projects have been stripped off from the method when authors have downplayed problems that surround the definition of task durations, the choice of the repetitive unit or batch size, cycle time, and the definition of buffers between tasks. Yang and Iaonnou's (2001) paper present an extensive list of variables that should be considered in a LOB and how different software should be able to model these variables. Other modeling problems related to scheduling and the LOB are discussed by Brodetskaia and Sacks (2007), as they observed variability, lack of sequence, work flow discontinuity, and change in task durations in construction projects.

Efforts have been made by authors to advance the frontier of knowledge related to the consideration of all variables and difficulties related to the data used for scheduling purposes. Several authors have discussed the importance, for instance, of reducing batch sizes (Tommelein et al. 1999; Alves and Tommelein, 2004; Nielsen and Thomassen, 2004;) and reducing cycle times (Santos et al, 1999;; Ballard, 2001; Walsh et al., 2003). These papers have fulfilled their goals in terms of discussing and disseminating batch and cycle time concepts for the IGLC community; however, the cases presented are often trivial and are close to common sense. In some cases, authors have introduced other difficulties in addition to the ones indicated above. Walsh et al. (2003) highlighted the importance of subcontracting practices for batch sizes, cycle times, and lead times indicated in construction project schedules.

Horman (2001) and O'Brien (2000) demonstrated the implications of medium-term planning in production capacity and work-in-process and how decisions made at this level can affect operational variables such as task durations and crew productivity. Other papers have addressed the definition and location of buffers to account for variations in production rates, resource availability, and lead times in construction projects (Sakamoto et al., 2002; Alves and Tommelein, 2004). These papers discuss the implications of defining buffers in terms of crew productivity, lead time, and resource starvation, but fail to present how the definition of buffers should be put into practice and negotiated with construction crews. In Knapp et al.'s (2006) paper, they discuss a way to enhance the negotiation process, which takes place while tasks are being scheduled, through the use of the "phase planning". In the phase planning, specialty contractors in charge of tasks taking place in a same phase negotiate the sequencing, the grouping of tasks, and how they use project's floats. Thus, the scheduling is not a task carried out in an office far from the people and the place where activities take place. Ballard (1997) highlights the importance of planning similar activities together and Coelho and Formoso (2003) suggest that at the medium-level planning, safety and learning aspects should also be considered.

Along the same lines, Fisher and Kunz (2004) suggest that different IT solutions (e.g., visual 3D and 4D models, building information models, and knowledge-base models) should be used to enhance communication among project participants and coordination of trades throughout the project's life cycle. These authors highlight that pressures to finish projects on time, on budget, and with the desired quality requires that project managers use systems capable of delivering real time information and showing the impacts design and scheduling decisions have in the project's overall performance.

Based on the literature reviewed, there is a group of variables and solutions that should be considered for scheduling tasks at different planning levels. On one hand, the literature suggests that for the strategic- or long-term planning a restrict number of variables should be considered because there is not enough precise information regarding the whole duration of a project (Laufer and Tucker, 1987). On the other hand, one can argue that there should be a basic "awareness level" about operational variables (productivity, cycle times, batches, sequencing, and interacting crews, amongst others) often considered in medium- and short-term levels that should be considered in the long-term planning.

This paper presents a discussion about different scenarios (different batch sizes, cycle times, lead times, sequencing, work packaging, team reutilization, repetition, learning effect, continuity, capacity, and crews interference) represented by LOBs as a means to evaluate the operational (day-to-day) implications of decisions made at the long-term planning level. The LOBs were developed in MS Excel® and served as a basis to present different scenarios to upper and middle management personnel and discuss their impressions about the best way to carry out the project tasks.

CASE DESCRIPTION

THE PROJECT

The study was carried out in a medium-sized construction company (Construtora C. Rolim Engenharia Ltda.) in the city of Fortaleza, North-eastern Brazil. The project analyzed is a 22-storey residential building. Given the upscale character of this project, the clients were entitled to change the apartment internal distribution of walls and choose the unit's finishing. In order to discipline the changes, the company alerted clients about deadlines for the customization of each apartment. However, during the project, not all clients used to make up their minds by the deadlines proposed by the company, contributing to increase the variability of the production tasks in terms of time, capacity, and sequencing. For this project C. Rolim Engenharia was in charge of executing masonry, flooring, wall plastering and flooring, and installation of doors and windows. Subcontracted services included: structural concrete, water-proofing, gypsum-related services (plastering, walls and ceiling), aluminum windows and doors, mechanical systems, and painting.

LINE OF BALANCE AND PRODUCTION SYSTEM DESIGN

The line of balance (LOB) method was used by the company's Lean Initiative Coordinator (Coordinator) to develop and present different tactical scenarios to the project's managers so that they could agree on a preferred way to carry out the project (not necessarily the best way according to Lean Construction standards!). In this paper, a tactical scenario is a graphical representation of how processes are carried out in the construction site; how related tasks are grouped and batched for the project's repetitive units; the sequencing of tasks (from top to bottom, from bottom to top); the indication of cycle times, lead times and buffers between processes and tasks; amongst other variables related to the project's production system design.

The LOBs depicting the different tactical scenarios were developed in MS Excel® spreadsheets and presented to the managers. Since the first rounds of presentation and discussions about the tactical scenarios, the managers could notice the link between variables such as long lead times and their impact on the project final duration. They also noticed the possibility of grouping tasks together (in work packages) to reduce task's cycle time from start to completion (avoiding work in process) and to make the project management an easier task for them.

The managers decided that groups of tasks belonging to the same type of service (i.e., carried out by the same trade) should be grouped into work packages and completed by production cells (i.e., teams in charge of delivering a complete product defined by the management) from start to finish, instead of being left out for specialized crews to finish small parts of the tasks. Before the implementation of production cells, the masonry process had a long cycle time from start to finish as the process was divided in several small handoffs executed by different crews and teams in different points of time.

In addition to discussing lead time and cycle time implications, the Coordinator tried to make other variables related to the scenarios presented more explicit, i.e., the relationship between production rates and pace, work in process (WIP), the management of physical flows (workers, materials, equipment), repetition of tasks executed by the same teams, and the learning effect.

Table 1 presents two tactical scenarios developed by the Coordinator and the results obtained for each regarding the work packages of the following processes: ceramic tiles for walls, and gypsum plastering and ceiling. These processes were chosen due to the volume of work they represent and the influence they had in the project's cycle time.

For this paper, only two of these scenarios are discussed due to length limitation, a detailed description can be found in Kemmer (2006). The simulation using the LOB considered combinations of different scenarios:

- Cycle time to complete work packages (in days) – Short (SCT) and Long (LCT)
- Process path – from the bottom to top of the building (UP) and from top to bottom (DOWN)
- Workforce utilization – With Re-Utilization of teams (WRU) and Without Reutilization of teams (WORU)

The data presented in Table 1 shows the impacts on lead time (in days) when changes were made to the cycle time necessary to complete the work packages, the number of teams assigned to complete them, the number of times a team develops the same work package (number of repetitions per team), and the execution path adopted. Table 1 shows the impacts the cycle time reduction has in other variables such as lead time, number of crews necessary to complete the work packages, work-in-process (number of tasks developed in parallel by the teams).

Table 1: Tactical scenarios and variables of interest

Work Packages	Tactical Scenarios	Variables of Interest			
		Cycle time (days)	Lead time (days)	Number of teams	Number of repetitions per team
Ceramic Tiles (walls)	3 - SCT/UP/WRU	10	80	3	7(8)
	4 - LCT/UP/WRU	20	100	5	4(5)
Gypsum (plastering and ceiling)	3 - SCT/UP/WRU	7	56	3	7(8)
	4 - LCT/UP/WRU	15	90	4	5(6)

Based on the results of Table 1, the managers analyzed in a systemic way the impacts long-term decisions represented in the LOBs would have in the project's short-term planning, i.e., number of crews in the project, work packaging, and time to complete work packages.

During the meetings to analyze the tactical scenarios, the managers tended to favor the increase in the number of teams to speed up the pace of work and to reduce lead times. However, this increase resulted in an increase in WIP and in supervision-related tasks, as many teams where executing work packages at the same time. Also, due to the higher volumes of WIP in these scenarios, logistically speaking there were more tasks and physical flows to be managed at the site when compared to scenarios with short cycle work packages and reutilization of teams.

This initiative also resulted in an uneven flow of work with peaks and valleys throughout the execution of processes and a decrease in the number of repetitions per team slowing down the gains due to the learning effect. This behavior illustrates the dominance of the transformation view in lieu of the flow view as it favors increasing the number of workers as the sole way to meet deadlines, without a careful consideration of the impact this decision has in the project's physical flows (i.e., workers, material, and equipment). Several scenarios were developed and presented to project managers; however, due to space limitations, this paper presents only two of them.

Figure 1 shows part of a LOB that represents a tactical scenario in which the work packages for ceramic tiles (pink boxes) and gypsum plastering (blue boxes) had short cycle times whereas figure 2 presents the same work packages with longer cycle times than the ones shown in figure 1. An analysis of figures 1 and 2 reveals that changes in the cycle times for both work packages resulted in changes in the lead time to complete the execution of these processes, the number of crews to carry them out, and the number of times each crew performs the same cycle of work. The analysis of both tactical scenarios was carried out based on Lean Construction concepts and principles.

Figure 1 presents a better tactical scenario than the one presented in figure 2 based on the variables of interest presented in Table 1. As an example, figure 1 shows that in the tactical scenario 1 teams execute the same work package (ceramic tiles) up to 8 times, whereas in the tactical scenario 2 (figure 2) the crews execute the work package up to 5 times only. Also, it is worth noting that in the tactical scenario 1, there are six crews to be managed at the site, for both processes from start to finish, whereas tactical scenario 2 has nine crews (a 50% increase) for the same processes. Thus, the increase in WIP is clearly observed in the scenarios presented. By choosing the tactical scenario 2, managers must be aware of an increase in WIP, the physical flows at the site, and their managerial duties to supervise the crews.

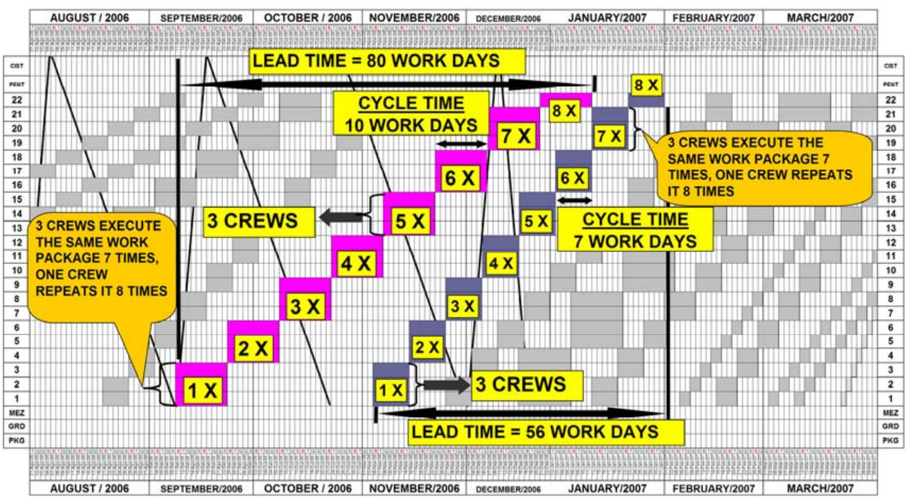

Figure 1 – Short cycle time (SCT), Upward path (Up), with reutilization of teams (WRU)

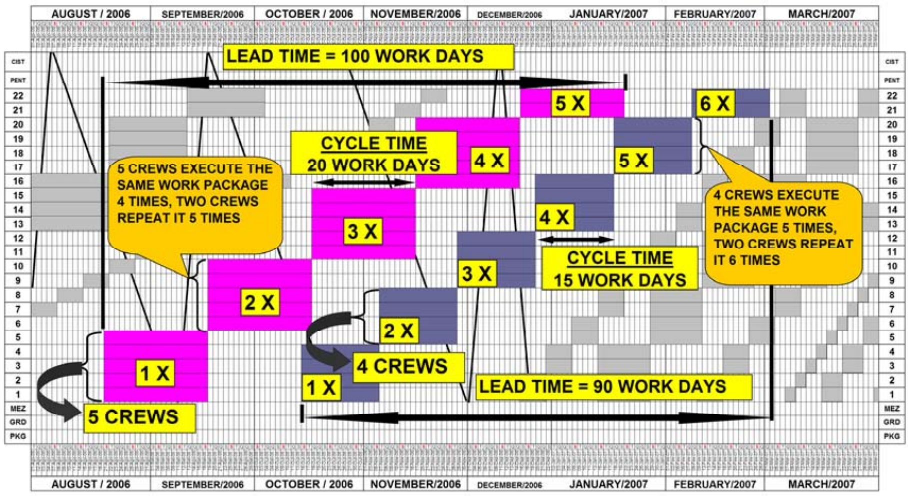

Figure 2 – Long cycle time (LCT), Upward path (Up), with reutilization of teams (WRU)

The use of LOBs to develop tactical scenarios and the long-term plan enhanced communication in the planning process as managers could evaluate, discuss, and negotiate the impacts of their decisions in the long run. The use of LOBs also served as a basis for the analysis of workforce reutilization in different phases of the same project as well as different projects enhancing continuity. In this regard, the company decided to incentive multi-tasking to keep workers longer in the same project (avoiding hiring and firing costs) and to keep using these workers in production cells for different processes.

MANAGEMENT COMMENTS ON THE DIFFERENT SCENARIOS PRESENTED

During the process to develop the tactical scenarios using LOBs, and the definition of the project's production system design, the Coordinator registered comments and suggestions from the managers regarding the variables and results obtained for different scenarios.

Path

Managers did not like the plans in which the flooring and ceramic tiles (walls) were executed from the top of the building to the bottom because they would have to wait all the previous activities to be finished at the last floor to start the descending activities all the way down to the building. Therefore, they have considered that scenario as a risky one, especially when projects have short durations.

Short cycle time and larger teams

In order to reduce cycle times, each team should have more employees to carry out the same amount of work in a shorter period of time. Larger teams should receive orders from the project management or be self-managed by its members and have autonomy to divide the work amongst themselves. According to the project managers, at the time this work was developed, the use of larger teams could cause problems and instability at the construction site because employees were not used to working in groups and having to divide the work and pay by themselves without help from the project supervisors.

Barriers to the implementation of plans with short cycle times

One of the main problems regarding the use of larger teams to carry out the tasks was the division of money among the team members. According to the project manager, the more productive workers could complain about the equal division of money among the team members. The production supervisor suggested that this kind of problem rarely happens when the work is carried out in pairs of workers instead of larger teams. The company managers also pointed out that the division of work in small batches among team members was a problem; even though this would allow workers to carry out work packages simultaneously. According to the managers, there could be space conflicts and loss of productivity due to differences in the productivity of team members. These differences could also result in disaggregation of teams because some workers could work faster than others and ask for the next part of a work package in a different area of the building.

CONCLUSIONS

The different LOBs developed and presented to managers in this study revealed cultural and tacit barriers to the implementation of plans with shorter cycle times, and lead times, as well as teams with a higher number of workers. In other words, some of the tenets of Lean Construction were not well accepted due to cultural barriers. A production system with larger teams working in an autonomous way (i.e., assigning tasks to its members to complete the work packages) was not welcome by the project managers as they intuitively concluded that workers would complain about their pay. Managers also concluded that the continuity and conclusion of work packages would suffer due to differences in workers productivities. However, other experiences developed in the company proved them wrong, workers are able to autonomously manage the division of work and pay among themselves as well as manage working in small batches within a production cell. Also, the simulations have shown that in order to reduce cycle times and lead times, some technical considerations should be made. This may imply in changes in design and work packaging to accommodate the execution of smaller batches without compromising the final product and its value for internal and external clients.

The analysis presented in this paper is based on low cost and low-tech applications, thus the findings are limited by these contextual characteristics. However, some barriers encountered by practitioners to implement tactical scenarios that are a closer match to Lean Construction tenets may be overcome with the use of 4D planning applications which allow project participants to collaborate and visualize the impact of their choices getting materialized throughout time (Fisher and Kunz, 2004).

Finally, differently from the papers about LOB presented in IGLC conferences and elsewhere, the study presented the use of LOB as a means to simulate and discuss decisions related to the design of a production system for a multi-store building and its impacts on daily operations. As the

LOBs were presented to the company/project managers, different cultural aspects surfaced regarding the adoption of Lean Construction concepts. As suggested by previous studies about LOB, the method results in a user-friendly plan which allows for easy recognition of interferences, sequence of processes, process path, cycle times, lead times, and buffers, amongst other variables. Previous studies have presented software, algorithms and rules to implement the LOB; however, they have not discussed the impacts these decisions have in worker relations, incentives, and pay as well as how managers perceive these impacts and consequences in their production system. The authors hope to have contributed to the literature about LOB and their use to communicate to and educate managers about production system design using Lean Construction concepts and principles.

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