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COLLABORATIVE METHOD FOR TRAINING AND IMPLEMENTING THE LINE OF BALANCE

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ABSTRACT

The Line of Balance (LOB) is a planning technique that has been used for more than 30 years in construction. However, what is rarely discussed is how the LOB should be applied in projects already in progress. This research was developed in the Design Science Research (DSR) format and sought to analyze how LOB can bring about significant changes in the management of collaboration, planning and production. This paper puts forward a collaborative method of training on LOB in projects that are already in progress for which it draws on a two case studies on multifamily residential building. The benefits of LOB for those involved in the workshop were collected by gathering multiple pieces of evidence and analyzing the correlations. In the participants' perception, there are three main benefits concerning to adopting LOB: (i) understanding the sequencing of activities and how to achieve the uninterrupted flow of teams; (ii) assessing the risk of mobilization and remobilization; (iii) assessing milestone dates and constraints. Moreover, participants´ perception, the training had a excellent evaluation, and it contributed to increasing their collaboration and engagement in relation to the planning of the project.

KEYWORDS

Lean Construction, Line of Balance, Collaboration, Visual management, Design Science

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INTRODUCTION

Several authors have pointed out the low application of more visual long-term planning techniques, which enables both collaboration between the management and production teams and a better understanding of the flow and rhythm of activities has been pointed (Bulhoes; Formoso, 2005; Viana et al., 2010).

One of the techniques that has been acknowledged by bringing more transparency to the long-term plan is the Line of Balance (LOB). It graphically represents production flows over time, where the y axis refers to the location units and the x axis to time (Biotto, 2019). For Mendes Jr; Heineck (1999), in the LOB, the trajectory of the teams, the durations and the locations of the tasks at a given moment can be visualized.

According Olivieri et al., (2019) and Lucko (2014), LOB belongs to a family of location-based planning methodologies that are workflow-oriented, such as the Linear Scheduling Method (LSM) or flowline, repetitive scheduling method (Harris;Ioannou, 1998), and location based management system (Kenley;Seppännen, 2010). These methodologies show similarities in objectives such as reduce WIP by fixing a production rate between activities, (Biotto, et al. 2017) and to increase the continuous use of resources and how uniform these resources are distributed (Ungureanu et al., 2019; Lucko et al., 2014). However, Su;Lucko (2016) claim that the graphical visualization of multiple teams is only feasible for LOB.

Over time, several studies have been conducted that seek to strengthen applying LOB in civil construction, and have sought to demonstrate the tool's potential assistance in simulating scenarios (Kemmer, 2008; Valente et al., 2013), papers that provided evidence that less interference between teams results in productivity gains and less risk of demobilizing and remobilizing on the construction site (Kankainen;Seppänen, 2003). In the field of theory, Moura et al. (2014), based on a literature review highlighted that the LOB has a strong relationship with the concepts and principles of Lean Construction, as for example the concepts of production and tranfers batches, the importance of production leveling, the visualization of work-in-progress and the focus in reduce this type of waste, and the focus of synchronization in production.

Few studies assess teams' understanding of the benefits of LOB during their first contact with it. Moreover, studies do not usually discuss the implementation process when the project is already in progress. There are many contracts and teams already mobilized and of activities in execution. With regard to this, Mendes Jr (1998) proposed a methodology for applying LOB in buildings with multiple floors. The focus of his study is to draw up a pre-plan of the macro activities of the entire works, but the paper does not point out any evidence of the evaluation regarding the step-by-step process from the perspective of the teams that took part; Valente et al., (2014) propose guidelines to apply LOB in non-repetitive works, but the evaluation of the applications in a case study showed only either difficulties related to physical interferences that prevented the teams to attend the planned rhythm, or the need to increase the tools to support LOB when drawing up the schedule; Seppänen (2005) studied the benefits of using LOB in a commercial building, by applying site-based production control tools, the greater focus being on comparing control data and computer simulations, but with few interactions with project teams during construction and does not assess the construction team´s understanding of the proposed method.

Recent studies of LOB implementation take into account complex mathematical and statistical models for scheduling and balancing teams. Tokdenir et. al., (2019) presents a risk assessment of tasks based on scenarios with LOB, the analysis takes into account a

Monte Carlo simulation. Damci (2020) revisits the concept of natural rhythm of production, arguing that there is an optimization of team size for different tasks and that multiples of these teams transformed into workload must be used to calculate the necessary pace. Ammar (2019) proposes an interesting and counter-intuitive use of the LOB, where some tasks are interrupted to promote project optimization. However, these researches do not evaluate the understanding of the concepts that the tool proposes for the project stakeholders who make decisions based on the schedule information, also most of the research takes into account the application of LOB in an initial phase of the project and not discuss collaboration and commitment to the planning process in a hostile scenario.

Despite the growing use of LOB in companies in the sector, there are still few studies that present a method of implementation in works already started. The application of LOB "as imagined" suggest the start of this in an initial phase of the project, as many studies propose. However, sometimes the application of LOB "as done" happen when the project already started, and these projects presents, within the scope of planning, traditional methodologies already implemented, such as the critical path method (CPM). In addition, scenarios of delays in activities, interference between teams and WIP are expected in these situations. This is where the need for training the concepts and a change management strategy for stakeholder engagement arise in the face of the adoption of the new planning method using the LOB.

This study puts forward a collaborative method for training and implementing LOB in repetitive residential buldings that have already started. In addition, the project aims to train the management and production team in the concepts and techniques of developing the LOB. In the end, an evaluation was proposed based on two case studies of the perception of the people involved in the implementation concerning the processes of the framework and to the benefits pointed out in the literature.

This research aims to contribute with a methodology for projects in progress that wish to use the LOB to readjust the schedule, balance the teams and optimize resource deliveries.

RESEARCH METHOD

Design Science Research (DSR) was adopted in this research, which strategy is related to development and evaluation artifacts with a focus on solve practical problems (Hevner, et.al, 2004; Holmström et al. 2009). DSR was used as an interactive process between understanding a problem and developing a solution which are undertaken in incremental learning cycles (Lukka 2003). The artifact developed was a collaborative method for training and implementing the LOB in works that are in progress. The evaluation of this artifact was based on the employees' perception of the usefulness of the steps of the method and the benefits of applying LOB.

The method was applied in two case studies carried out in residential projects of company X, located in the Brazilian state of São Paulo. Company X was selected because it has been implementing the concepts and principles of Lean Construction and Last Planner ® aided by the authors of this paper who have acted as consultants to this company. Table 1 gives a brief description of each case study and the scope of action in relation to improving the method.

Table 1: Description of the projects and the scope of each case study

Case Study 1 – Project Description	Case Study 1 – Scope	Case Study 2 – Project Description	Case Study 2 - Scope
Low-end residential project, horizontal condominium, 13 towers with 4 floors	- Implement proposed method for collaborative Line of Balance Workshop;	Low-end residential project, horizontal condominium, 28 towers with 4 floors.	- Refine proposed method for collaborative Line of Balance Workshop;
Four apartments per floor, ranging from 43.06 to 56.98 m².	- Collect participants' feedback about the Line of Balance method;	Four apartments per floor, ranging from 43.06 to 46.7 m².	- Collect participants' feedback about the Line of Balance method;
48.4% executed from schedule		51.6% executed from schedule	
-14.3% deviation from the initial schedule		-15.0% deviation from the initial schedule	

The research followed the following steps: (i) determine the research objective theoretical framework; (ii) develop a method for applied LOB in projects in progress; (iii) evaluate the method based on the employees' perceptions; and (iv) tabulate and analyze data and draw conclusions. For the development step of the method, an artifact was developed and tested in two case studies (Table 2). The main sources of evidence and data collection procedures are summarized in Table 2.

Table 2: Main sources of evidence

Case Study	1	2
Duration	10 weeks	9 weeks
Participant observation in planning meetings	2 Line of Balance meetings	2 Line of Balance meetings
Direct Observations	20 one- to four-hour site visits	20 one- to four-hour site visits
Document Analysis	Schedule, weekly plans, control charts	
Interviews	Discussion of data with production managers	
Survey with participants	Survey related to benefits and collaboration of Line Balance workshop with 9 participants	
Total Hours	30	27

The development step of the method started with a literature review, a first version of the method was proposed on the basis of Kenley;Seppanen (2010), Mendes Jr;Heineck (1997) and Valente et al. (2014). In the first test round of the framework implemented in case study 1, it was necessary to collect data from the current scenario of the activities in progress in order to identify interferences between crews and remaining activities, this information would be the input for the start dates in the LOB in the current state. This collection was done through interviews with the participants and field observations, however, many noises in communication and conflicting information appeared. For the second round of the experiment, it was necessary to insert a subphase focused on analyzing the work-in-progress. In this subphase, the participants were gathered to map

activities and units remaining in a visual board, the purpose of the tool was to facilitate the use of implicit knowledge and generate consensus on the information collected. At the end of the case study, the final version of the method was presented.

To evaluate the training method developed, an analysis of the benefits of applying the LOB included in papers already published by the International Group for Lean Construction (IGLC) was carried out. 17 articles were consulted. The list of benefits considered will be presented in the results.

COLLABORATIVE METHOD FOR TRAINING AND IMPLEMENTING THE LINE OF BALANCE

The final version of the method was presented, it is consists of two phases (Preparation and a Workshop) that together include 8 subphases as shown in Figure 1.

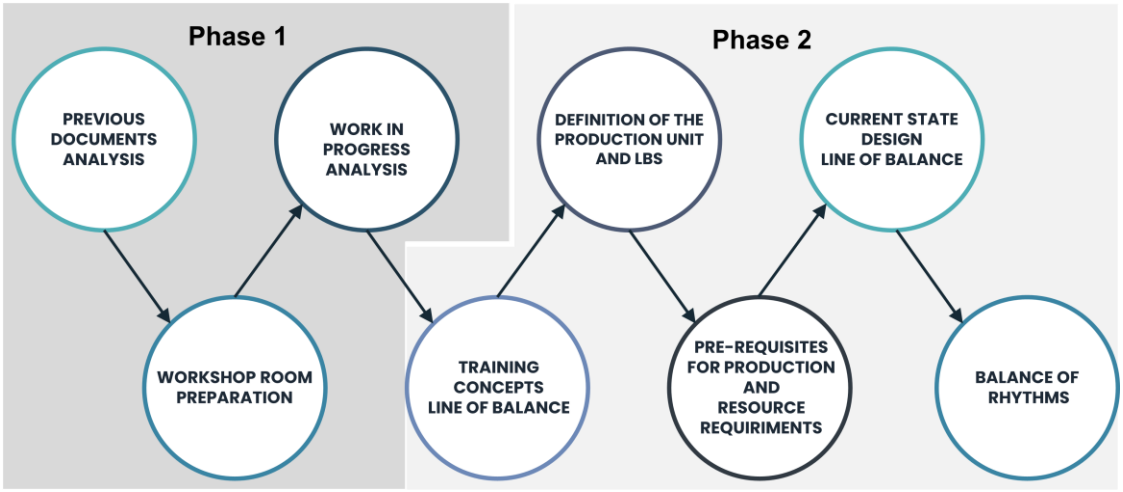

Figura 1- Method for Collaboative Line of Balance

Phase 1: Preparation

This phase includes three main subphases: (i) preliminary study of the project: a quantitative survey was carried out according to the physical locations of the project and the scope of the services. The productivities of construction services are estimated based on a historical company database, characteristics and size of the project; (ii) preparation of the "war-room" with visual management boards for the collaborative dynamics of the Line of Balance and the Balance of the Services; (iii) As these were construction services that were already in progress, a workshop of the work in progress analysis had to be carried out: the dynamics aimed to let the construction team clearly see the amount of work-in-progress of each service in each place of work. Based on this identification, the remain units of outstanding services in each location unit were recorded (Figure 2).

We can see the example in Figure 2 of the Pipes and Ducts / Shaft EPS activity pack with balance of 12 units in tower 3 side A and side B while the subsequent package Gypsum Plastering has balances in all towers before the third, that is, too much WIP.

	Tower 1 - Blocks A,B,C,D,E					Tower 2 - Blocks A,B,C,D,E,F						Tower 3 - Blocks A,B,C,D,E,F					
	1A	1B	1C	1D	1E	2A	2B	2C	2D	2E	2F	3A	3B	3C	3D	3E	3F
Structural Bricklaying	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Slab Concreting	0	0	0	0	0	0	0	0	0	0	0	4	4	4	4	4	4
Aluminum Window	0	0	0	0	0	0	0	0	0	0	0	4	4	4	4	4	4
Pipes and Ducts / Shaft EPS	0	0	0	0	0	0	0	0	0	0	0	12	12	8	8	8	8
Gypsum plastering	0	0	0	3	0	2	3	0	5	9	8	16	16	16	12	12	12
Waterproofing floor	0	0	0	0	0	4	4	0	4	8	4	16	16	16	16	12	12
Subfloor	1	4	1	3	1	7	6	6	2	6	4	16	16	16	16	16	16
Ceramic wall coating	0	0	7	0	2	7	8	4	12	12	12	16	16	16	16	16	16
Ceramic Floor coating	16	16	16	16	16	15	16	16	16	16	16	16	16	16	16	16	16
Gypsum lining	1	0	4	12	12	16	16	16	16	16	16	16	16	16	16	16	16
Heavy cleaning	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
Painting (1st coat)	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16

Key to Figure 2
16 — 16 units remaining
2F — Tower 2 and Block F

Figure 2: Board of units remaining used during the Workshop of the WIP analysis

Phase 2: Collaborative Workshop of Line of Balance

The second phase begins with training on long-term planning and the Line of Balance technique. This training seeks to present the concepts and principles behind the theme and to level up the knowledge of members of the construction team.

After this subphase, a start is made to define the size of the lot and where work will take place (Production Unit/ Location Breakdown Structure) collaboratively with the workshop participants. During this moment, participants are also instructed to reflect on the project execution strategy between the blocks (Figure 3).

Figure 3: Project Execution Strategy

Schramm, et al. (2004) define project execution strategy as a segmentation of smaller projects in order to create continuous flow of work, but these segments have limitations with some design decisions. For the case of Figure 3, the execution strategy was defined in towers, whose deliveries were defined from towers 1A to 2F due to the earlier delivery

of the leisure areas and entrance of the condominium as a project limitation due to business constraints, and 3F to 3A moving to 5A to 5E and finally 4A to 4F by logistical priorities of access of materials and release of the construction site.

The next subphase is to define the network of precedence and dimensioning of resources, which seeks to map the ideal flow of activities for carrying out the services in the production unit and to dimension the resources available for each activity of the sequence of construction based on the quantitative survey and on historic productivity. The resources needed were defined in the preparation phase.

The subphase about the Design of the Current State of the LOB involves a collaborative workshop in which participants are encouraged to fill in the visual board of the LOB by using sticky notes, representing the workflow of teams across locations over time. At this point in time, they are used like the balance of services prepared in phase 1.

The last subphase of the method is to balance the rhythms and draw the future state of the LOB (Figure 4). At this point in the dynamics, participants were instructed to eliminate work- in-progress between activities, thereby aiming at a continuous flow between activities, and they were encouraged to optimize the flow of services, thus avoiding work being interrupted as this could result in demobilization and remobilization.

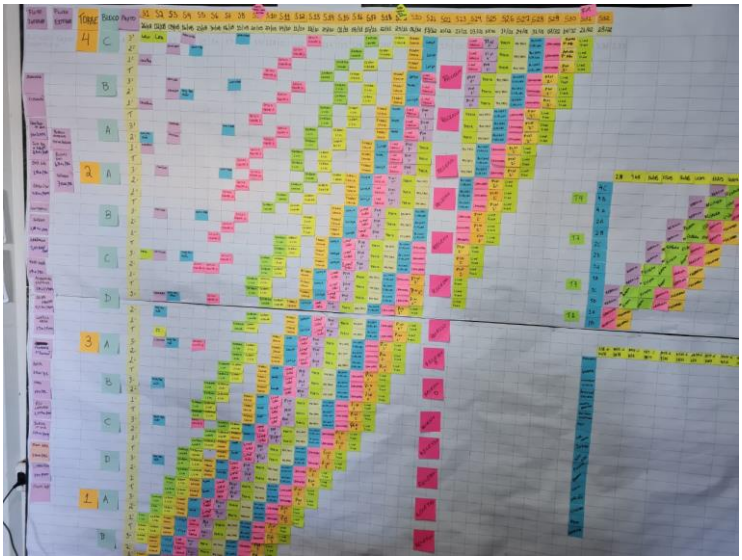

Figure 4: Balance of the work crews' rhythms

RESULTS

The survey carried out with 8 participants from the two case studies brought relevant information about the visualization of the benefits that the line of balance generates in the management of the works.

The benefits assessed by the survey were selected based on an analysis of the literature of IGLC community. Initially, 17 papers were identified that discuss the Line of Balance, of which 7 were selected that listed the benefits on the use of the technique. Table 3 presents the list of benefits that were evaluated at the end of each case study along with the evaluation of the usefulness of each step of the proposed method.

Table 3: List of the Benefits of LOB in the literature

Authors, Year	Formulated Questions
Valente et al., 2013	01. Ease of managing teams
Seppänen, 2005	02. Lower risk of team demobilization 03. More realistic plans due to the ease of analyzing buffers
Mendes Jr; Heineck, 1998	04. Negotiation of work between crews
Kankainen; Seppänen, 2003	05. Schedule of supplies with date as early as possible 06. Schedule of supplies: better visualization of restriction dates.
Moura et al., 2014	07. Improves task sequencing
Kemmer et al., 2008	08. Ease of simulation of scenarios and analysis

In the evaluation of the benefits of the LOB each participant chose 3 benefits that they would consider the most important of the 8 in the questionnaire. Figure 6 showed that the 3 main benefits perceived by users, among the 8 possible questions, were: (1.6) Understanding the best sequencing of activities and how to achieve continuity of tasks which received 75% of the votes; (1.3) Identify when the mobilization and desmobilization of teams should take place - 50% of the votes; and (1.8) Understanding of milestone dates for project constrains - 50% of the votes. In summary, 6 of the 8 participants (75%) chose question 1.6 as one of the 3 most relevant benefits of the LOB; no participant chose question 1.4; and the other results per question can be found in figure 5.

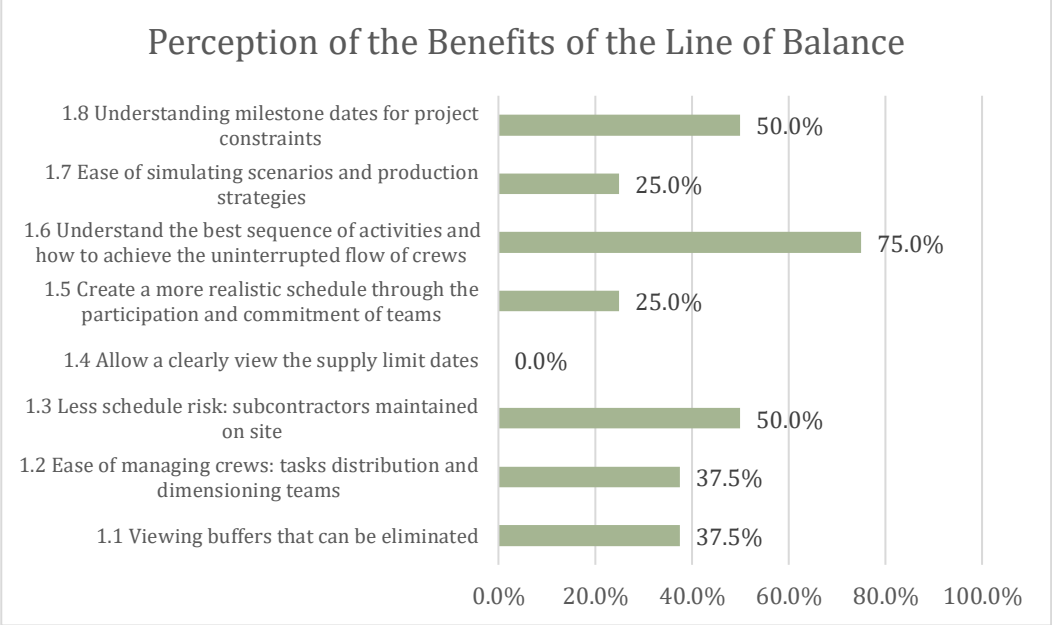

Figure 5: Perception of the Benefits of the Line Of Balance

The cross-analysis data from the perception of benefits between managers and production positions, it is observed that benefit 1.6 was the one most pointed out for both areas – 22% and 29% of the responses, respectively. Benefit 1.6 was also the only one mentioned by

the two areas. In second and third place in the list of benefits observed by production position are: 1.1 and 1.2, both of which were preferred by 21% of respondents. Among the managers, the evaluation pointed to benefits 1.3, 1.7 and 1.8 in the sequence of preferences, both of which were preferred by 22% of respondents.

The questionnaire was also used to seek to understand if, after the training, there was an increase in participants collaborating with the planning of the works. The average of the participants' evaluation was 4.78 on a scale of 1 to 5, thereby demonstrating the methodology managed to increase collaboration and engagement, post-training. As to what the main change brought about by LOB was, managers reported that traditional planning stipulated monthly goals only for the physical-financial progress of the tasks. It was not possible to understand the workload and correct sequence of activities by using this method, which generated a large amount of work-in-progress on the project. Among the feedback comments made, the following stand out: “We were able to visualize how to recover some overdue activities, such as ceramics”, “The biggest advantage is that everyone can visualize the project execution strategy of the schedule and when to start the tasks so that we finish on the deadline needed".

As for the evaluation of the main activities involved in the collaborative method, the overall average was a score of 4.61 on a scale of 1 - 5, with a standard deviation of 0.59 and a coefficient of variation of 13%, thus representing a low deviation, which means a satisfactory result (very good). The following issues stood out: (2.3) Definitions of the sequencing of macro activities, the average score being 4.85 points, (2.5) Designing the LOB in the current state, for which the average score was 4.75 points and (2.8) Improvement of scenarios in the future state, which received an average score of 4.75 points (see Figure 6).

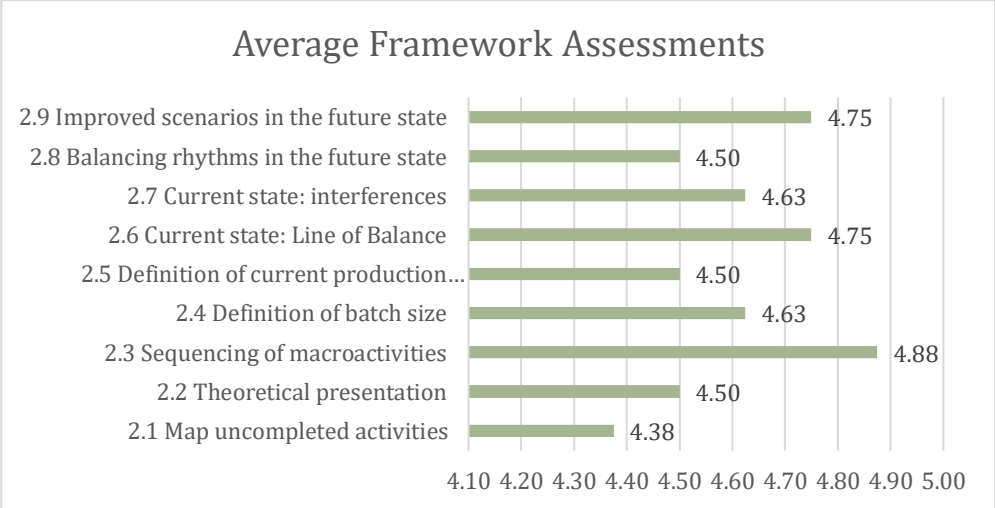

Figure 6: Average Framework Assessments

DISCUSSIONS

Combining the analyzes of the benefits, some similarities are observed between the highest scores of the questions 1.6 Understand the best sequence of activities and how to achieve the continuous flow of tasks unanimous preference among the participants and the evaluation 2.3 Sequencing of macroactivities with a score of 4.88 points for a total of 5.00. These similarities reinforced the methodological increment of case study 2, where the board of remaining units was used to understand the sequence and work in progress

of activities in the current scenario that finally allow the creation of the future state by defining a standard sequencing and balancing the rhythms of production.

The cross analysis demonstrate some interesting about the results, the numbers indicate that the benefits most mentioned by the managers include strategic aspects, such as risk management, scenarios of production. On the other, the benefits most mentioned by the production engineers include operational aspects, such as control and dimensioning of teams. This reinforces the importance of the tool being shared by both areas, in order to favor an integrated and complementary action.

A single question: 1.4 Allow a clearly view of the supply limit dates does not receive preferential voting by both the managers and production sectors, we infer that this question is closely related to the current moment of the research, where the Covid-19 pandemic and supply chain disruption results in a lack of confidence about delivery times.

CONCLUSIONS

This paper presents a collaborative methodology for training and implementing the Line of Balance in residential projects which have already started and with a traditional system of planning based on Pert-CPM, a context that is little addressed in current articles. The article then analyzes the acceptance of the methodology from the user's perspective.

The paper has shown that the Line of Balance can be implemented in this context and that users see the benefits of its use. The collaborative methodology proposed for constructing the LOB creates greater team engagement, thereby disseminating information on the rhythm, the sequencing of activities and the dimensioning of resources. Thus, the interference between consecutive tasks becomes clear, and it becomes possible to assess the risks for the current scenario with greater precision and, consequently, to project the future state.

The evidence gathered shows that crews who used the tool and participated in implementing the methodology noticed benefits such as: (i) understanding the sequence of activities and how to achieve an uninterrupted flow; (ii) the ability to assess the risk of demobilization and remobilization of work teams; and (iii) clarity about the milestone dates of the project and the constraints involved in order to comply with these. The fact that both construction works feature repeatability and several buildings are distributed on the same site may have contributed to the choice of the 3 main benefits identified, since both works presented excessive WIP due to the distribution of the teams without following the correct sequence of attack.

Another important point that was evaluated by having the responses of the participants is that among the activities that are part of the method, sequencing macro-activities, drawing up the current status of the LOB and improving the LOB scenario were the best evaluated by the participants, thus demonstrating the importance of the method for increasing the transparency and the capacity of the LOB to facilitate the simulation of scenarios as suggested by the literature.

One limitation of the present research is that the potential for reducing the size of the lot was not considered in the case studies (in case study 1, a floor was adopted and in case study 2 a tower was adopted). Despite this practice being an important asset for reducing construction time, for the training of case studies 1 and 2, the team of researchers considered it more appropriate to address this aspect in a second moment, since the current problems of the works were closely related to the dispersion of teams in the works without following a standard sequence for the flow of production This was identified by analyzing the balance of services table. Another limitation is due to the survey, the fact

that it contains only 8 evaluations prevents a quantitative analysis that validates the questionnaires, and then this research is qualitative.

Given that the study considered case studies with similar scenarios, such as evolutions of approximately 50% advance in the schedule and belonging to the low-end residential project with horizontal condominium market, future research can explore to what stage of a work in progress the methodology is still valid, for the same product or testing the framework in different construction projects, such as road projects, infrastructure and sanitation.

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