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PROPOSAL FOR A DEADLINE DEVIATION INDEX BASED ON LINE OF BALANCE AND RHYTHM DEVIATION DATA

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ABSTRACT

The line of balance (LOB) plays an important role in the implementation of Location-Based Planning and Control (LBPC), inducing most activities to be carried out at only one production rate and enabling the established deadlines to be met. Monitoring deviations from these deadlines is essential for project success, particularly in the construction industry. Rhythm deviation, an indicator rooted in Lean Construction principles and closely linked to LBPC, reveals the interference of critical tasks with other project activities and enables the analysis of how rhythm deviation of critical activities affects the project's deadline deviation. Analysing deadlines using the LOB technique in combination with rhythm deviation helps identify which activities are associated with project delays and advancements, allowing for corrective actions to improve workflow. However, this topic receives limited attention in the literature. The aim of this research is to propose a Deadline Deviation Index for monitoring and projecting delays and advancements in construction projects based on LOB and rhythm deviation data. This paper adopts an Action-Research methodology within a Case Study Approach. It presents findings from a case study involving 12 residential building projects that utilized location-based methods for scheduling and control, alongside rhythm deviation for monitoring critical processes. The results underscore how integrating the LOB technique with rhythm deviation enhances workflow and deadline management, thereby refining the sector's ability to estimate delays and advancements.

KEYWORDS

Location-Based Planning and Control (LBPC), Takt planning (TP), Line-of-Balance, Rhythm Deviation, Deadline Deviation.

INTRODUCTION

Traditionally, companies in the construction industry have relied on physical progress (a metric based on the Earned Value Management) as an indicator to measure project performance and progress (in terms of the volume of work carried out) over time (Kim & Ballard, 2002). However, result indicators, such as physical progress, tend to be reactive, focusing on the past and inefficient for supporting decision-making (Sarhan and Fox, 2013). Additionally, this indicator does not reflect time deviation, or a deadline projection based on Lean principles. Analysing the performance and progress of a project based on Lean principles should consider a set of factors: causes of problems, waste elimination, continuous improvement, zero defects,

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just-in-time, multifunctional teams, variability, and cycle time of critical processes (Karlsson & Åhlstrom, 1996; Koskela, 1992). In this way, process indicators can enhance the reliability of result indicators, as they focus on assessing performance at intermediate stages while providing information during execution to identify possible losses and problems (Braglia et al., 2019).

In this context, LBPC can address the shortcomings of traditional models. LBPC can be defined as a planning and control approach that allows for: (i) identifying critical construction processes in a time-location-context relationship; (ii) explicitly managing workflows on-site; (iii) supporting decision-making at different planning levels (Lucko et al., 2014). LBPC involves a set of techniques, including the line of balance (LOB), which represents the master plan (Ballard & Tommelein, 2021).

Adopting the Location Breakdown Structure (Kenley & Seppänen, 2010) and applying the LOB technique enables a better understanding of a project composed of repetitive activities because it allows for adjusting activities' production rates. It facilitates a smooth and efficient flow of resources and requires less time and effort to produce than network schedules (Arditi & Albulak, 1986). The LOB technique provides a clear overview of the project's overall status by quantitatively representing the cumulative completions of activities associated with a planned number at a given time (Suhail & Neale, 1994). It graphically reveals any imbalances that suggest a deviation from the plan due to the uneven progress of activities, enabling management to focus on assessing the deviation quantitatively (Khisty, 1970). The major benefits of the LOB are that several concepts related to Lean Production Philosophy are explicitly used, such as batch size, work-in-progress, cycle time, and the rhythm of processes (Schramm et al., 2006).

The rhythm deviation of critical activities is a performance indicator that incorporates lean concepts, strongly related to LBPC, specifically to Takt Time Planning (TTP) (Barth et al., 2019). According to Barth et al. (2019), the rhythm deviation control represents a form of critical process control, considering only fully accomplished tasks (batches). Each team must complete their work in a specified batch within a certain amount of time, also called takt time (Frandson et al., 2013; 2014). In this context, monitoring the rhythms of critical activities and their impacts on other activities can provide the trend of completing the last critical process (Barth et al., 2019), and consequently, the deadline projection.

Studies on LBPC (Kala et al., 2012; Seppänen et al., 2013; Frandson et al., 2013; 2014) have not extensively explored integrating LOB technique with performance indicators, such as the rhythm deviation of critical processes, to analyse deadline control in construction projects. Managing workflow through LOB technique alongside analysing rhythm deviations has the potential to proactively control delays and overruns in a production planning and control system based on Lean principles. So, this research aims to propose the application of a Deadline Deviation Index for monitoring delays and advancements in construction projects, as well as to establish a graphical representation indicating deadlines based on LOB and rhythm deviation data.

CASE STUDY

With 60 years of history, the company under study is currently the largest real estate group in Chile and one of the largest in South America. It is a fully integrated company that acquires land, designs, and constructs projects, and sells the end products. Most of residential building projects delivered by the company exhibit a high degree of repetitiveness, such as horizontal housing estates and vertical buildings. This company operates in 13 out of the 15 regions of Chile and sells more than 3,000 units per year. The company initiated a significant transformation process that resulted in a larger corporation with different brands focusing on distinct customer segments.

PREVIOUS RESEARCH AND PRACTICE

A Lean Implementation Program has been carried out in the company with the support of a consultancy firm and a research institution, both from Brazil. Previous research (Barth et al. 2019; Barth et al. 2020) reported the implementation process and presents a preliminary assessment of the impacts of the Lean implementation program.

RESEARCH METHOD

The methodological approach adopted in this investigation was Action-Research, based on a Case Study Approach. Action-Research is an approach that allows the active participation of the researcher in the observed phenomenon (Thiollent, 2005). Thiollent (2005) defines action research as a specific type of empirical-based research that is conceived and carried out through action in which researchers and some participants in the situation or problem are involved cooperatively. According to Dick (1993), action research has two objectives: action to bring about change in organizations and research to increase understanding of the topic under study.

A Lean Implementation Program was conducted within the company with the assistance of a consultancy firm. The researchers, who also acted as consultants and facilitators, were actively engaged in executing interventions or modifications based on the research findings, collaborating closely with company stakeholders to drive change. Additionally, the researchers maintained a continuous process of reflection to refine the research methodology and gain deeper insights into the identified challenges and potential solutions. Lastly, they disseminated the findings of the action research to pertinent employees, thereby enriching the collective knowledge base and potentially catalysing further initiatives.

The proposed Deadline Deviation Index has been tested and refined in 12 projects undertaken by the company. Ten out of the twelve projects had implemented Last Planner System (LPS) and LBPC, as well as the rhythm deviation of critical activities for analysis of the project deadline. Multiple sources of evidence were utilized in each project: interviews with site engineers and project managers, participant observations in (LPS) meetings, direct observations of the construction site, and analysis of planning documents.

The steps used to implement this Index are as follows: (a) train individuals to comprehend the significance of measuring rhythm deviation based on Lean concepts and principles; (b) designate responsibility for data collection and analysis; (c) create a rhythm deviation matrix and charts; (d) gather data; (e) utilize visual aids to disseminate information; (f) generate the Deadline Deviation Index; (g) analyse data, discuss rhythm deviations, deadline deviations, and establish corrective actions; and (h) report to various hierarchical levels within the company.

DISCUSSION AND RESULTS

LINE OF BALANCE DELIVERY STAGES

One of the fundamental stages in the development of LOB is the identification of Delivery Stages or milestones of the construction project. These Delivery Stages play a crucial role in referencing and predicting potential project delays or advancements in relation to the existing Master Plan. Therefore, the LOB model implemented in the studies must effectively demonstrate the different stages of delivery. The first delivery stage was associated with rough construction; the second delivery stage involved raw finishes. The third delivery stage addressed punch list items, and the fourth delivery stage focused on client delivery. The Figure 1 illustrates the workflows and delivery stages (both partial and final) using the LOB technique.

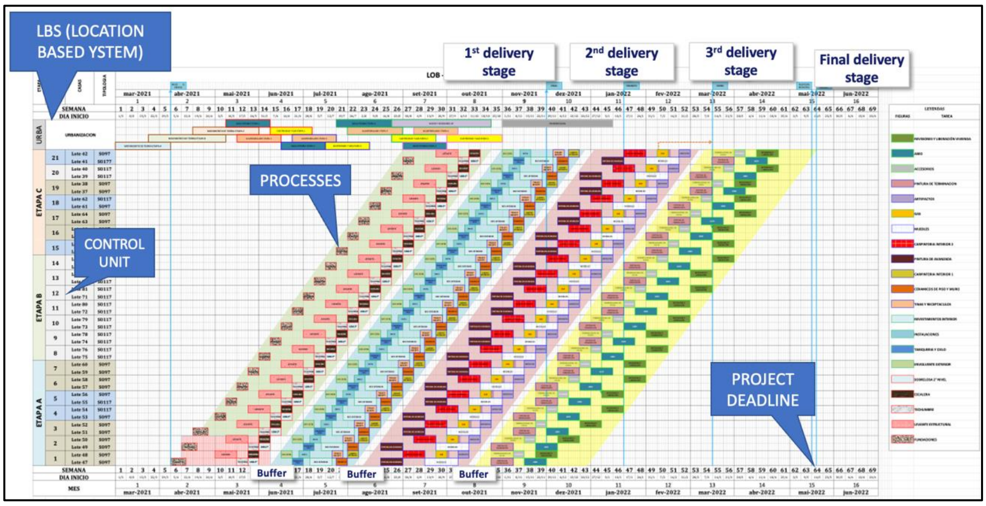

Figure 1: Example of Definition of workflows (whole project) and Delivery Stages (partial and final) through the LOB technique

RHYTHM DEVIATION FOR CRITICAL PROCESSES

The LOB developed for the construction projects under study, along with their respective delivery stages, provided the data that served as input for the creation of rhythm deviation control charts. In this context, planned and real completion dates, as well as the corresponding quantity of planned and real batches completed within a specific period, were compiled into an integrated database that allowed for the generation of rhythm deviation control charts. The rhythm deviation encourages the entire team, including subcontractors, to prioritize batch completion alongside integrated quality control measures. In this study, all 12 residential construction projects analysed applied the rhythm deviation in monitoring critical activities.

Figure 2 illustrates the rhythm deviation chart developed for a critical activity. The rhythm deviation is represented by the difference (in weeks) between the planned date in the current LOB and the real execution date of the critical activity. This allows monitoring the actual pace of the activity in relation to the planned pace in the current LOB, as well as projecting the execution pace until the completion of the activity based on resource analysis and constraints of each critical activity. The data enable the analysis of strategies and resources needed to reduce pace deviation in future weeks.

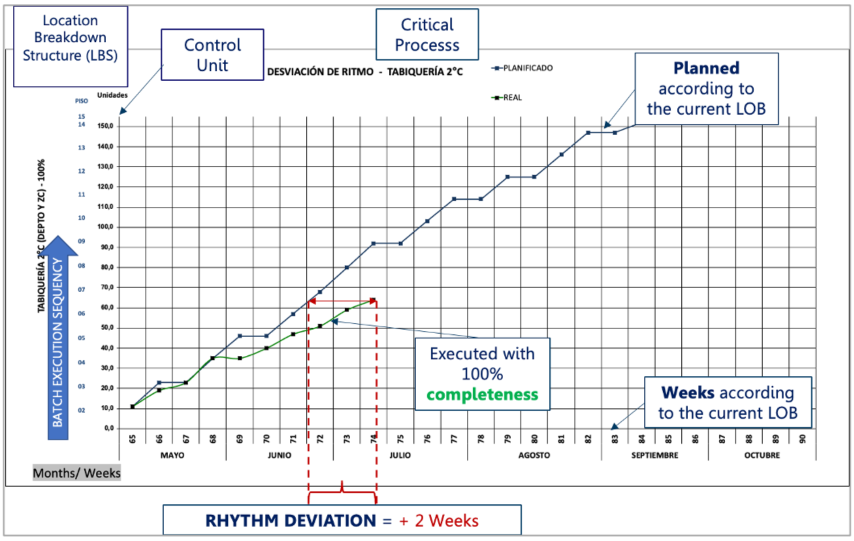

Figure 2: Example of a chart to monitor the rhythm deviation of one critical construction process.

Figure 3 illustrates the integrated rhythm deviation chart of different critical activities, enabling monitoring of the effects that critical tasks have on other activities. The following analyses can be conducted: (a) checking for possible clashes between critical activities based on real paces and projections, (b) analysing the paces of projections in a consolidated manner, and (c) examining the impact of real paces and projections on the intermediate plan. Considering the pivotal role many of these activities play in production, both in terms of time and cost, any adjustment in the pace of a process line justifies a comprehensive analysis of its impact on others.

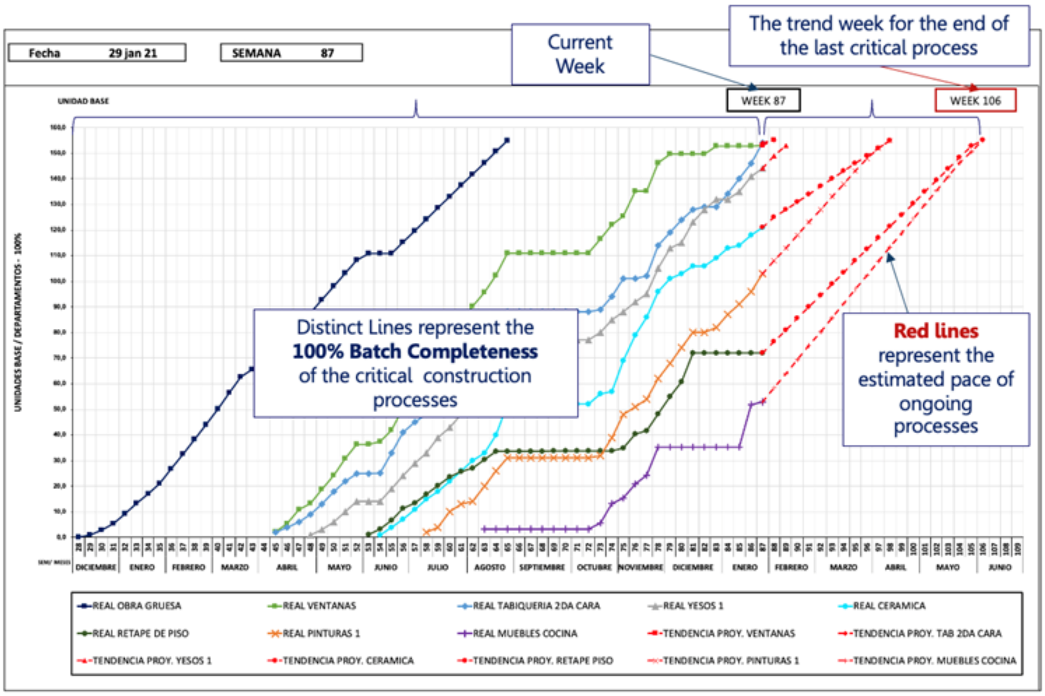

Figure 3: Example of an integrated chart to monitor the rhythm of different critical construction processes.

DEADLINE DEVIATION INDEX AND PROJECTION CHARTS

The data generated by the rhythm deviation provided the necessary information to generate the Deadline Deviation Index. In this context, data can be collected weekly by the construction site manager or by someone experienced in planning and control, simultaneously with the weekly plan data, to optimize data collection and processing. Both individual and integrated rhythm deviation charts facilitate data visualization for calculating the Deadline Deviation Index.

Deadline Deviation Index is calculated by the ratio of the sum of weighted delays and advances in critical processes (measured in weeks) to the total duration of critical activities on site, according to the formula outlined in Equation 1.

$$DD = \frac{\left[\sum \text{Number Weeks late X processes duration} - \sum \text{Number Weeks in advance X processes duration}\right]}{\sum \text{processes duration}}$$

Equation 1: Deadline Deviation Index Formula.

Lower and upper limit charts were employed to depict and monitor the Deadline Deviation index over the course of the project. These charts enable the establishment of delay or advancement thresholds tailored to each delivery stage. In the case of the company under study, upper and lower limits of 4 weeks were set as triggers to prompt the formulation of an action plan or adjustment of strategy within the lookahead planning process. This proactive approach aims to primarily address project delays identified through this indicator. Figure 4 illustrates an example of a Deadline Deviation Index Chart utilized during performance management meetings.

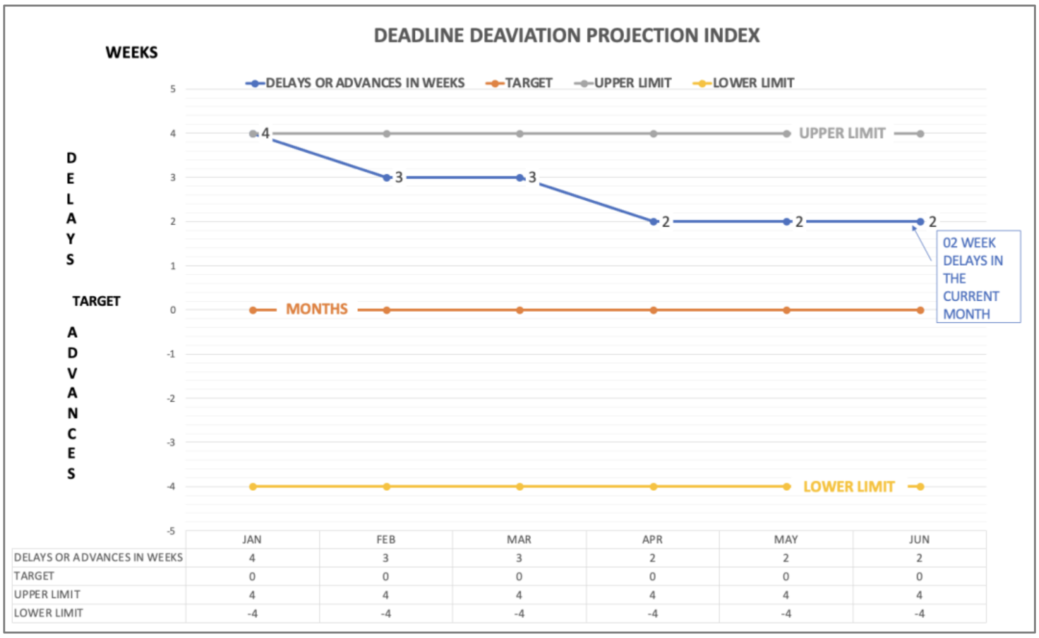

Figure 4: Deadline Deviation Index Chart applied in performance management meetings (example)

INDEX APPLICATION PROCESS

Throughout this study, data regarding the Deadline Deviation Index was examined across 12 construction projects. This indicator was precisely captured at the time of each delivery stages to visualize its progression throughout each project. This facilitated a flow of information supporting decision-making for both the project managers and the group of researchers, aiming to address identified delays and redirect the project's trajectory.

The implementation of the Deadline Deviation Index necessitates prior adoption of the LOB Technique and rhythm deviation charts. Initiating this tool involves training relevant personnel, emphasizing the advantages of maintaining accurate data and ensuring complete batch execution. The application process encompasses data collection, processing, and analysis.

Data Collection: Completion data should be gathered weekly by a qualified professional to assess task fulfillment and quality. This assessment can be synchronized with weekly task monitoring to minimize additional time for data processing. Recorded data should feed into a control table to generate rhythm deviation charts.

Data Processing: Processing involves data storage, visualization, and dissemination. Processed data yields actionable insights for decision-making across various analysis scenarios. Information should be presented in an accessible format for all stakeholders. Indicators and charts derived from rhythm deviations support analytical processes.

Analysis of Data and Information: Analysis of rhythm deviations primarily aligns with medium-term planning, although time projection analyses occur during specific meetings to assess project performance. For residential projects exceeding 12 months (typical in this study's sample), performance review meetings are held monthly. Thus, it's advisable to conduct time projection analyses more frequently to ensure timely intervention and course correction.

INFORMATION AND DATA ANALYSIS

An initial evaluation of the implementation of the Deadline Deviation Index was conducted across the 12 projects under study. This assessment utilized four distinct classifications based on the stage of Lean implementation within each project: Prior Lean implementation (PL), Early Lean implementation (EL), Basic Lean (BL) practices implementation, and Initial Stability (IS) achieved with Lean. Figure 5 illustrates the outcomes for each project categorized under one of these four implementation stages.

Furthermore, for this analysis, Deadline Deviation data was collected at the four distinct stages of project delivery. Since the projects did not occur simultaneously, it was necessary to establish a comparable timeframe for this evaluation. Projects 1 and 2 were analysed prior to the introduction of Lean practices within the company. Projects 3 and 4 were in the initial stages of implementing lean practices. In contrast, projects 5, 6, 7, 8, and 9 fully engaged in the implementation of fundamental Lean practices. Projects 10, 11, and 12 can be considered the most advanced in terms of Lean implementation compared to the others, having achieved an initial level of stability. Figure 5 displays the outcomes of the Deadline Deviation Index across four distinct delivery stages for 12 projects.

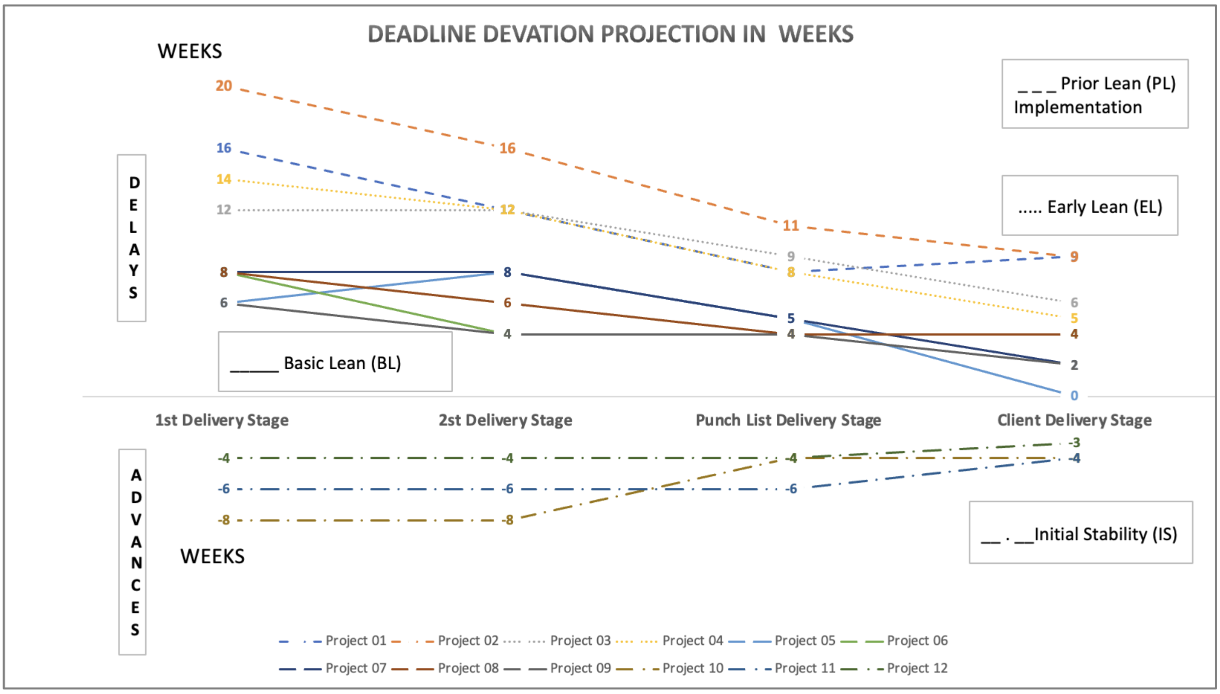

Figure 5: Results of Deadline Deviation Index during 4 different deliveries stages, for 12 projects.

From the analysis of the chart presented in Figure 5, it is noticed that the Deadline Deviation data exhibit greater variability across different delivery stages for projects executed before the implementation of Lean practices in the company and for projects in the early stages of Lean implementation, such as Projects 1, 2, 3, and 4.

As the Lean implementation stage progresses, there is a decrease in variability in the Deadline Deviation data across different delivery stages. For Projects 5, 6, 7, 8, and 9, which were fully engaged in implementing Lean practices, the variation in the Deadline Deviation index is lower than for Projects 1, 2, 3, and 4.

Finally, the Deadline Deviation data remains more stable across different delivery stages for Projects 10, 11, and 12, i.e., for projects in a more advanced stage of Lean implementation.

In this context, it is observed that for projects further advanced in Lean implementation practices, the Deadline Deviation index obtained from LOB data and rhythm deviation data provides a fairly accurate projection of the real project completion, regardless of the project stage. The indicator, therefore, proves effective in monitoring delays and advancements in construction projects, reflecting the Deadline Deviation based on Lean principles.

CONCLUSIONS

The research methodology employs an Action-Research approach within a Case Study framework, demonstrating the practical application of the proposed Index in real-world construction projects. This research has proposed and tested an index that may be used to monitoring and projecting delays and advancements of construction projects that integrates the Line of Balance technique with rhythm deviation analysis. This index represents an approach and, like other indexes, should not be analysed in isolation. Combining it with other information such as cycle time, batch adherence, batch completeness index, and percentage of plans completed (PPC) provides a more accurate project status.

LBPC is a critical aspect of Lean construction, allowing for the explicit management of workflows on-site and supporting decision-making at different planning levels. By integrating LBPC with the proposed Deadline Deviation Index, the paper contributes to advancing knowledge in the field of Lean construction management.

The findings of this study expose on the effective utilization of 12 residential building projects management tools, notably the Line of Balance technique, Rhythm Deviation control, and the Deadline Deviation Index, within construction projects. The Line of Balance technique, when coupled with the identification of delivery stages, serves as a valuable predictive tool for managing project timelines and mitigating delays. Likewise, Rhythm Deviation control, integrating lean principles, emphasizes the completion of tasks within specified timeframes, fostering a culture of efficiency and quality across project teams.

The findings of this study expose on the effective utilization of various project management tools, notably the Line of Balance technique, Rhythm Deviation control, and the Deadline Deviation Index, within construction projects. The Line of Balance technique, when coupled with the identification of delivery stages, serves as a valuable predictive tool for managing project timelines and mitigating delays. Likewise, Rhythm Deviation control, integrating lean principles, emphasizes the completion of tasks within specified timeframes, fostering a culture of efficiency and quality across project teams.

The implementation of the Deadline Deviation Index, alongside these techniques, offers a comprehensive approach to performance monitoring and decision-making. By systematically gathering and analysing data at different project delivery stages, stakeholders can identify trends, anticipate challenges, and proactively address deviations from planned timelines. The paper introduces practical tools such as lower and upper limit charts, coupled with the Index, provide actionable insights for timely intervention, strategy adjustments, performance monitoring and decision-making thereby enhancing overall project management effectiveness.

The analysis of research results further highlights the importance of Lean implementation stages in influencing project performance. Projects exhibiting Initial Stability with Lean practices demonstrate improved resilience to timeline deviations compared to those at earlier stages of implementation. This underscores the significance of continuous improvement efforts and organizational learning in optimizing project outcomes.

Future studies could explore the application of the proposed tool in non-repetitive projects, to further expand knowledge and understanding in the field of Lean construction management. This aspect contributes to the ongoing discourse on continuous improvement and innovation in construction practices.

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