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LAST PLANNER SYSTEM: PULL PLANNING AS A DOCUMENTATION MANAGEMENT TOOL IN PHOTOVOLTAIC PROJECTS

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ABSTRACT

The article discusses the application of the Last Planner System (LPS) in the context of infrastructure projects, focusing specifically on the renewable energy sector. A Brazilian company specialized in the design and construction of photovoltaic plants was chosen as the research scenario. LPS was introduced to the company as a tool for production control and management, providing stability to the production system. This article explores the application of LPS in design management, highlighting the complexity of the construction design process and proposing the integration of LPS principles into design management. Pull planning was incorporated into design management to establish a reliable flow in the iterative work performed by designers. The pull planning process is described in detail, including the creation of process flows, document analysis, board assembly, milestone definition, task segmentation of process flows, and weekly schedule structuring. Challenges were identified during the practical application of the tool, leading to the conclusion that there is room for improvement. In summary, this study demonstrates the potential of LPS and pull planning in improving the management of infrastructure projects, with a specific emphasis on documentation and design management in photovoltaic projects.

KEYWORDS

Last Planner System, Lean construction, Pull planning, Solar PV plant

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INTRODUCTION

Infrastructure projects are typically costly enterprises with great strategic importance for a region, country, or organization and high added value for the population (Dave et al., 2013). These projects have lower complexity than building projects, involve a more limited array of professionals, and encompass a wider variety of typologies, such as roads, bridges, and dams, among others (Yabuki, 2010). Interestingly, given their large scale and long execution cycles, infrastructure projects are highly conducive to improvement (Dave et al., 2013).

Improvement, as understood in the context of the Toyota Production System (TPS), focuses on increasing value to customers through waste elimination (Onho, 1988). For this, production systems need to operate in a stable and predictable manner (Onho, 1988).

Building upon this idea, Viana et al. (2010) presented the Last Planner System (LPS) as a tool for production control and management, providing a basic level of stability to the production system and enabling the implementation of more elaborate lean concepts. LPS converts activities that need to be carried out (long term) into tasks that can be effectively performed (medium term), eliminating anything that may prevent or limit production (restrictions) and identifying a set of activities to be undertaken as part of the weekly plan (short term), thereby lending greater reliability to established plans (Ballard, 2000).

A pull planning step and the term "should" were introduced to the LPS practice as a strategy to enhance the connection between long- and medium-term plans (Ballard, 1999). Pull planning offers a new perspective on collaboration and workflows, placing attention on what "can" be done in the current scenario of the project, rather than on what "should" be done (Silva et al., 2022).

Several studies have been conducted on LPS adoption in the civil construction sector. In the context of infrastructure projects, such studies are still incipient (Antonini et al., 2022). A recent study described the efforts put in place by the UK highways supply chain for the creation of numerous continuous improvement cells, in line with its commitment to improve performance and embrace lean construction principles (Tezel et al., 2018). As for infrastructure projects related to energy production, such as photovoltaic power stations, research is even more embryonic. A search carried out in the International Group of Lean Construction (IGLC) database for the keywords "solar," "photovoltaic," and "solar energy" retrieved only three publications related to the energy sector. However, the identified articles did not address themes related to lean principles. Furthermore, Construction of photovoltaic plants has some particularities that must be considered. This type of construction has a fast execution cycle and, as consequence, a short response time and a longer-term constraint analysis. Therefore, these characteristics need to be considered in the process of implementing LPS routines.

In view of these gaps, this study aimed to investigate the application of LPS in the context of photovoltaic projects. The objective is to identify how LPS and pull planning can aid in long-, medium-, and short-term planning for managing documentation (projects, bills of materials, manuals, regulations) over the entire course of implementation of solar photovoltaic plants.

The research is divided into three main sections. First, a brief literature review is presented on lean thinking and LPS, focusing on pull planning. Subsequently, the research context is described. Finally, the developed documentation management method and results are discussed. The article also suggests new perspectives for exploring lean practices in the solar energy farm sector.

DESIGN MANAGEMENT

In the field of construction, both the design process and the resulting product have high complexity (Bolviken et al. 2010). Designing requires an ongoing process of negotiation and adjustment (oscillation or conversation) between criteria and alternatives, resulting in the gradual determination of ends and means (Bolviken et al., 2010). Bolviken et al. (2010) stated that, in simple terms, the decision-making process can be seen as an integral part of the design process. Design management involves effectively overseeing the design process (Best 2006).

As design and construction phases are normally conceived separately (Alarcón & Mardones, 1998), it can be difficult to integrate design and construction information (Alshawi & Ingirige, 2003, as cited in Dave et al., 2008). Common challenges include disruptions at the design–construction interface, such as divergent production sequences and priorities, ultimately resulting in delays, rework, and waiting for project participants (e.g., designers, suppliers, and builders) (Biotto et al., 2022). Dave et al. (2015) suggested an improved design–construction interface, where design information is released with a pull from the master schedule.

To date, lean construction has had far more influence on production than on design. Nevertheless, we believe that it is possible to apply lean concepts to design management. This hypothesis was proposed by Bolviken et al. (2010), who argued that lean construction and LPS principles are equally relevant to design and production in construction.

In this paper, LPS will be used for design management according to a pull planning approach, following a reverse plan of each phase's task, pulling each task from the end milestone toward the phase start date (Alarcon et al., 2004). Pull planning in design is one of the newer additions to the lean thinking toolkit, aiming to establish a reliable flow in the iterative work performed by designers (Tvedt, 2020).

PULL PLANNING

Pull planning was incorporated into LPS to allow the structuring of a project phase or milestone collaboratively among stakeholders (Ballard, 2008). It connects the master and lookahead plans (Biotto et al., 2022). The term pull planning refers to the lean concept of "pull" as a request from downstream, in contrast to the topdown "push" applied in traditional practice (Tsao et al., 2014).

The pull plan can be scheduled using a diverse range of tools, such as Gantt charts (Knapp et al., 2006) or location-based schedule (LBS) techniques, such as line of balance (LOB) (O'Brien et al., 1985), flowline (Kenley & Seppänen, 2010), and takt time planning (Fiallo C & Howell, 2012). In agreement with Biotto et al. (2022), who suggested the use of LBS to plan the whole project in a reverse manner (from construction to design), the authors of this paper believe that LOB and LPS should encompass the entire project. For pull planning and line-of-balance scheduling, it is necessary to define zones, takt times, trade sequences, and trade durations and balance their workflow (Frandson et al., 2013).

Pull planning defines how work will be delivered from one project actor (owners, designers, contractors, suppliers, construction companies) to the next (Tsao et al., 2014). Furthermore, this tool provides the basic technique and approach for establishing "who should be doing what work and when" (Tsao and Tommelein, 2004) in order to achieve the proposed milestones. Pull planning also brings a new perspective on workflow, considering a collaborative approach that focuses on what can be done rather than on what should be done (Silva et al., 2022).

As recommended by Silva et al. (2022), the workshop for implementing pull planning should ideally be scheduled at least one month, if not two, before the beginning of the actual work. In a pull planning workshop, all parties involved in the implementation process should participate collaboratively. Working backward from an end milestone is challenging, especially for project teams that have not pull planned before. Therefore, at the beginning of the workshop, it is important to explain to attendees that the meeting will proceed in three phases, as described by Tsao et al. (2014). (1) The first step is the backward pass. It will define any work necessary to support the end milestone. (2) Subsequently comes the forward pass, when the attendees will check the workflow logic and include any additional activities required to support the end milestone. (3) The last phase is the tightening pass. In this step, the team will divide the work into smaller batches and balance workflows so as to reduce the overall duration. Even with the development of software options to aid in LPS implementation, Tsao and Howell (2022) still recommend the use of sticky notes on walls in pull planning sessions, as they provide a tangible and accessible means for first-line planners/foremen in design and construction to interact in a hands-on manner.

In this article, pull planning will be implemented in design management based on the milestones defined using the LOB technique. As described by Tvedt (2020), pull planning is used to increase productivity in the design phase. The primary objective is to establish a dependable flow in the iterative work conducted by designers, fostering collaborative engagement to formulate the optimal plan for the design phase. This process, in turn, aims to minimize waste (Tvedt, 2020).

RESEARCH METHOD

METHOD DESCRIPTION

This article adopted a design science research approach. This method assists in the search for solutions in the realm of innovation and continuous improvement (Carneiro et al. 2019) while attempting to fill the gap between theory and practice through the development of a reliable artifact (Rocha et al., 2012). Research development should be guided by its practical utility for both the organization and academia, fostering the cultivation and application of theoretical knowledge (Monteiro, 2015; Järvinen, 2007; Lukka, 2003).

As will be described in the next section, the research was conducted in a that integrates last planner routines with the design management.

DESCRIPTION OF THE STUDY COMPANY AND PROJECTS

The study company, hereafter referred to as Company X, stands out in the development and delivery of operational projects for national and international energy sectors under EPC contracts. From feasibility studies to project execution, Company X prioritizes quality, safety, and efficiency, seeking efficient and adaptable energy solutions. Adhering to high levels of quality and sustainability, it follows international standards, protects health and safety, adopts socioenvironmental practices, and holds certifications of excellence. The company is ISO 9001, 14001, 19600, 37001, and 45001 certified.

The study encompassed two projects (P and M) for the implementation of photovoltaic plants. Both projects had the same organizational structure, as shown in Figure 1. Pull planning was developed within the design sector. Project P (Figure 2) consists of a solar park in Ceará State, northeastern Brazil, covering an area of approximately 8.90 km^2. The park contains 443,190 modules, 4,345 trackers, and 13,035 strings, corresponding to a power generation of 295 MWp. The project started in February 2023 and has an execution period of 12 months. The second project, Project M, consists of a solar park located in Piauí State, covering an area of approximately 9.83 km^2. The park contains 676,566 modules, 6,633 trackers, and 1,716 string-inverters, corresponding to 445 MWp. The project started in February 2023 and has an execution period of 14 months.

The design sector is responsible for design management. The plans for Projects P and M were developed by an outsourced, independent project office. The design sector within Company X was in charge of the review, validation, decision-making, and internal approval of the designs.

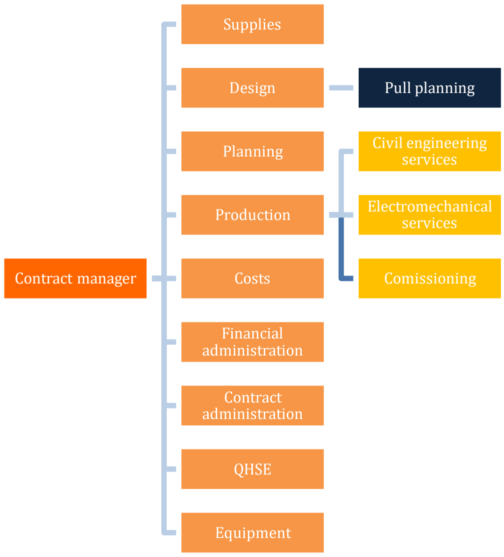

Figure 1: Organizational structure of Projects P and M in Company X

Figure 2: Aerial view of Project P

THE LEAN APPROACH IN COMPANY X

The implementation of the lean approach in Company X (Figure 3) began in February 2023, when the fundamental concepts of lean were applied in a pilot project. This was a crucial milestone for the dissemination of lean principles in construction, expanding their application to various areas of the company. The central goal was the gradual and sustainable integration of lean principles within the company.

The first phase of the project consisted of investigating the company's culture and processes. This phase was called the diagnostic phase, in which pull planning and long-term horizon sessions were applied. After the diagnosis, we focused our efforts on LPS implementation, dividing the actions into long-, medium-, and short-term goals. This period was fundamental to establish a solid foundation for application of LPS principles, referred to here as ramp-up.

In addition to LPS routines and with the objective of supporting its application, logistics studies were carried out to analyze productivity gains and promote integration between logistics and production teams. In this stage, called support, pull planning was carried out as described below.

Throughout the schedule, we dedicated several weeks to field actions through Kaizen events. These events challenged the team to achieve the predefined production rhythms, not only promoting immediate operational efficiency but also cultivating an organizational culture conducive to continuous improvement at all levels.

It is relevant to note that, during implementation of the lean approach, our scope increased, allowing the expansion of practices to different sectors of the company. This achievement highlights the flexibility and adaptability of the lean approach in the face of emerging challenges.

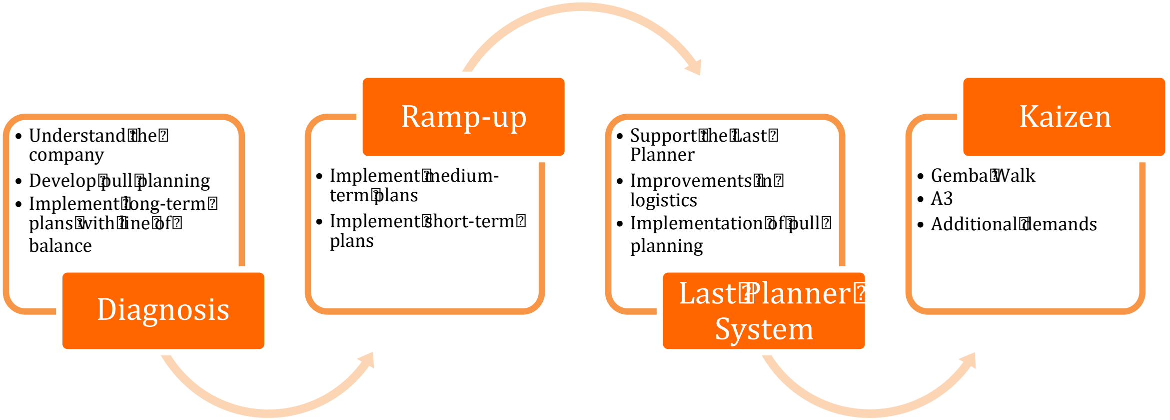

Figure 3: Implementation of lean construction in Company X

RESULTS

The business model of Company X is structured according to the contractual modality of Engineering, Procurement, and Construction (EPC) (Figure 4). Thus, the lean implementation project focused on the areas of supply and construction. LPS routines were used as supporting tools during implementation. The tasks performed by the engineering sector have a great influence on the development of construction and supply activities, generating an impact on job execution. Therefore, it was necessary to identify and structure the flow of tasks and deliveries performed in the field of engineering.

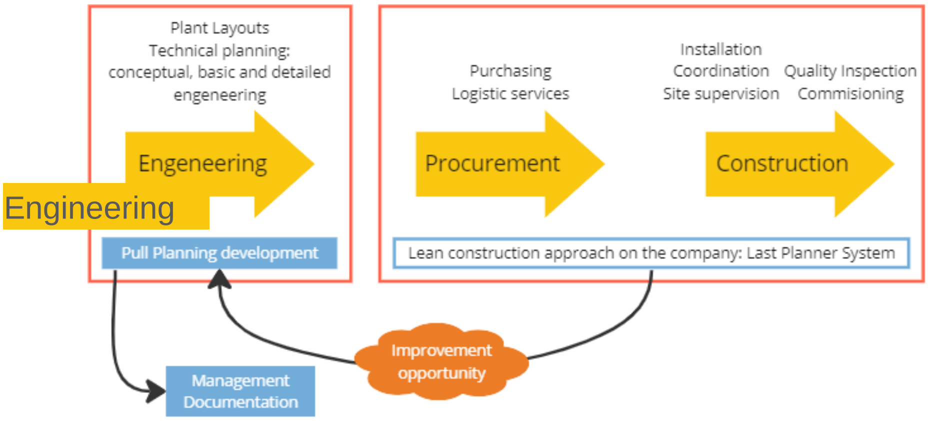

Figure 4: Lean implementation approach and opportunity for improvement

As mentioned, photovoltaic plant projects have specific characteristics. The fast execution cycle demands a short response time and a longer horizon for viewing constraints - in Project M, 8 weeks were analyzed. In supply sector, there was a high lead time for material procurement and production, and in engineering area, tasks focused on project management rather than development, as shown in Figure 5.

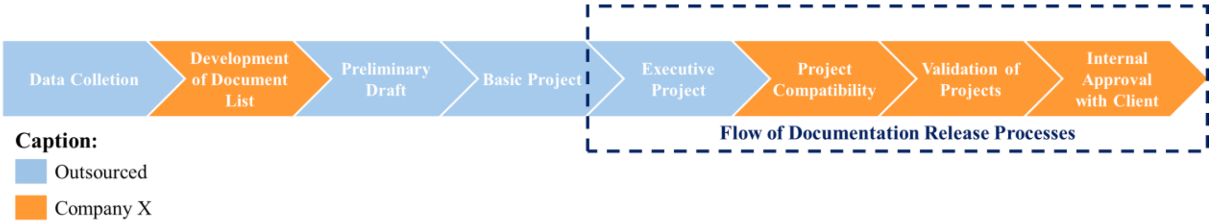

Figure 5: Flow of tasks performed by engineering

Given the need to improve the flow of tasks performed by the engineering sector (Figure 5), pull planning was proposed to improve the structuring of activities in the sector, with a focus on construction planning. Pull planning was implemented in five stages. The first four stages comprised pull planning sessions and the fifth comprised continuous monitoring of the developed plan. This tool allows creating a demand balance for an uninterrupted work system, in which value is obtained in the correct delivery flow (throughput) (Tsao et al., 2014). The workshop helps teams understand the constraints and bottlenecks of tasks and value collaboration. The planning process was carried out backward, taking as reference the milestones of the project, in a collaborative and multidisciplinary way (Tsao et al., 2014).

Pull planning was implemented through the following five stages: (i) definition of the flow of documentation release processes, (ii) documentation analysis (projects, manuals, etc.) and activity alignment, (iii) assembly of the pull planning board, (iv) definition of milestones and process flow for each activity, and (v) structuring of a weekly schedule to be monitored by the engineering sector. These steps are detailed below.

DEFINITION OF THE FLOW OF DOCUMENTATION RELEASE PROCESSES

This is the first step in the development of the engineering pull planning. The stages and flow of the development, analysis, and release of documentations are defined collaboratively with the engineering sector. Here, a flow composed of five activities was developed, encompassing the entire process (Figure 6).

Legend	Activity	Estimated time
	Begin the development of the project/document	Dependent on the document
	Internal analysis and revisions	5 days
	Collaborative posting	10 days
	Time to answer comments	5 days
	Posting for analysis of reviews – 2nd review by the client	3 days
	Released for work	1 day

Figure 6: Description of the activity flow in pull planning

ANALYSIS OF THE DOCUMENTATION LIST (PROJECTS, MANUALS, BILL OF MATERIALS, AND OTHERS) AND ALIGNMENT OF LOB

As mentioned in the chapter "The Lean Approach in Company X", during the diagnosis step, were conducted Long Term dynamics linked to the implementation of the Line of Balance. The objective was to use this tool as the Master Scheduling for the entire project, following the milestones already defined with the client. From the developed LOB, it was possible to map the Document List with all the services defined in this Master Planning. The focus was to identify each document, including projects, manuals, lists, and guidelines, needed for the execution of activities by production teams (Figure 7).

UFV PANATI - LIST OF GENERAL DOCUMENTS

GRE Code	Document Description	Code of Discipline	Designer Date (Supplie	New date - Action Plan 2 (Collaborative post'	Customer Comments	Designer Comments	Collaborative Status	First Issue	Current Date	Revision Number
PAN-PVG-CV-DWG-010	TERRAPLANAGEM - PLANTA PANATI 5	CIVIL	21/05/2023	26/05/2023			Liberado para Obra	26/05/2023	03/08/2023	01
PAN-PVG-CV-DWG-013	TERRAPLANAGEM - PANATI 6 SEÇÕES TRANSVERSAIS E LONGITUDINAIS	CIVIL	26/05/2023	31/05/2023			Liberado para Obra	31/05/2023	07/08/2023	00
PAN-PVG-CV-DWG-012	TERRAPLANAGEM - PLANTA PANATI 6	CIVIL	26/05/2023	31/05/2023			Liberado para Obra	31/05/2023	03/08/2023	01
PAN-PVG-EL-DWG-006	DETALHES CONSTRUTIVOS - TRAVESSIAS SUBTERRÂNEAS (PAN II)	ELÉTRICA	11/06/2023	16/06/2023	08/06/2023		Liberado para Obra	13/06/2023	02/10/2023	00
PAN-PVG-EL-DWG-009	DETALHES CONSTRUTIVOS - TRAVESSIAS SUBTERRÂNEAS (PAN III)	ELÉTRICA	16/06/2023	21/06/2023			Liberado para Obra	19/06/2023	04/10/2023	00
PAN-PVG-EL-DWG-011	DETALHES CONSTRUTIVOS - TRAVESSIAS SUBTERRÂNEAS (PAN IV)	ELÉTRICA	19/06/2023	24/06/2023			Liberado para Obra	26/06/2023	06/10/2023	00

Distribution of cuttings + Topography	Topographic Location	Stake Map
Staking Tracker + SI	Drilling, Jig, Concreting	-
BT Ditch + Solar	Ditch excavation	BT Traced plan BT Cable Desing Memory Constructions details – BT Ditch
	Terra cable launch	Ground plan
	Pile backfilling	Constructions details – Grounding mesh
	Launch of BT cable + Solar conduit + Backfill	BT Cutting Plan Cable List BT

Figure 7: Description of the flow of activities in pull planning

Assembly of the Pull Planning Board

A pull planning board was assembled, in which the horizontal axis represents the timeline in days or weeks, as required by the project. The vertical axis is composed of the different activities and their respective documents, which are arranged in the order in which they will be executed (Figure 8).

The definition of the axes is the starting point for visualizing the flow of subsequent steps. This definition establishes the level of detail of monitoring activities in short-term planning to be developed at the last stage of the process.

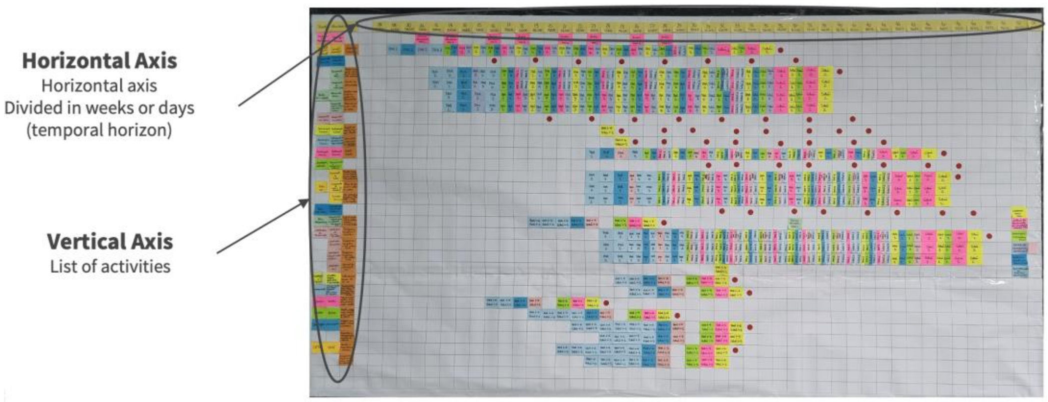

Figure 8: Pull planning board

Definition of Milestones and Process Flows per Activity

For each activity represented on the board, a delivery milestone was defined. In Project P, the milestone was validated according to the date defined in the document list. In Project M, the delivery was adjusted according to the production milestones defined by the balance sheet. It should be noted that, in this case, the unit of delivery of documentation was determined per sub-plot for most documents, as defined in the list of documents. The sub-plot unit is the same adopted in LOB planning, allowing for a better interface between the design and physical planning of the enterprise (Figure 9).

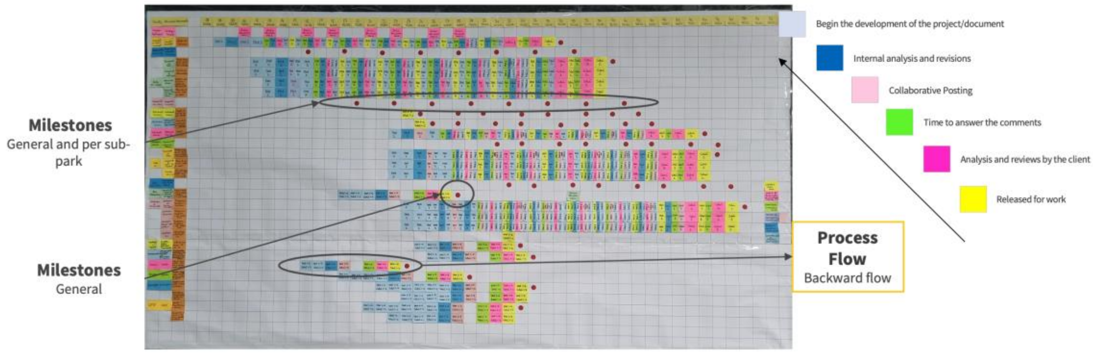

Figure 9: Pull planning board with process flow

Having defined the milestones, we determined the process flow in a backward manner, obeying the estimated delivery times of each stage. The process flow is the lined up colorful post-its that is signaled in Figure 9 as "Process Flow" and each post-it color represents a step of the process, as already explained in chapter "Definition of the flow of documentation release processes". This stage was developed collaboratively with the participation of the engineering sector coordinator, engineers, lean facilitator, planning manager, and lean consultant. With the completion of the process flow, the start date of the activity was determined, so as to meet contractual milestones.

STRUCTURING OF THE WEEKLY SCHEDULE

In the final stage, with the definition of long-term planning for engineering documentation, a weekly schedule was structured, taking into consideration the delivery times defined in each stage of the process (Figure 10).

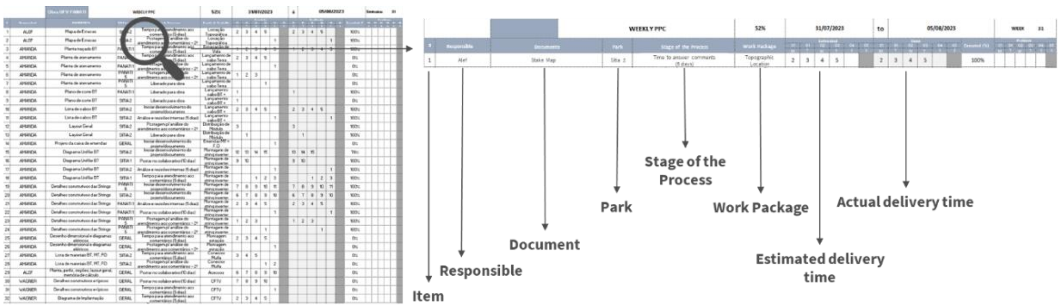

Figure 10: Process flow in the pull planning board

The definition of the weekly schedule allowed the engineering team to perform a short-term analysis for effective decision-making through percent plan complete (PPC) indicators, taking into account the completion of the activities scheduled for the week. In this case, the definitions that directly impact activity execution are communicated in advance to the leaders of the production team and the support team during medium-term planning.

IMPLICATIONS FOR PRACTITIONERS

Pull Planning is just the first step within the implementation of LPS as a routine in the Engineering area. As next steps, it is important that:

- Long Term: The document list and milestones of the Pull Planning continue to be aligned with the Line of Balance and the Master Scheduling;
- Medium Term: The activities developed in the Pull Planning are presented within the Lookahead routine to enable the analysis of constraints of these services by all sectors;

- Short Term: Execution of the Weekly Schedule, with the possibility of Check-in/Check-out, identifying problems for non-completion of the task, PPC and root cause analysis.

In Figure 11, you can see the PPC indicators of the Weekly Schedule of Project P. It is possible to identify that, as a pilot project, there is room for improvement, both in terms of adherence and in the concepts implemented.

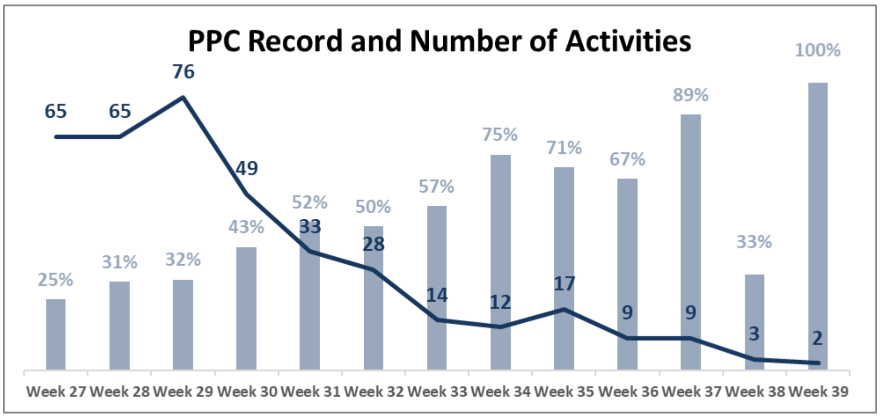

Figure 11: PPC record and number of activities from Project P from Weekly Schedule

CONCLUSIONS

Lean implementation in case study Company X effectively promoted LPS adoption and application of long, medium, and short-term tools. As already mentioned by Tsao et al. (2014) and Tsao and Tommelein (2004), the Pull planning sessions were successful in fostering collaboration and understanding among the entire team and we could understand that the prooseed tool and routine enable the better understanding and visualization of the whole project and the responsibilities considering the defined milestones. But, we could also identify that team members encountered challenges in utilizing pull planning as a management tool.

The proposed pull planning for design management provided the engineering team with greater clarity about the flow and time required for documentation, which directly influences production. Regarding the medium-term horizon, in both projects, teams had problems with anticipating constrains. The teams stopped reporting their delivery milestones in medium-term meetings, minimizing the visualization of constraints and bottlenecks for complying with the planned schedule. In the short-term management of Project M, there was insufficient compliance with the weekly schedule to produce noticeable results. In the case of Project P, the adherence was slightly higher. The planning team carried out the weekly monitoring tasks: the average PPC was 56%, and complementary data revealed an evolution of PPC as the volume of deliveries of the week reduced.

These findings revealed opportunities for improvement. A better connection of the Pull Planning for design management with the line of balance is an opportuninty. In this manner, it is possible to obtain project delivery milestones and use batches consistent with the work front attack plan. For more precise planning, it is advisable to conduct pull planning with the supply sector prior to the engineering sector, as discussed by Biotto et al. (2022). Therefore, the initial supply milestones may be used as the delivery date for the engineering pull planning. In this scenario, it is suggested that the list of documents be developed only after pull planning, to maintain the dates defined during planning.

In general, the Pull Planning for design management has great potential to align the expectations and needs of the various sectors of a project. Pull planning can generate collaborate|on and a better understanding of the demand and pace required by the client.

Additionally, it can function as a managerial tool for overseeing activities and to build a better connection between Engineering and Construction phases in EPC Projects.

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