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LEAN THINKING FOR A DIGITAL LAST PLANNER SYSTEM

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ABSTRACT

Lean Construction (LC) has emerged as a strategy to enhance productivity in the construction industry, with its effectiveness determined by how well its processes are implemented. However, its implementation is often obstructed by the traditional management hierarchy that dominates the industry and by a general lack of understanding of LC principles. This challenge is compounded by the partial adoption of lean processes on projects, which is further limited by the existing fragmented approaches and siloed management styles commonly found in the construction sector. The digitization of construction is recognized as a crucial factor in enhancing management and project delivery, as well as facilitating collaborative working practices. While digital technologies are vital, they alone are not enough to achieve the desired results; they must be integrated with lean thinking and a clearly defined production control system. This production control system relies on team collaboration, which is most effective when all stakeholders actively contribute and share their knowledge and plans. By using various digital tools, we can develop and improve effective lean production management systems throughout the project lifecycle. This approach allows for the creation of a centralized information management system, which is essential for supporting every aspect of the Last Planner System® (LPS). In this paper, we will explore a process for managing and enhancing the quality of a production control system using digital tools and lean thinking. Additionally, we will present a case study that illustrates how centrally managed information from the digital last planner system provided the project team with situational awareness. This awareness enabled the team to identify coordination challenges and respond quickly to implement improvements, enhancing construction delivery.

KEYWORDS

Lean Construction, Internet of Things, Production control.

INTRODUCTION

Construction projects, as bespoke projects, present unique challenges. The concurrent work on design and manufacturing, the geographical uniqueness, and the variety of project types, from new builds to regeneration or repurposing, all contribute to the complexity of the task. This has resulted in construction project delivery being hindered by inefficient design management and poor communication (Särkilahti et al. 2024). Where information flow is ineffective, this can create mistrust and poor team integration and communication (Tauriainen et al. 2016).This complexity arising from project teams comprising of interconnected stakeholders is

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exacerbated by the variability arising from internal processes (e.g., decision-making processes or production processes) and external factors including supply chain management and regulatory compliance. Understanding and managing project complexity is crucial for effective project planning (Tommelein et al. 2024).

LPS is a lean process delivery method that has been employed to improve project delivery. The implementation of the lean production philosophy in construction creates an additional demand for Performance Measurement Systems (PMS) (Maskell 1991). Performance measurement is crucial for managers, providing feedback that helps monitor company progress that can when used effectively boosts motivation and communication, and identifies potential issues (Kusrini et al. 2014; Sardana 2009).

Digitizing information management and integrating digital production management connects project workflows to improve quality, safety and productivity. Lean construction originated as a set of effective actions to specific problems in construction, that has evolved through the adoption and adaptation of methods and principles of lean production (Koskela et al. 2019). Stakeholder engagement is crucial to the success of any system, and the LPS relies on detailed look ahead plans that are refined in collaboration meetings with other stakeholders.

The digital platform approach allows the information to be sorted to provide clarity and improve communication that can assist situational awareness, this improves the decision-making process. Thus supporting the underlying principles of production, the effects of dependence and variation through supply and assembly chains (Howell 1999). This is a crucial point to supplement the processes that underscore LC, where the goal is to provide management the near real time information managing construction in short cycle times to apply continuous improvements to the overall project delivery.

This paper will explore this approach and present a case study that demonstrates how digital tools can support LPS. Researchers explain that case studies investigate complex phenomena in their natural settings to enhance our understanding of them (Yin 2009). The study will examine the monitoring of stakeholder engagement, which is essential for successful coordination meetings. The quality of Weekly Work Plans (WWP), and how they are developed directly from these meetings and managed in the field. How this process provides reliable feedback that can identify areas for improvement and enhance productivity throughout the project.

LITERATURE REVIEW

Construction management process addresses the effective planning, organisation, coordination, monitoring and reporting on the principle business of construction (Harris et al. 2020).The management process is focused on contract administration in order to achieve economic success and profitability for the enterprise concerned (Harris et al. 2020). Construction contracts are binding agreements developed to obligate participants to deliver a project (Willis and Alves 2019).

Traditional project management delivery struggles to manage the complexity of construction projects or cope with the variety of unforeseen situations that occur during the construction phase (Yiu and Cheung 2006). This can lead to conflict, the causes of which can be ambiguous contract terms, late material and equipment procurement, changed conditions, poor communication, under developed or late design and force majeure events (Harmon 2003). Existing production management techniques are not equipped to manage construction projects, the entrenched operational practices characterised by siloed mindset between key stakeholders present challenges in collaboration and knowledge sharing (Gordon et al. 2024). The use of LC can provide the improvements that traditional management processes are not achieving if implemented correctly. Some researchers emphasize that significant improvements in the LPS require a "holistic implementation" of the planning and control system. Hamzeh and Bergstrom

(2010) note that LPS is not a "stand-alone tool" and stress the need for a comprehensive implementation strategy for overall success.

Fujimoto (1999), states that learning and improvement are essential for the high performance of the Toyota Production System. Additionally, the importance of waste as a starting point for improvement in the TPS is well established (Hino 2024). In the conventional Western management model, technology is expected to deliver higher performance. Additionally, there is a reluctance to disclose and acknowledge failures, which hinders learning. (Brady 2014). Where lean management came from the Toyota Production System, a more project based production management paradigm was presented by (Koskela 1999). The 'TFV' theory of production in complementary ways, namely, as Transformation (T) of raw materials into standing structures, as a Flow(F) of the raw material and information through various production processes, and as Value (V) generation and creation for owners through the elimination of value loss (realized outcome versus best possible).

If we look at the lean construction process transforming design to an artifact, the method is scientific, where specification aligns with formulating a proposed plan, production corresponds to conducting a first run study, and inspection reflects the validation of the plan. Together, these three steps create a dynamic scientific process for acquiring knowledge now recognised as the plan-do-check-act cycle (PDCA) and is widely applied to quality functions and Lean production (Koskela et al. 2019). Countermeasures are developed through analysis of task deviations and corrections are examined using Plan-Do-Check-Act cycle.

Digital Production Control Methodology

To apply control in production, it will be necessary to understand the productivity of the project. Measurements are applied to activities to assist the understanding of productivity. Attempts to improve the productivity will be more successful where critical issues can be identified and methods to tackle them can be developed through a series of steps (Jagoda et al. 2013).

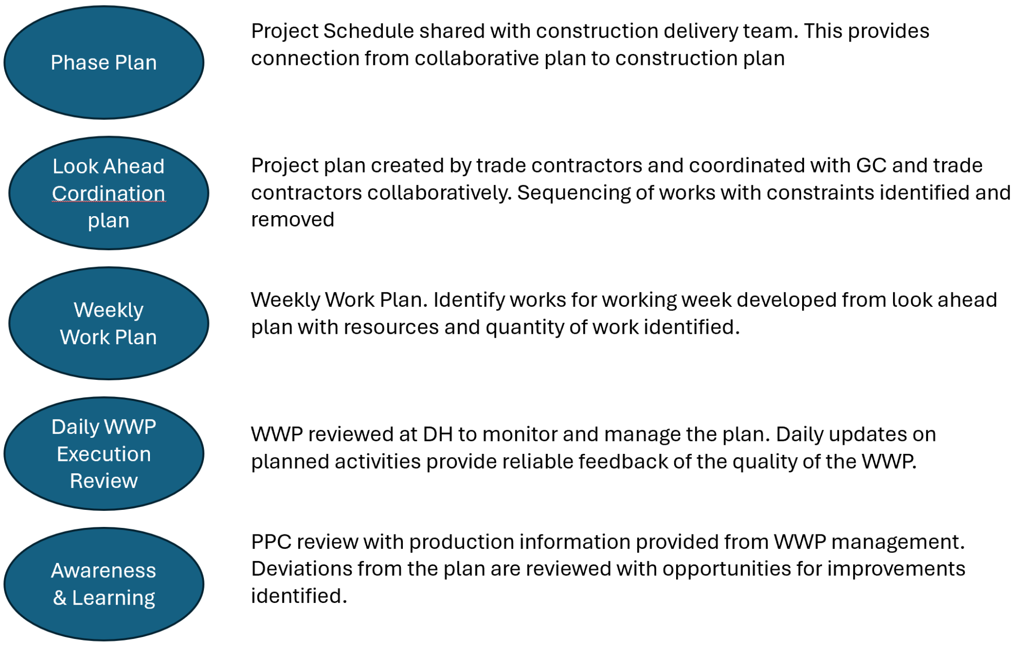

Figure 1: Last Planner system applied to production control for the project.

Working in a production system allows multiple stakeholders to plan in a process of transferring design information to assembly and sequential installation works that can be validated and quality approved. The LPS is a production control system that aligns with the PDCA dynamic control system. The Last Planner is called a "system" because it is structured to perform specific functions in order to accomplish the purpose of planning and control (Ballard and Tommelein 2021).

This system manages a project phase plan and develops a Weekly Work Plan (WWP) that is created directly from the phase plan. Creating the WWP from the phase plan is a critical step in this process. The effectiveness of the WWP is measured using the Planned Percent Complete (PPC) score (Ballard and Howell 2003). Regularly preparing and evaluating weekly work plans increases awareness among teams and can highlight opportunities for improving the construction process. The relationship between planning and executing the plan forms the foundation of the production control system. One of the most effective ways to manage WWP is to validate them during Daily Huddles (DH). When the information presented focuses solely on prepared WWP, any additions or omissions identified during the DH can be addressed and incorporated to enhance the development of the WWP. The DH is a brief collaborative meeting held each morning, involving interdependent groups that outline their planned activities for the day. Fuemana and Puolitaival 2013, describe the DH as a crucial component of production planning and control. During these meetings, prepared plans are referred to, allowing the team to manage, plan, and adjust production efforts to minimize waste.

Executing this part of the system has proven to be difficult. The unavailability of work plans and attendees' unfamiliarity with the weekly plan developed in the system have been shown to detract from its effectiveness(Gao et al. 2024)

DIGITAL LPS

The LPS is a construction-based lean system developed for the construction industry. Due to its unique feature of involving work crews in collaborative discussions, LPS is also referred to as collaborative planning in the UK (Daniel et al. 2017). There have been many studies of LPS—from what it is and its origins (Ballard 2000), to its principles, fundamentals, and how to use it effectively (McHugh et al. 2021). Studies have shown the positive impact of LPS on performance, and the barriers to implementing LPS (Perez and Ghosh 2018) have been extensively documented.

There are many case studies of LPS implementation globally, from countries like Ireland (McHugh et al. 2022a) to the continents of South America (Bortolazza et al. 2005), providing research material for practitioners to find a relevance to their local context. The term "Last Planner" specifically refers to those who are responsible for executing work tasks, particularly the project site delivery teams. These individuals need access to the system, which operates as a bottom-up process rather than imposing plans on construction workers. The system is organized in a tiered structure that includes master planning, phase planning, look-ahead planning, and, ultimately, weekly production activity management (McHugh et al. 2022b).

Implementing LPS will increase the understanding of the process and systematically create higher performing, more productive teams. It is important to understand that LPS is only one tool to assist the understanding of the production system where teams can continuously iterate more realistic plans resulting in more efficient delivery. In order for the system to lead to measurable performance improvement, the implementing organization must be committed to learning, changing, and focusing on people and philosophy and not only focusing on tools and methods (Liker 2020).

PERFORMANCE DASHBOARDS

Production control metrics should be considered when devising a production control system. Traditional production control metrics, such as cost and time deviation, which are strongly based on the thermostat model; in that context control means to meet a predefined standard by correcting deviations, without putting much effort into identifying and eliminating the root causes of these deviations (Koskela and Howell, 2002). By contrast, the metrics in a Lean

Production system should point out different types of problems and support a deep understanding of the main problems (Koskela and Howell, 2002).

Performance dashboards (PD) should include metrics on production system usage and relevant information that challenges teams, fostering creative tension for continuous improvement (Spear and Bowen, 1999). When designed effectively, these dashboards aid in enhancing performance and facilitating learning (Pavlov and Bourne, 2011). Improving system usage and project execution metrics leads to a more efficient production system. Near real-time feedback from the field provides clarity for teams, enabling quick assessment and rapid implementation of improvements.

CASE STUDY

BACKGROUND

The study was undertaken on a Data Centre construction project. The project consisted of the construction of 3No energy centres and associated administration and technical buildings. The first phase of the project was to construct Energy Centre 1 (EC01). This centre was constructed to house three No gas fuelled generator engines to supply the power for the campus. The construction of the building was time critical to house 3 pre ordered generator engines. Pre-Construction Works commenced in early 2024, with site works commencing in May 2024. The EC01 building had to be completed by the end of November 2024, to allow the engines to be installed.

INTRODUCTION

The case study was conducted over a 9-month period. This period starts with the initial stakeholder meeting where design and construction functions presented their plans to all stakeholders. This plan was developed to highlighting the key project milestone of the generator delivery which was scheduled 9 months from the meeting. This plan was mapped, and key challenges were identified. This plan was further developed used Visilean® cloud-based software that allowed the teams to coordinate and develop work plans. This provided clarity on the route and the key challenges had an action plan which was developed and managed through the LPS.

Figure 2: Day One Collaborative Planning Session

Design activities were linked to construction start dates and a design LPS systematically developed the design collaboratively between the design team and the project delivery team. This process reduced the negative cycle of technical submittals and design changes. The sequencing of works from enabling works such as existing service diversions and installing new infrastructure was undertaken in parallel.

Following the development of the plan, key time sensitive constraints were identified with action owner or owners identified. The day 1 plan was developed into a 6 week look ahead plan where key constraints were sequenced to be actioned. A series of workshops were developed with the key milestones identified (Start on Site date, Design release date, Procurement dates, health & Safety prerequisites, Regulatory body requirements)

The production process followed LPS where daily huddles, weekly work plans and PPC were used to measure performance. Deliverables were specific measurable and timebound. The team had access to each other and were able to develop relationships to achieve the share goals. Developing phase plans on a software platform allows all team members to collaborate. The transparency of working on a collaborative forum provides teams with a greater insight.

WWP Development and Management

The critical difference with preparing execution 'weekly work plans' from the phase plan defines one plan that is managed from inception to execution. The plans are developed and executed collaboratively. The benefit of developing the look ahead plans with the frontline workers allows each team to develop a working relationship with each other allowing greater team integration to manage project variability.

This means that plans can be adjusted at a site team level to suit project conditions while also ensuring that the tasks are relevant to the success of the project. These plans were developed and refined in weekly collaborative co-ordination meetings that reviewed look ahead plans and agreed the weekly work plan for the following week. The quality of these plans is maintained through DH's which will only refer to the created plans which prevents ad-hoc deviations.

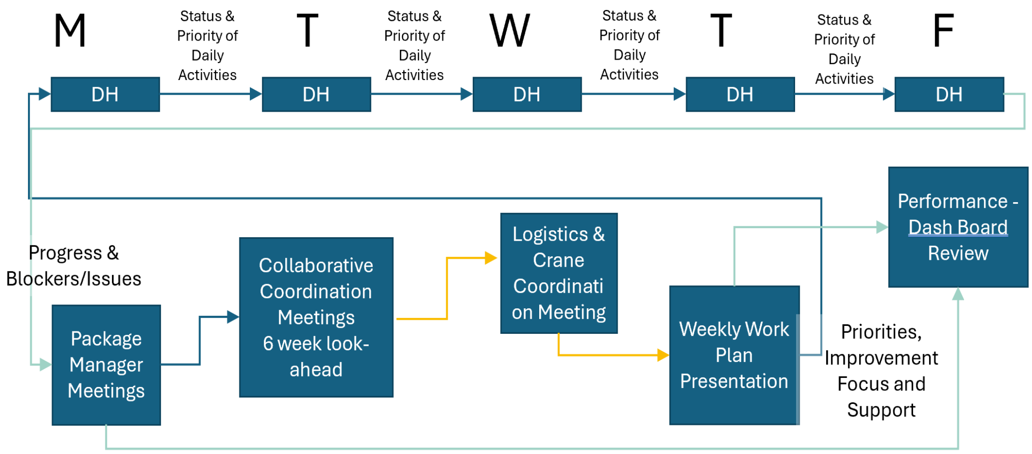

Figure 3: LPS Meeting structure.

Digital tools can support the management of the WWP. BIM based tools with 360° imaging technology can be used to support project communication. Working on the phase plan and developing WWP directly from this ensures the team are working collectively and reaffirming a shared goal. This allows the status of the plan to be communicated to the trades. This review process allows trades to monitor and update their plans, thus reinforcing the commitment process that is expected when developing the WWP.

Package Meetings

A package meeting is an individual principal contractor meeting with the trade contractor to understand a develop look ahead plans and understand the resources required to achieve the plan. This detailed plan is required before a collaborative planning session takes place. Understanding what each package can achieve allows for improved coordination and a greater understanding of interfaces and make ready needs in the collaborative meetings. Providing a structure for teams to develop their plans and highlight their make ready needs. This meeting provides the opportunity for trades to manage the resources that they require to complete their forecasted works. It highlights all prerequisite actions required to make the plans ready and constraint free.

AREA CO-ORDINATION 6 WEEK LOOK AHEAD MEETING

The main contractor has an opportunity to co-ordinate the work areas and review the developed work package weekly work plans. The trades have an opportunity to communicate their plans and highlight interfaces with others and outstanding constraints.

The project is divided into specific work area ‘swim lanes’ where teams can co-ordinate and communicate their plans. From this a coordinated weekly work plan can be developed that is committed and constraint free.

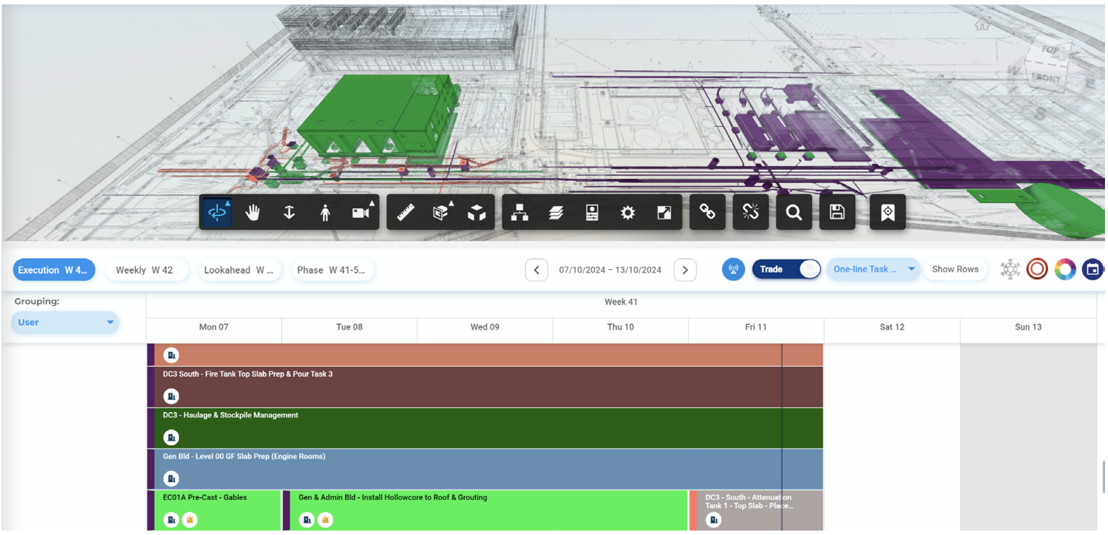

Figure 4: 4D project visualization

PRODUCTION ACTIVITY TRACKING

Developing WWP requires specific production information. The detailed information should quantify the task and identify the resources required to achieve the task. This provides the team with an understanding of the effort required to complete tasks. Any deviation from the task success can be recorded. It can be determined if it was internal or external influences that affected the task. Presentation and monitoring of WWP is crucial to the implementation of LPS. Digitization can help communicating and monitoring prepared WWP that can be supported by Reality Capture tools such as unmanned Airial Vehicles as shown in Figure 5.

The planned activities were taken from the phase plan and organized into a six-week look-ahead plan. Each activity was accurately described and time-bound, sized to realistic quantities that were measurable and achievable with the necessary identified preparations. These were then managed by the team from the WWP that was clearly outlined on a weekly basis.

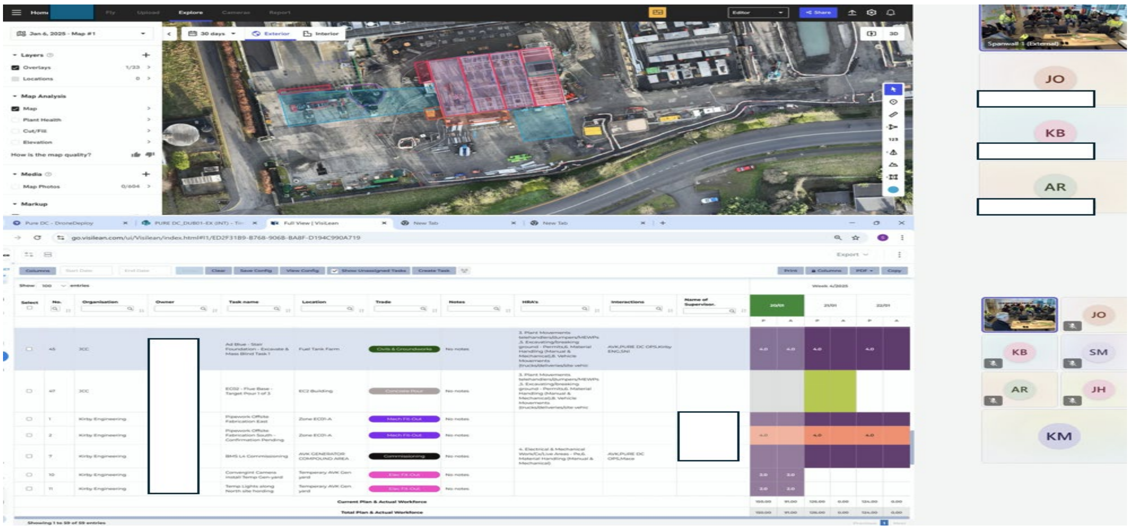

Figure 5: Digital Daily Huddles using reality capture.

Defining the activities in this way allows the teams to measure the performance of the planning process. This standardization made it easier to prepare performance dashboards. The tracking of the volume of activities produced by each trade and the quantity of make ready needs formed the basis for the production meetings. This level of detail allowed teams to communicate effectively and size and sequence their work. This was particularly important as they were multiple trades working in proximity with each other.

Project Dashboards

Project dashboards (PD) were developed to measure the effectiveness of the production system and the accuracy of the planned works. One of the biggest challenges in construction is to control production proactively rather than firefight when problems occur. The PD highlighted deviations for the plan and expected quantities of resources and productivity. It was important to structure the information that we gathered within a common data environment (CDE) to ensure that that the information can be organised by work package and project location. All design, production, and Quality activities were catalogued to allow PD to be built to relate to programme and commercial functions for project reporting.

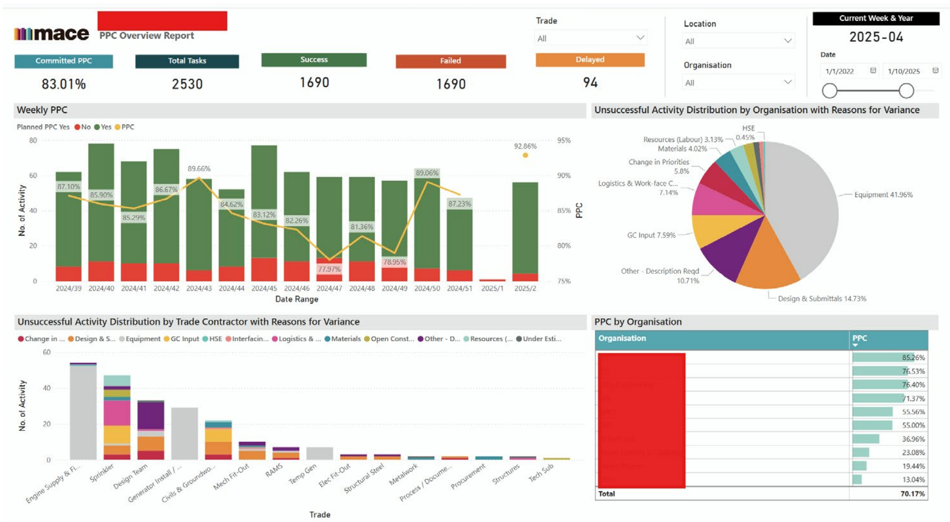

Figure 6: Project Performance (PPC) dashboard.

Utilizing Power BI® project data to create a PD allows for near real-time updates, significantly enhancing the quality of the information available. The design of these dashboards effectively presents the essential data required for managing the production control system.

By emphasizing performance in specific areas, teams can focus their efforts on improvements and accurately identify the root causes of any deviations from the established plan. These issues are discussed during collaboration meetings, enabling the team to develop a robust improvement plan.

The primary aim of the PD in the production system is to identify opportunities for enhancement. By highlighting these areas, project teams can concentrate on continuous improvement, eliminate waste, and prioritize value creation.

LEAN THINKING

The production control system's effectiveness was demonstrated through the monitoring of information quality and quantity. A collaborative approach was essential, as new disciplines were invited to participate in project production meetings six weeks before physical work began. This proactive engagement fostered relationships with contractors and helped teams familiarize themselves with the software and expected information quality.

The process identified several opportunities for improvement. Key bottlenecks within the production system were observed and addressed through design modifications. The flow of work was hindered by the high volume of activities and the cramped layout of the facility. This revealed an opportunity for enhancement, which was recognised by collecting production data and constructively challenging the existing processes.

The effectiveness of the production control system was that both the process with the quality and the quantity of information provided was visible and audited. This meant that participation in the system improved through collaboration as information needed to support the meeting structure was available at all levels. As the project developed, new disciplines were added to VisiLean® and invited to the project production meetings six weeks before they started physical work on the project. This was important as it reinforced a relationship with the other contractors and helped the new teams familiarise themselves with the software and the quality of information expected from each other in the meeting.

Building relationships is essential in a lean production system. A common collaboration platform helped teams identify interfaces and understand each other's work plans. Utilizing Building Information Modeling (BIM) and reality capture improved clarity in production meetings, highlighting bottlenecks and allowing for prioritization of time-sensitive tasks. This understanding enabled the team to collectively enhance production efficiency.

FINDINGS

The implementation process was introduced early in the construction phase to include planning of engineering and procurement processes. This improved collaboration between design, quality and construction teams was significant. The teams collaborated to redesign elements of works to remove identified construction bottlenecks. The improved collaboration between design and construction teams allowed the development of construction improvements that will further increase productivity.

Through the co-ordination meeting and intensive planning, the construction plan was modified so that the project team could deviate from the plan at short notice and achieve the target engine install date. Key amongst these was the decision to construct the internal floor slabs in parallel with the roof slabs. This involved amending the roof prop design and organising works on site so both items could safely proceed shown in Figure 7.

Figure 7: Modified Construction Sequence

The implementation of working the Floor Slab & Roof Slab in parallel allowed the target to be achieved, and provided some float whereby the works to allow engine install were complete two weeks early. This method provided a safer and more ergonomic placement of concrete. Further review of the plan for a subsequent identical building has resulted in a design change to the sub structure foundations, namely the introduction of a dwarf wall to act as a shutter and allow the floor slabs to be constructed with the Engine Plinth thereby eliminating the roof / floor slab interface entirely.

DISCUSSION AND CONCLUSION

There is a strong emphasis on the correct use of lean tools and processes aimed at achieving productivity improvements. One of the main shortcomings of LPS has been the practical challenge of getting teams to build trust and collaborate with each other. A constant need to reconcile production data with short term plans is another major hurdle to LPS implementation. The case study highlighted that through effective utilisation of digital LPS platforms such hurdles can be overcome. The case study highlights that information collected digitally and presented clearly can lead to better understanding of production sequences and volumes by teams.

Another major finding of the case study was the use of visual production techniques (integrated LPS and BIM) and near real time dashboards, as this allowed managers to control production proactively. A key limitation of LPS can be the availability of production information during short term planning meetings as well daily huddles. It is evident that digital LPS tools are being adopted widely, and the case study also presented a way to standardise their implementation by demonstrating a repeatable, structured implementation method.

The digital construction field is rapidly developing with research emerging in reality capture, artificial intelligence and sensor-based technologies. Its interactions with Lean Construction and how it can be synergistic for effective production control should be explored. These improvements need input from all project stakeholders, and digital information can offer valuable insights for implementing these enhancements. By effectively incorporating IoT technology and managing information properly, further exploration in this area is essential.

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