

Decision Framework for HVAC Installation Work Package Readiness and Lean Production Control: A Worked Example

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ABSTRACT

The installation of the HVAC equipment relies on a number of factors, including availability of approved designs, compatibility of the dimensions, availability of fabricated materials, the availability of crew access to the site, the availability of the work that needs to be done before the installation, the availability of the crew, and the inspection parameters. The weekly plan may thus include a scheduled installation task that cannot be performed. This conceptual study is designed to suggest a framework to evaluate the readiness of a mechanical work package prior to its deployment to an installation crew. Eight evidence-based gate domains are aggregated into a binary release decision rule, and the rest of the constraints get owners and are pushed to a look-ahead register. The framework separates package readiness from weekly commitment reliability and quantifies separately first pass inspection yield, waiting, rework and accepted output. These measures are explained using an example HVAC zone. These measures are illustrated with an example HVAC zone, which includes a demonstration of how changes to the commitment denominator can affect the reported performance. The example shows how the framework works but does not make a productivity claim or identify waste in an identified project. It needs to be tested in the practice of mechanical installation to determine its effectiveness, which requires the corresponding test of the package-level records, verified geometric tolerances, labor hours, and inspection results.

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1. Introduction

Heating, Ventilation and Air Conditioning (HVAC) installation is one of the major elements in building construction that influences the environmental quality of a building, energy performance, comfort level, safety of the building, and timely building commissioning. The HVAC work undertaken is also highly reliant on the Architectural and Structural work undertaken, Electrical, Plumbing and Fire-protection work, Controls work, and Finishing. Even if the drawings are complete, equipment is not in place, access is blocked, work is not finished, permits are pending, or there is no equipment or labor, an HVAC crew would not operate efficiently. This leads to waiting time, rework, interruption in workflow, and poor work productivity. It is therefore crucial that an HVAC installation work package has a structured readiness-based decision framework to decide when it can be released to the field and when it can be

kept off until its constraints have been removed (Mossman, 2005; Wambeke et al., 2012). A work package is the smallest piece of work, as practically possible, which can be planned, assigned, implemented, measured, and controlled. It usually sets clear boundaries, a timeline, a team with clear roles, materials and equipment, drawings, quality requirements, and what will be delivered. Advanced Work Packaging (AWP) is a process of developing installation work packages from Larger Construction Work Packages and developing them in the field with limited time. They are intended to cover all the equipment a crew might require to complete a particular task safely, efficiently, and to the appropriate quality standard. A work package for an HVAC project could include ductwork, chilled-water pipe, and air-handling-unit installation, duct insulation, terminal device installation, and air-handling-unit controls wiring, testing, balancing, and/or commissioning preparation. The primary criterion for the work packages is that the work should not be released simply because it is scheduled. Instead, it is only to be released when it can be carried out without any foreseeable disruption. The acceptable and accepted drawings, materials, tools and lifting devices, trained and skilled individuals, safe site access, previous activity, permits, inspections, and quality control are all part of a viable HVAC installation package. All of these issues can lead to delays in package release, locating lost parts, back-and-forth work, or prematurely giving up on a part. The delay reduces the reliability of the plan and often makes the plan more cumbersome and difficult.

Lean production control is a useful management philosophy for these challenges. The aim of lean construction is to generate more value and reduce waste – waste of waiting time, waste of unnecessary movement, waste of unnecessary inventory, waste of rework, overproduction, and underused labour. Lean production control is not just about push scheduling, but it is about pull scheduling as well. (Love et al., 2003). Push scheduling is the approach used in old fashioned production planning/scheduling methods, which means that activities are scheduled in accordance with a master schedule irrespective of the field conditions. Pull system: Work is picked up and released according to the actual needs downstream, the ability of the crew, and confirmed readiness. This method helps to keep the work flowing by making sure crews are only turned to work what they can do within their schedules. The Last Planner System (LPS) is especially applicable to HVAC work-package control, as it turns long-term project schedules into short-term production commitments. Lean planning principles include screening planned assignments for constraints, eliminating constraints before they become a problem, only taking in quality assignments, and assessing the percentage of planned activities completed as promised. In the case of HVAC installations, this would involve running the package through a look-ahead process in order to verify the availability of the drawings, delivery of materials, access to work fronts, coordination clearance, readiness of equipment, safety conditions, and inspection requirements. If these conditions are not met, the activity should not be scheduled to be installed at this time but should be kept in the look-ahead plan for later.

The worked example is helpful as an example of how the decision framework is implemented in a real HVAC installation scenario. Think about installing supply air ductwork and variable-air-volume terminals in a floor of a commercial building. The project team needs to ensure that coordinated mechanical drawings have been issued, the delivery of duct sections and hangers, the availability of ceiling space, completion of structural supports, resolution of the clash between the electrical system, fire protection system, and the mechanical system, the availability of lifting equipment, and the labor capacity of the HVAC team have been coordinated before the release. Once all materials, access, and coordination approvals are verified, the package is released as ready. If the ceiling area is still not clear because of another trade or because there is no required duct fitting, the package should be denied, and the constraint should be documented and ownership of the constraint resolution given to either party (Bertelsen & Koskela, 2002; Koskela et al., 2002). When combined with lean production control, readiness gates can enhance project predictability and resource utilization. The construction studies of pull control reveal a need to filter pending work packages by readiness before assigning them to the crews, and to prioritize work packages in real time based on available trade capacity. This is an excellent way of decreasing the risk of having high cost crews idle or wait on a work front that is not ready for the specialist labor that is necessary. It also fosters greater collaboration among mechanical, electrical and plumbing, structural and finishing trades — a critical component in tight building environments.

Originating in the 1950s with the Toyota Motor Company, the Toyota Production System (TPS) established the foundational principles of Lean Production through its dual pillars of Just-In-Time (JIT) workflow and smart automation, or autonomation, as described by the Construction Industry Institute (CII) (2005) as shown in more detail in the Figure, (1). Researchers subsequently coined the term "lean" to emphasize the system's stark contrast to traditional mass or craft manufacturing, specifically highlighting its rigorous focus on waste eradication (Womack et al., 1990).

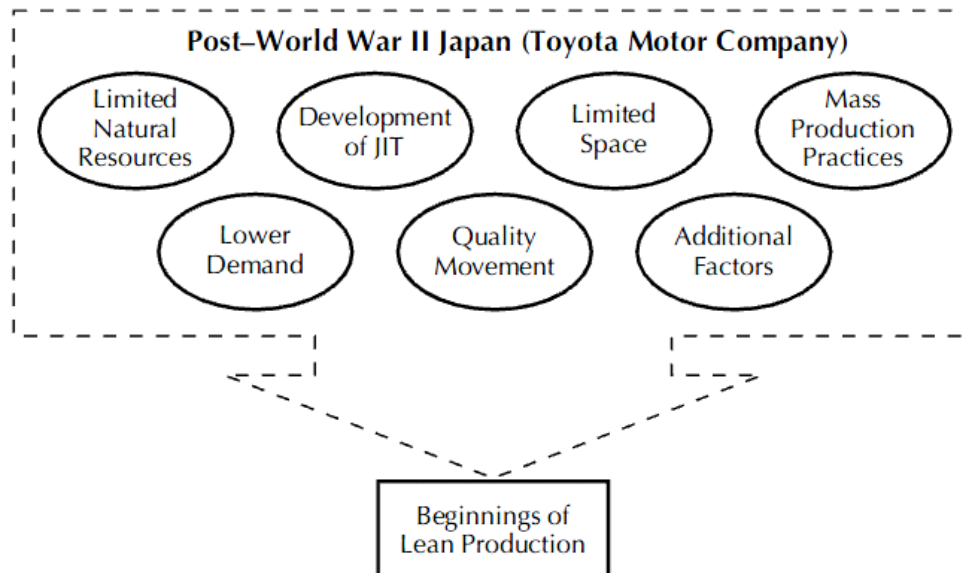


Figure 1: Lean Production Beginning

The start of lean production is shown in Figure 1. In Figure 1, lean production begins. This emerging philosophy was strongly influenced by Total Quality Management, which took a number of fundamental objectives to eliminate non-value-adding elements to maximize customer value, to make sure that the operational flow is continuous and reliable, by distributing decision-making, and to continuously pursue perfection to meet customer requirements with complete precision and minimum stocks. This model began to become widespread in the main manufacturing industries of both the USA and Europe by the early 1990s, and it later spread into a variety of other areas, including administration and customized services. This change in manufacturing concepts was brought to the construction industry by Koskela (1992), who gave birth to the TFV (Transformation, Flow and Value generation) theory. This three-part system gave birth to a new discipline, Lean Construction, which is fundamentally different from traditional project management because it simultaneously integrates the design of the product and the design of the production process with continuous lifecycle production control to ensure the best overall project performance. The effective implementation of construction in this lean way requires a very profound understanding of production physics, especially how the supply chain is dependent and the different operating conditions, as well as a continuous process of planning and control, where planning and control are no longer a final step, but part of a strategy formulation process. Building on this theory, the focus of this research is on the core methods and stages of lean construction to systematically reduce waste produced in the construction industry. In the context of the above, the Last Planner System (LPS) is a principle lean application that has proven to be very successful in improving the management of projects, smoothing out the project flow and reducing stress levels for the people involved. The construction and application of a decision model in the readiness of work packages for the installation of HVAC systems in a lean production-control environment are therefore emphasized. The framework is designed to determine if a work package is ready to be executed, to determine what the constraints are that prevent it from being ready, to assign accountability for eliminating the constraints, and to enable timely delivery of good-quality work packages to HVAC crews.

2. Research Background

Lean production principles have been introduced in the construction industry to enhance productivity, minimize waste, and achieve more consistent project delivery. Researchers have previously found that resource deficiency, limited information, lack of coordination, and unresolved site constraints are significant issues in construction projects. Installations are especially challenging in the HVAC industry because there are a number of different materials, craftsmen, activities, and equipment that need to be synchronized with structural, electrical, plumbing, and architectural projects. The research of construction management suggests that it is possible to minimize waiting time, rework, material shortages, and interruptions in the workflow of the production process through improving the coordination and organization of the construction process (Construction Industry Institute (CII), 2007). These challenges can be amplified in HVAC installations when work spaces are not set up, or when information and materials are not available. Lean construction research suggests that systematic planning and identification of constraints early

in a construction project can help a construction team avoid the resulting waste, instead of reacting to the problem post-construction. The Last Planner System has been extensively researched as a method for increasing reliability in construction planning. Studies reveal that the Last Planner System should not just outline what should be done, or when it should be done, but also what can actually be done based on the existing conditions at the site at the time of planning. Research has shown that it is crucial to prepare work before putting it into production. This concept is very applicable to HVAC installations, as a scheduled activity may be inexecutable if drawings are not complete, materials have not yet arrived, access is limited, or expected activities have not yet been finished. Similar findings have also been observed in previous research studies that activities related to HVAC installation are closely related to other building systems, and therefore, strong coordination is needed for this process. Depending on the completion of structural, electrical, architectural, mechanical, and other works, installation of the ductwork, piping, equipment placement, insulation, testing, balancing, and commissioning may be dependent. The results of the research show that a lack of coordination between these activities can cause out-of-sequence work, increased labor hours, rework, and a disruption in the schedule (AlSehaimi & Koskela, 2008). Thus, assessing the readiness of HVAC work packages before releasing them can offer a practical way of mitigating these issues. Several studies have suggested implementing readiness assessment methods that combine multiple conditions and not a single one. Prerequisites and conditions that are important include design approval, material availability, labor availability, equipment readiness, site access, prerequisites being complete, safety requirements, coordination with other trades, etc. The literature shows that a multi-criteria approach offers a more realistic judgment of the readiness of a construction operation for execution. This can also be used to determine which constraint is blocking the release of a work package. Digital construction technologies have also increased opportunities for enhanced production control (Shewchuk & Guo, 2012). There has been recent research that has looked at how to use Building Information Modeling (BIM), digital schedules, mobile applications, and construction information systems to provide better access to project information. These technologies can offer up-to-date drawing, material, progress, and tradesmen coordination information. Yet, previous research highlights the importance of digital information when linked to decision-making processes. A readiness framework can then transform project information into measurable assessed readiness to start an HVAC work package. The use of simulation and decision-support techniques has also been an important focus of research in the field of construction management (Guo, 2009; Sacks & Goldin, 2007). Such techniques enable project teams to analyze the various conditions, to uncover the constraints, and to evaluate potential production-control decisions prior to their execution. Previous studies have shown that worked examples can be helpful when theoretical criteria are demonstrated through their use in real construction situations. In the case of HVAC installation, a worked example would be used to show how a work package is evaluated against the readiness criteria, and how the final release can be made.

Despite the integration of sophisticated technologies over the last four decades, the construction industry continues to struggle with chronic inefficiency and stagnating productivity levels. This global trend is evidenced by declining labor productivity in the United States since the mid-1960s and a notable reduction in Yen per man-hour in Japan between 1990 and 2004 (Teicholz, 2004). The limited capacity of current technological advances to simultaneously lower architectural and building costs while offering efficient process management is one of the main problems behind this lack of progress. As a result, Computer-Aided Design (CAD) accelerates drawing development, it does not prevent potential design errors that could facilitate costly corrections and hinder optimization of management (Li & Love, 1998; Love et al., 2000). This problem is particularly pertinent to the Design-Build (D/B) method, where the absence of technology support in terms of integration hinders the promised benefits in terms of improved quality and lower costs through increased constructability (Green, 1999). In 1993, the International Group for Lean Construction embraced lean construction, as noted by (Howell & Ballard, 1998; Koskela, 1997), and it has since gained traction within the industry with the aim of delivering maximum value to consumers while minimizing waste. Conte and Gransberg (2001) conducted successful empirical studies in Brazil, and Saradara et al. (2024) have also contributed to this emerging approach. Researchers have emphasized that alignment between contractors and subcontractors (Miller et al., 2002), consistency in processes (Thomas et al., 2002; Thomas et al., 2003), and the stability of material flows (Bashford et al., 2005; Thomas et al., 2003) are essential for this process development. Utilizing advanced simulation and modeling techniques, like the LEAPCON model for high-rise residential developments (Sacks et al., 2007) and BIM-integrated lean methodologies (Sacks, Radosavljevic, et al., 2010), research indicates that a comprehensive application of the lean process can lead to significant enhancements in performance (Al-Sudairi et al., 1999; Mao & Zhang, 2008). Furthermore, these sophisticated technologies have shifted the concept of lean project management, redefining the role of a project manager as a client-focused leader who acts as a mediator in communication (Gabriel, 1997). Practical field evaluations of tools like the Last Planner System, huddle meetings, and increased visualization have shown significant promise in medium-sized firms (Salem et al., 2005; Salem et al., 2006; Song & Liang, 2011), although challenges in implementing 5S and fail-safe quality systems suggest a critical

need for behavioral shifts and specialized training. Emerging research continues to expand these boundaries by integrating industrial engineering work measurements (Agbulos et al., 2006), developing vertically integrated scheduling systems (Song & Liang, 2011), managing design via "last responsible moment" decision-making (Deshpande et al., 2012), and utilizing algorithmic approaches to optimize material handling and flow in residential construction.

3. Research Objectives

From a general perspective, the literature reviewed confirms that lean production control, constraint removal, information availability, availability of resources, and coordination have been found to contribute to the improvement of construction workflow. The literature also shows that these factors are not incorporated into a practical framework for decision-making related to readiness for the HVAC installation work package. Existing approaches focus on general construction planning and lean production or on single readiness conditions but not on multiple readiness conditions in one decision process. Thus, this work presents a structured process to evaluate HVAC work packages with multiple readiness criteria and applies the process to a worked example. The approach is meant to complement previous constraint identification, better coordination, less waiting and rework, and a better HVAC installation flow.

4. Lean Journey

The successful positioning of Lean construction methodologies is essentially anchored in unwavering leadership buy-in, which helps as the primary substance for founding a pervasive organizational culture centered on perpetual development. The project teams may achieve significant improvements in the areas of defense, high-quality monitoring, and general performance of utilized resources if these fundamental principles are correctly integrated into functional operations. The dynamic structural enablers, as well as targeted changes, are induced by strategic optimizations at the process and leadership levels. As can be seen in Figure (2), this top-down integration enhances the direct effectiveness of project-specific operations and ensures the sustainability and maintainability of performance gains in the long run. (Ballard et al., 2007).

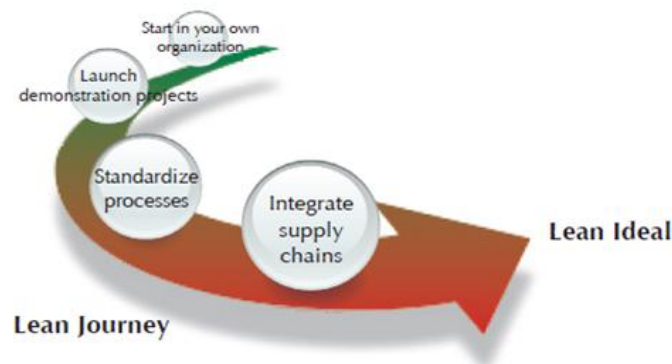


Figure 2: A Framework for Systematic Implementation

Looking for the lean ideal in construction is about the constant delivery of a customized product that also easily fits its purpose, is instantly arranged, and waste is totally removed from all downstream operations. To make this vision a reality, organizations will need to approve a strategy that is whole-product and starts with the choice of supply chain partners who are willing to adopt lean methods, and the creation of flexible organizational structures that favor financial moves on the basis of the best overall project return. It is a systemic approach which demands a very strict alignment of project scope, budget and preparation, as well as a proactive commitment to the improvement and development of construction techniques. In the design and production stages, professionalism is ensured through the evaluation of explicit alternatives based on clearly formulated criteria and the application of production controls based on lean theory to ensure the interweaving of Safety and Quality in the project's life cycle. In addition, the application of Just-In-Time (JIT) protocols which are activated by actual site petition, detailed assessments of material transformation, and the use of sophisticated computer modelling to combine product and process design plays a part in driving efficiency. On a basic level, workplace discipline is improved by introducing the 5S system (Sorting, Organizing, Preserving, Standardizing, Satisfying), which involves identifying and removing all the elements that are not essential in the workplace, and introducing Value Stream Mapping to visualize and improve all the elements of the procedure. These together act as a strong approach to achieving better project outcomes if they are implemented

in a way that is well-structured according to project requirements and after a thorough pre-project planning session.

5. Construction Wastes

The construction industry is a systemically inefficient industry at present, manifesting as pervasive delays and major cost overruns, all of which are driven by suboptimal construction management practices. Due to the common nature of these practical issues, it is imperative to rethink conventional operative techniques and move forward with stronger solution-driven management approaches. To describe these deficiencies, researchers such as (Koskela, 1992) call for a transition to contemporary production philosophies rooted in performance measures like value generation, cycle time, and the reduction of erraticism and waste. The empirical evidence is clear - it states that rework accounts for almost 30% of construction and that labor effectiveness is often as low as 40% and as high as 60%. In addition, material waste and safety-related incidents generate other financial issues, typically 10% of the total project value and 3-6% of the total project value, respectively. In the Australian construction industry, these poor performances also occur, with rework taking up to 35% of project budgets and half of cost overproductions, making rework one of the fundamental challenges to national productivity. Although it is difficult to calculate the non-value-added activities throughout the industry, several international studies have validated that waste amounts to an unnecessarily high proportion of production costs. Solving these productivity gaps demands a direction of change that is closer to a waste-based measure of productivity, a move that offers a more accurate picture of the cost of operation as well as gives the workforce a more meaningful way to understand and reflect on the data and, more importantly, to have a say in how it is managed: the comparative analysis of time waste in industrial versus construction is shown in Figure 3.

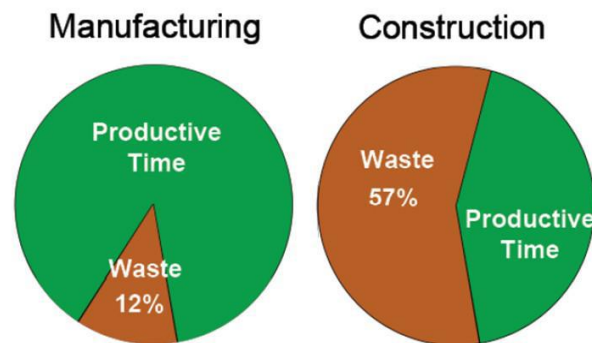


Figure 3: A Statistical Breakdown of Production Time Losses

In Lean Construction, waste is really redefined by ALARCÓN (1997), as being any use of any resource, material, equipment or labour, that is not the absolute minimum that would need to be used to produce value for the client. This view requires the demarcation of value-adding activities, which add value to the information and materials used to satisfy the project's requirements, and non-value-adding activities, which waste time, space or capital (ALARCÓN, 1997). The industry is traditionally preoccupied with physical material waste because it is more easily measurable, but tangible waste is also a result of deeper management flaws that drive waste, as argued by Formoso et al. (2002). This oversight is essential since construction waste can be presented in environmental aspects, such as the ecological effects of landfills, or in economic aspects, where it stems from preventable procedural mistakes, resulting in substantial economic losses (Formoso et al., 1999). These unproductive inefficiencies were identified by Koskela (1992) by using indicators such as poor constructability, poor safety, and non-productive time; and by Formoso et al. (1999) who created a comprehensive taxonomy of nine waste categories: overproduction (creating more than is immediately needed), substitution (using over-qualified resources), waiting (idle time from poor synchronization), transportation (unnecessary movement of goods), processing (inherent technological inefficiencies), inventory (excessive stock leading to capital tie-up), movement (inefficient human ergonomics), production of defects (resulting in rework), and external factors (such as weather and theft). ALARCÓN (1997) also distinguishes between three operational clusters of controllable causes of these wastes: flow-related problems (shortage of resources or information), conversion-related problems (defects in the conversion methods or poor planning), and management-related problems (ineffective decision-making or supervision). As a result, the complete performance of a project must be taken into account, including but not limited to the project's cost and schedule. For a detailed modeling approach, seven parameters must be considered, which are efficiency, effectiveness, quality excellence, productivity, standard of work life, capacity for innovation, and financial profitability.

6. Lean Thinking Principles

There are 5 important parameters that should be implemented, and they help lean be successful, and their goal is to improve functional performance and provide exceptional value. The first step is the exact definition of value, which involves defining excellence in terms of the client's point of view, and separating value-adding activities from those that are not value-adding. The second phase is to identify and map the value stream and to systematically remove all wastes within a value stream: overproduction, unnecessary material transport, excessive inventory, unnecessary motion, and defects; but still allow the departmental authority to stop the production process immediately if there are inconsistencies. The third principle builds on this and emphasizes the need to establish a seamless, continuous supply chain, with the intent of moving management away from the end product and towards the integrity of the supply chain. The fourth principle is the use of a "pull" system, a "Just-In-Time" (JIT) approach, which ensures that production is based on what the customer needs rather than on forecasts, thus enabling greater agility in meeting the client's request for change. Last, the framework is constantly evolving toward perfection, with every detail of the product produced under tight quality controls and all stakeholders, management, and workers kept in the loop on this process. Practically applied with the use of some site-based lean tools, examples of which are categorized and summarized in Fig. 4.

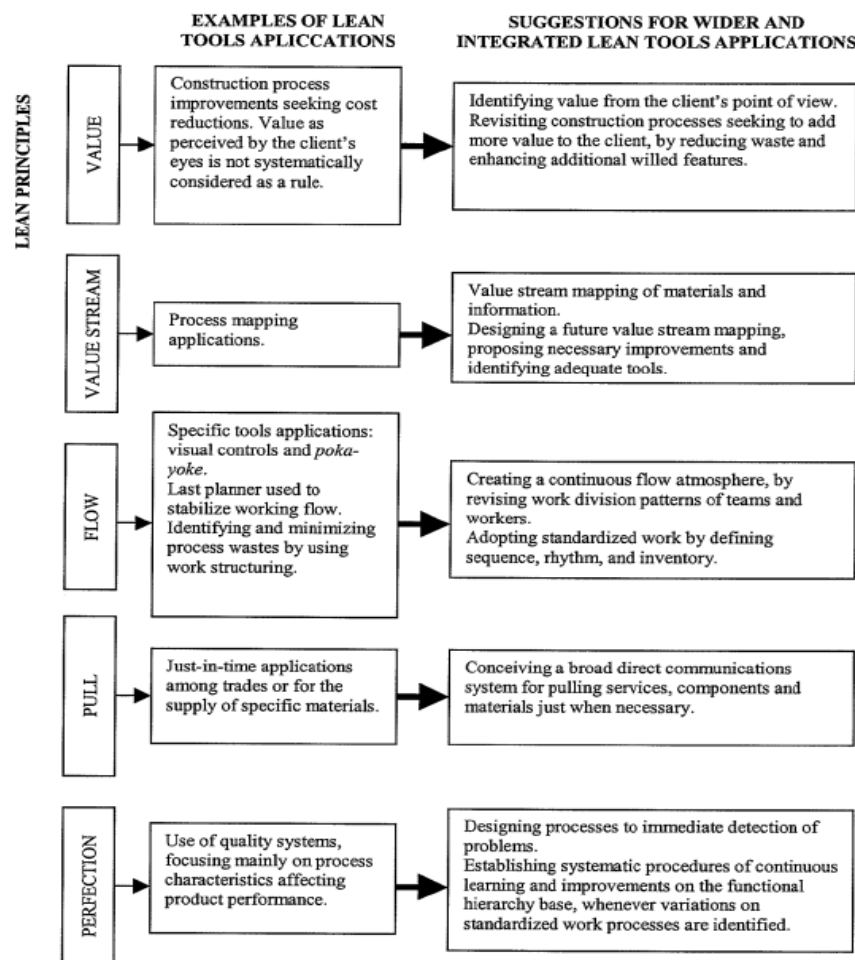


Figure 4: Lean Construction: Strategic Implementation and Best Practices (Picchi & Granja, 2004)

In 1992, Koskela developed the basic 11 principles for the main organization of Lean construction; the critical factor for improving the efficiency of manufacturing processes is, thus, to reduce the non-value-adding operations (commonly called waste) and at the same time increase the value added in the final product by satisfying the needs and preferences of the client (Koskela, 1992). This two-complexed approach both optimizes the workflow and helps address process variability, shorten cycle times and eliminate redundant steps, components or dependencies that can complicate complex manufacturing processes. This will result in a highly optimized manufacturing system which is very flexible to changes in market trends. It should also be noted that maintaining all these will require the development of a sound process control system, which would foster high levels of transparency throughout the manufacturing

process. Not only does this allow better management of resources, but it also makes the entire manufacturing process more flexible. In essence, this entire strategy of reducing waste and meeting the needs of the clients can bring about great innovations (Ballard et al., 2007).

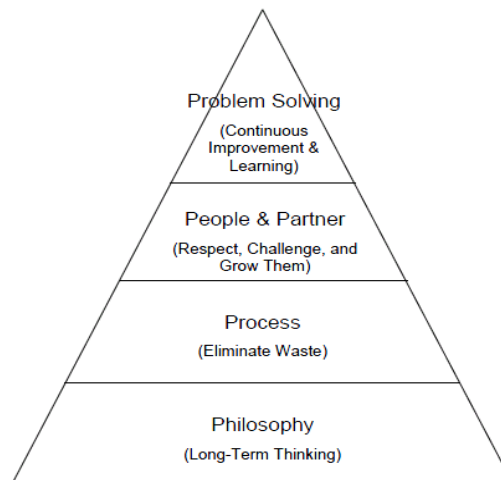


Figure 5: "4P" of the Lean Way

Lean methodology consists of 14 basic principles that can form a network for combining long-term goals with functional performance and development by transferring organizational culture. This method emphasizes sustainability and a long-term perspective rather than immediate financial profits. It also creates a structure in which pull systems can be adopted to mitigate the dangers of overproduction, while continuous flow processes help identify concealed inefficiencies. The companies can implement task standardization to empower their workforce and foster ongoing improvement by balancing workloads and cultivating an environment where stop-the-line protocols can contribute to building a cohesive quality system. The main features of this change would be the development of leaders and exceptional teams who embody the corporate philosophy and who are committed to showing respect while also challenging external partners in order that they may develop together. Finally, as a result of practicing genchi genbutsu, that is, obtaining an understanding through direct observation of situations and then reaching a decision as a result of a consensus-building process, which promotes strategic planning and rapid implementation, the company becomes a learning organization based on continuous reflection and improvement.

7. Lean Construction Techniques

Lean Construction is a paradigm shift from the "Transformation-Flow-Value" (TFV) theory, which was fundamental to the topic, to a broader paradigm that focuses on optimization of the flow of work and maximization of the value to stakeholders by systematically removing non-value-added activities (NVA) (Koskela, 1997; Koskela et al., 2002). This methodology brings the principles of lean production to the construction industry in order to improve reliability, speed up cycle times, and decrease variability for overall increased productivity. Lean's implementation is based on a continuous improvement culture, pull-based production control, and synchronized flow of material and information, and it is a set of integrated techniques that reduce the risk of the project (Paez et al., 2005). One way this is promoted through Concurrent Engineering is by having multidisciplinary teams perform tasks simultaneously and using network analysis methods, such as CPM and PERT, to overlap activities and reduce transfer times, and to involve subcontractors in the design phase. The use of look-ahead schedules (usually 2 to 6 weeks) to protect the downstream work from uncertainty upstream, and to ensure tasks are only added to production when all constraints have been lifted, is complemented by the Last Planner System (LPS) (Mossman, 2005). Daily Huddle Meetings ensure real-time coordination, helping teams align their work and promptly resolve bottlenecks. For managing material logistics, the Kanban System relies on the "Just-in-Time" principle, which is implemented by "satellite stores" (also located at the site) and "marketplaces" (which are mobile resources with visual signals or bins that can only be pulled when they are needed). In addition, the inclusion of the Plan of Conditions and Work Environment (PCMAT) formats in the short-term planning and feedback loops into the day-to-day environment makes health and safety a central focus rather than a secondary one. Quality is managed at the source and not through a reactive inspection process, supported by a range of Quality Management Tools and Visual Inspection aids, including progress charts and material identification tags, which increase transparency and communication between decision makers and workforce. In the Lean Construction

Institute's terminology, this is a different way of doing project management: align the design closely with the client's requirements and budget; use the master schedule as a coordination map and not as a command list; minimize the project duration and cost by making the flow more reliable and eliminating waste at each interface.

8. The Strategic Channels for Lean Implementation

8.1 Educational Project Delivery System (EPDS)

Lean Project Delivery System (LPDS) is a complex conceptual system that was carefully designed by Ballard (2000) to enable lean construction principles to be systematically applied in project-based production systems. The LPDS consists of five main phases and is further broken down into three phases of decision-making, execution, and implementation, some of which may involve special software. One of the key elements of this model is the intentional overlap of the phases, with a shared module between each phase to ensure the continuity of the process and cross-functional alignment. As a way of ensuring operational stability and efficiency, the framework also includes lean work structuring and production control as overarching disciplines that are used throughout the project life cycle. Moreover, the model puts a strong focus on a solid learning loop, encouraging the full documentation and use of project learnings to inform future project engagements for continuous improvement.

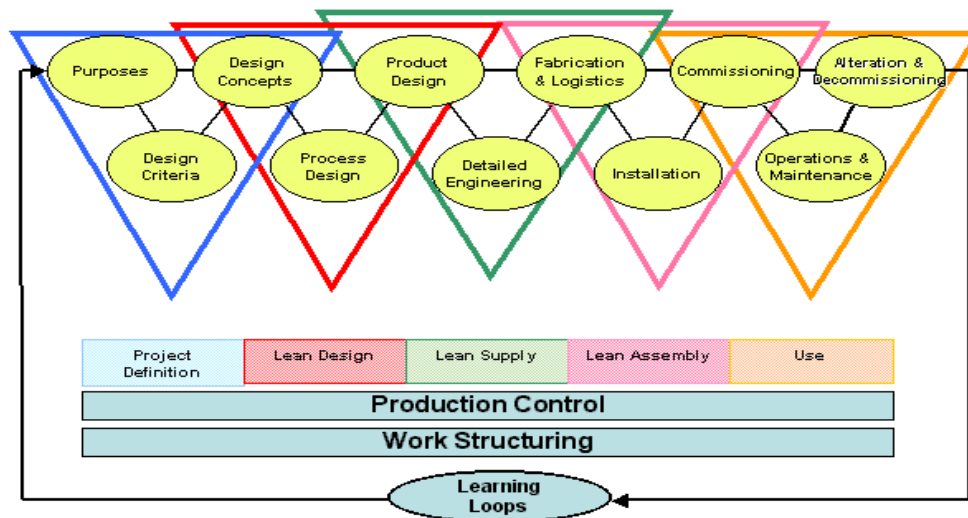


Figure 6: Lean Project Delivery System

The Lean Project Delivery System (LPDS) is an integrated system made up of fifteen modules and is based mainly on four overlapping triads that enable a smooth transition from the beginning of a project to its design, supply, and assembly. The structured approach, as described by Ballard (2000), enables continuity between stages, including project definition (including the identification of needs, design criteria, and conceptualization) and lean design, lean supply, and lean assembly, and overarching governance and feedback throughout the lifecycle via the use of specialized modules relating to production control, work structuring, and post-occupancy evaluation. While classic plan-pull-variance reporting approaches, LPDS emphasizes value creation by the use of cross-functional teams at the start of the planning process and moves away from the retrospective focus of variance detection to real-time workflow management in project control. The model indicates the use of pull strategies for control of data transfer, as well as the capacity of standardized positions and stock buffers to perform an effort to deal with process validation. Focusing on reliable work rather than just on productivity means that a process can be trustworthy. This in turn results in a culture of learning and continual improvement, since quick system adaptation and feedback are incorporated into the process, and this leads to the overall organization of work in order to make better use of time and effort. Last Planner System (LPS) is covered in this section. In an era of the continuous effort to achieve efficiency in the construction industry, planning and control mechanisms are an integral part of the foundation of project success. In the context of Lean Construction, these two elements are considered to be dynamic processes that change during the project and are connected (Ballard, 2000; Howell & Ballard, 1998). At the heart of this approach is the Last Planner System (LPS), a collaborative management tool that aims to smooth out the flow, counteract inherent uncertainty, and encourage foresight by monitoring performance continuously. The LPS is described by Mossman (2005) as a sociotechnical entity that enables critical communication among site management, trade foremen, and the movement of work between the production units, changing the emphasis of control from the individual worker to the movement of work. This

system is based on the two main levels: workflow control (achieved by look-ahead planning) and production unit control (achieved by detailed weekly work plans). The LPS includes features like master scheduling, phase planning, and the Percent Plan Complete (PPC) metric to make planning a learning cycle. PPC identifies the reliability of planning, but cannot be used directly to measure productivity; it can be used as an indirect indicator of productivity when variability in the processes is reduced, and resources are matched to real-time demands, thereby reducing waste and enhancing overall performance (Junior et al., 1998). The application of the LPS includes a systematic review of past performance, in which the number of completed tasks is compared with the number of tasks that were committed, and is followed by an extensive analysis of “reasons for non-completion” to identify corrective actions. This recursive programming enables the project program to be adjusted as the project proceeds and, in many cases, results in project programs that are delivered on time and on budget, and provide a more predictable, less stressful working environment (Junior et al., 1998). Successful implementation brings significant advantages, such as increased cooperation with subcontractors, shorter delivery dates, and more predictable processes, as noted by Fernandez-Solis et al. (2013). The shift to such a Lean methodology, however, is not smooth sailing, and there are great challenges that can hinder the complete implementation of this approach, including organizational complacency, a lack of willingness to change culture, a lack of specialized training, and contractual rigidities. In spite of all these challenges, the four key principles of the LPS – collaborative programming workshops, ‘make-ready’ process to prepare tasks, disciplined production planning and a dedication to ongoing improvement – offer a strong structure to support modernizing construction management and unlock sustainable productivity improvements within the industry.

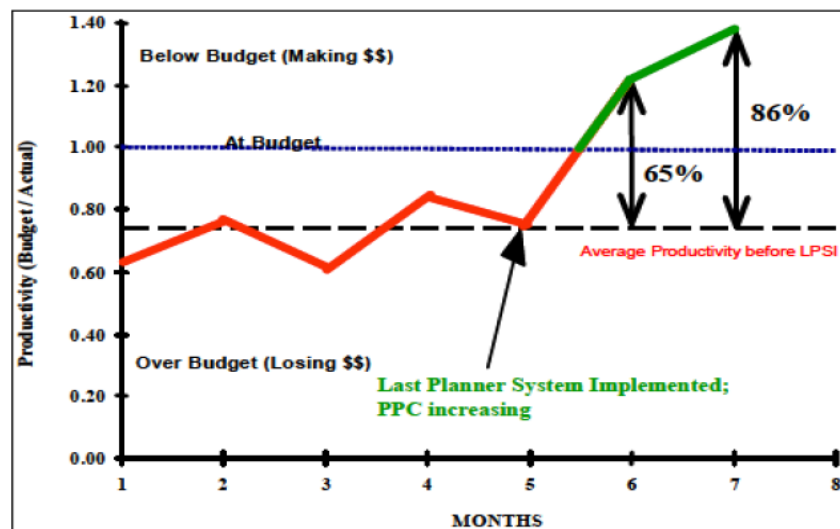


Figure 7: Optimizing Operational Efficiency through LPS

Despite being components of project management, Last Planner System (LPS) and Critical Path Method (CPM) are used at various project levels. CPM which gives planning, milestone setting, managing of logical events and long-term goals, on the other hand, LPS provides information about planning of production, deals with accuracy and immediate reliability of project workflow, as well as direct coordination of work on site. As can be seen in Table (1), project teams can shift from theoretical scheduling based on CPM to real project management, which is based on LPS, from the project high-level goals to construction productivity on a daily basis.

Table 1: Establishing Structural Separation Between Strategy and Production

Critical Path Method	Last Planner System
CPM Logic Embedded in Software	Applied common sense
High Maintenance	Low maintenance
Managing Critical Path	Managing variability
Focus On Managing Work-Dates	Focus on managing workflow.
Planning Based on Contracts	Planning based on interdependencies

LPS, which is an advanced version of traditional project management, has its main focus on scheduling process moves from a top-down approach to the expertise of people in the workplace, foremen, site supervisors, and subject matter experts. The technique will go through a series of screening choices, with the purpose of increasing the efficiency of workflow while addressing specific challenges, and this also includes the question of how to do and what

to do about master scheduling, what can be done by overcoming difficulties, and how to do work through continuous improvements. This system puts theory and practice together in planning, and enables those responsible for implementing the plan to control the following four major tasks; the structure of Figures 8.1 and 8.2 illustrates how this approach's cyclical nature produces a dependable planning process.

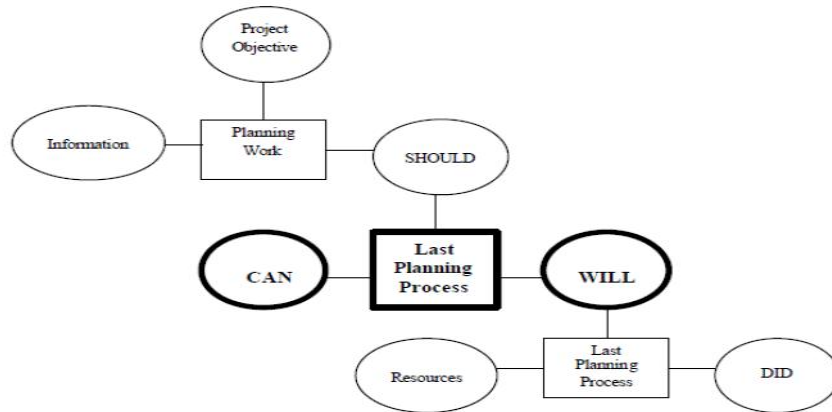


Figure 8.1: Overview of the Last Planner System, as by Howell and Ballard (1998).

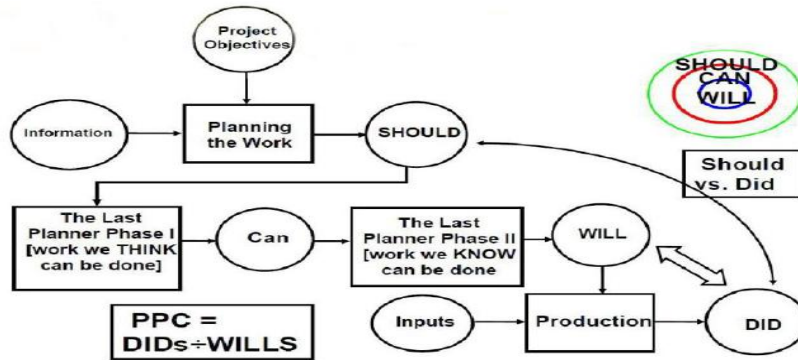


Figure 8.2: Overview of the Last Planner System

In order to achieve successful production based on the Lean Construction methodology, organizational commitments, physical readiness, and requirements formulation are the following parameters that are important for good production management. It is important in this process that the strategic timetable that defines what “SHOULD BE DONE” is translated into a set of assignments and compared with the real job site limits, and what, therefore, “CAN BE DONE.” A reliable assignment is only established when the “Last Planner” identifies the overlap between these two categories to decide what WILL be done. A good assignment is one that is well defined, well scheduled, supported by resources, and can be done by the labor crew available. The Last Planner keeps only “absolute” commitments in the weekly plan, which are the ones that are required by the schedule, by screening out the “hopeful” or “probable” commitments. A continuous cycle of goal identification, feasibility assessment, and commitment securing leads to a high-reliability work process and is repeated continuously.

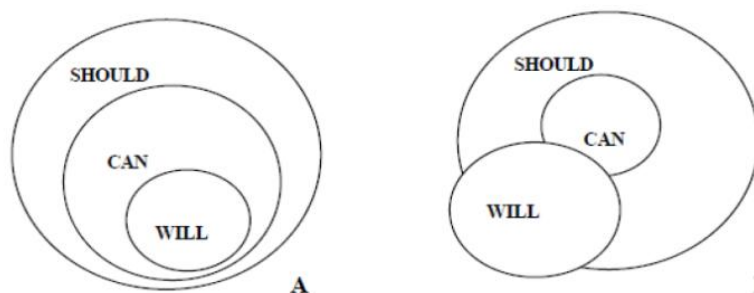


Figure 9: Conceptual Framework of the Should-Can-Will Model (Howell & Ballard, 1998)

Task Allocation is important to the reliability and effectiveness of LPS, as can be seen in Figure (9), which demonstrates the two different scenarios. In Figure (9), part (B) represents that there is a lack of control mechanisms, and in this way, potential failure can occur; it shows a situation with highly variable settings. On the other hand, part (A) shows a successful pattern with careful validity and soundness of tasks, and it provides the likelihood of a highly successful pattern. The basic fundamentals of dependable promise from Figure 8.1 are that effective action occurs when the project team brings what “should” happen together with what “can” happen to achieve a real commitment of what “will” happen. This is achieved by following the four-tiered structure of LPS (Master Schedule, items of long-lead procurement, key milestones). The next phase is the scheduling of the trades, which includes resolving operational conflicts and defining hand-offs to other trades with the practice of “pull planning”. The final step is the Weekly Work Plan (WWP), and the third step is the ‘make-ready’ process to remove any obstacles and make the work ready for installation. At this terminal level, crews make specific short-term commitments, the results of which are analyzed using the Percent Plan Completed (PPC) metric to facilitate a “deep dive” into root causes of non-conformance, thereby fostering a cycle of continuous improvement as detailed in the process flow of Figure (10).

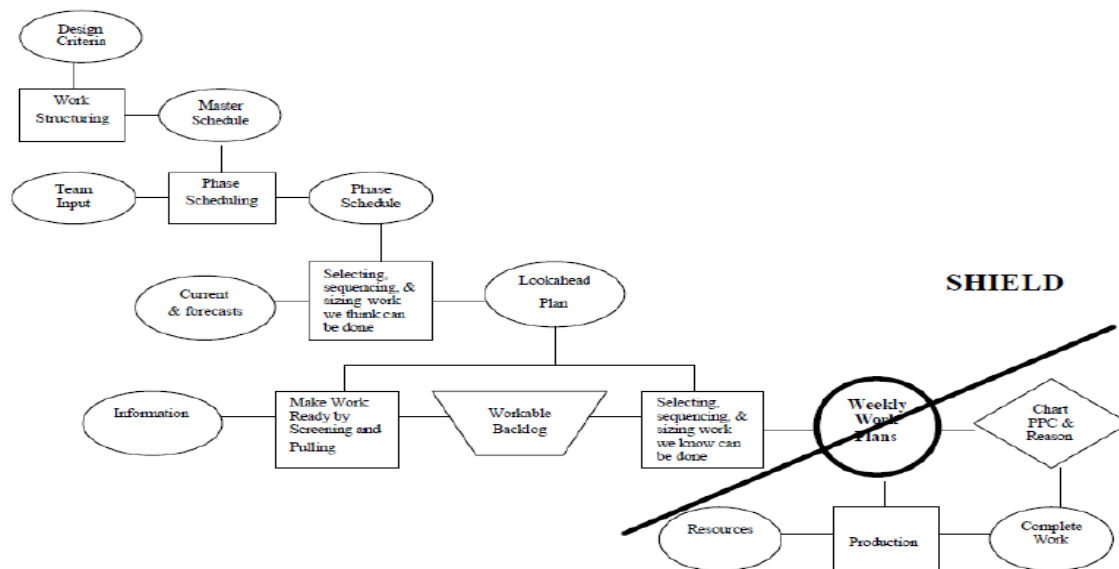


Figure 10: Implementation Framework for the LPS

Figure 11 below provides a picture of how the Last Planner System (LPS) is introduced, and the systematic process flow needed to get project performance stable. Figure 12 below depicts the conceptual connections between the LPS methodologies and the fundamental lean principles of waste elimination and workflow reliability. Both diagrams illustrate the careful way production control is taken care of by turning from a push system of scheduling to pull scheduling and ensuring that all “Should-Can-Will-Did” restrictions are observed and that work packages are issued only when all requirements have been met. The synergy mentioned above can act as a catalyst for continual site development and as a setting of accountability for the site foreman and the trade partners.

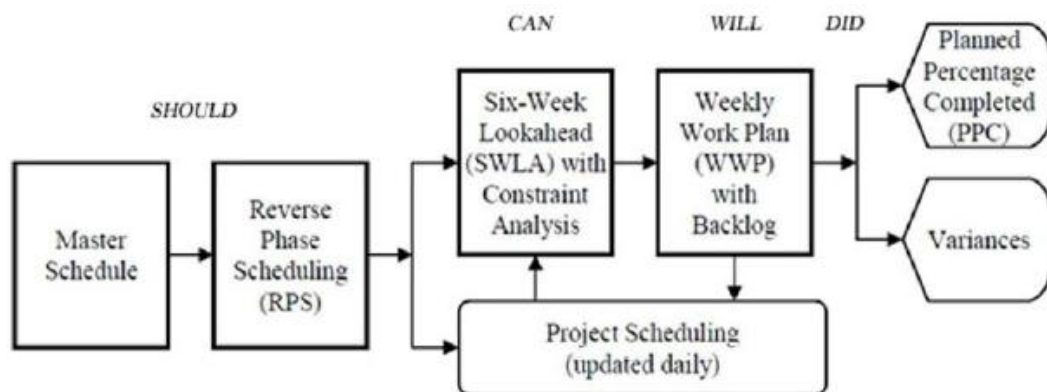


Figure 11: The Sequential Framework of LPS.

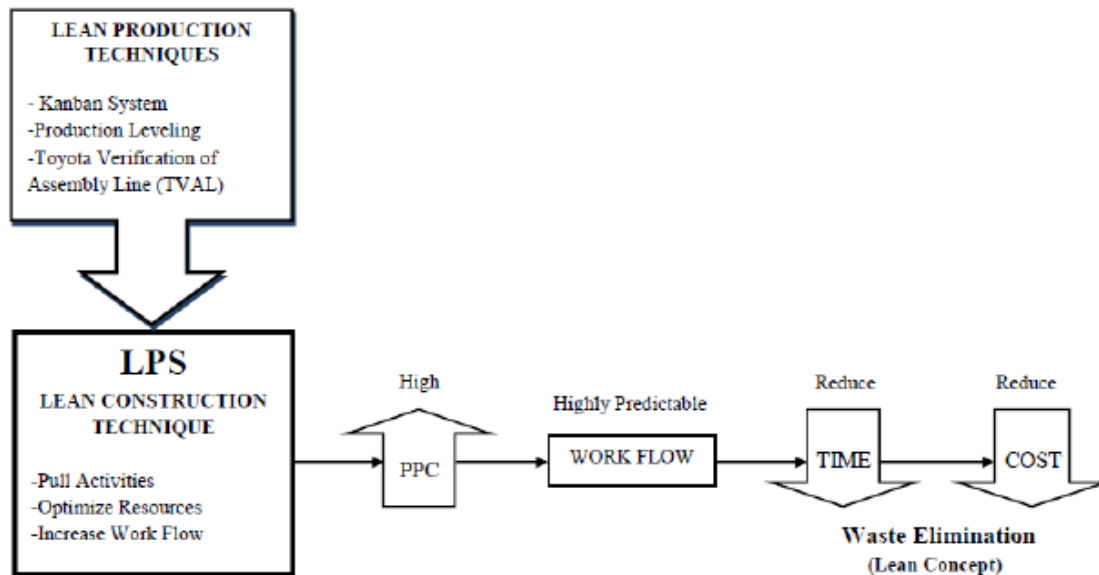


Figure 12: Operationalizing Lean Principles through the Last Planner System

By refining the Kim and Ballard (2010); Wambeke et al. (2012) regarding production control, it is evident that the Last Planner System (LPS) offers a superior framework for managing the complexities of modern construction. Wambeke et al. (2012) provided empirical evidence to demonstrate how LPS, especially in mechanical contracting situations, reduces or eliminates workflow variability. One of these scholars' major accomplishments was the application of the risk assessment matrix as a strategic tool for identifying the highly influential sources of unpredictability that need immediate action. Architecting these systems' theory foundations, Kim and Ballard (2010) compared EVM and LPS by analyzing the relationship between the two and two management theories: the Comparative Analysis of Management by Results (MBR) and Management by Means (MBM). The researchers noted that where labor is interdependent, meaning there are many tasks that require the other to perform, the MBR model (which underlies EVM and is more focused on outputs) is not enough in practice. The LPS, on the other hand, highlights the stability of manufacturing processes and techniques via the MBM theory. The case study evidence clearly shows that the MBM approach is more beneficial in field management due to considering the interdependency of construction operations.

8.2 Related Recent Works

The Last Planner System (LPS) was introduced in the construction industry by the seminal work of Ballard and Tommelein (2021), which provides a detailed description of how to practically implement LPS in today's construction industry. The authors make it clear that LPS is not just a scheduling tool, but an all-encompassing production control system that puts focus on "should" to "will" happen because of mutual commitment. The 5 levels of system master scheduling, phase pull planning, look-ahead planning, weekly work planning, and daily huddles that the guide describes will form a roadmap for a predictable workflow, reduction of variation, accountability, and continuous improvement for project teams. Koskela et al. (2019) provide an assessment of the Lean Construction movement in history, placing it in the context of a long history of lack of productivity in the construction industry. The authors argue that the traditional project management process is over and Lean principles need to be used to address the related inefficiencies. The study examines the history of the theoretical developments to shed light on how Lean Construction, as a localized practice, became a widely adopted philosophy with the promise to reverse the historical trend of decline in the industry by increasing the delivery of value and eliminating waste. The paper by Liu et al. (2024) explores the challenges and opportunities of digitalization in the sustainability context, covering the entire project lifecycle. The authors show how the use of increasingly digital technologies, such as cloud-based platforms and real-time data analytics, complements Lean practices to give improved environmental and operational outcomes. The study points out the need to incorporate the synergy between Lean and digital transformation, a more precise management of resources used, a better understanding of waste, and an increase in the overall agility of project delivery in a constantly changing market. In Bølviken and Koskela (2016), in a theoretical update, the authors further develop the TFFV theory and differentiate between factory floor and construction site's particular needs. They believe that while waste reduction

is the same goal in both facilities, the uncertainties and constraints of construction are greater than in manufacturing. The paper contends that a "one-size-fits-all" Lean mode is not enough – Lean Construction needs to be viewed as a different way of organizing the flow of resources and production in a non-repetitive, complex environment. From a technical and managerial point of view, Sacks, Koskela, et al. (2010) discuss the synergies between Building Information Modeling (BIM) and Lean Construction and first introduce the concept of Digital Twins. The authors discuss the concept of "Lean Intelligence" that can be achieved through BIM as the visual and data-driven basis of Lean workflows and the ability to simulate in real time and solve problems ahead of time. The use of Digital Twins can help project managers reach a higher level of transparency and coordination, ensuring Lean is followed by accurate and current digital models of the physical asset. Pikas et al. (2022) looked at the development of the Last Planner System from paper-based "sticky notes" to the present day, where it is embedded in a digital system. The study highlights the opportunities for digitalization to improve the social aspect of LPS, both in terms of access to data and remote collaboration. Moreover, the paper explores the impact that this transition will have on the future of production control and discusses the hybrid approach that will emerge, where humans and machines will work hand-in-hand, with humans supplemented by automated data collection, tracking, and predictive analyses, which will help to manage a complex set of interdependencies for a project. Pedó et al. (2022) worked on advanced techniques and developed the Visual Management (VM) technique to control the process on construction sites. He discussed that, with the help of VM, new digital platforms can be developed to communicate with workers and stakeholders. This work further expresses that if VM techniques are successful and digitalized, then there is a significant reduction in the gap of providing information to workers, work load can be managed and work can be managed timely. Digital Transformation is a wide-ranging research area that examines the effects of BIM and the Lean method when applied simultaneously to the built environment. The authors share proof that digital transformation works best when done by applying Lean principles and avoids the "digitalization of waste". It is crucial to note that when these two aspects are integrated, they are connected with each other to optimize communication, transition from design to construction, and to make sure that the final product fully satisfies the value requirements of the client (Sacks, Koskela, et al., 2010). Tezel et al. (2022) discuss the possibility of using blockchain technology to address the issues of trust and transparency in Lean projects. Contractual and financial flows can be aligned with Lean production milestones via the use of distributed ledger technology, according to the authors. This establishes a permanent record of pledges and achievements and diminishes the administrative hassle and conflicts that frequently occur in conventional building, fostering a more collaborative and dependable project setting. In the study by Zhang et al. (2016), lean frameworks are used in the context of high stakes in healthcare infrastructure. The authors illustrate how Lean design and Lean delivery models can increase operational efficiency and improve clinical results in such complex and regulated environments as hospitals. The study provides case evidence that early stakeholder involvement and "pull planning" are key to the effective management of the complex mechanical, electrical and plumbing (MEP) systems that occur in the healthcare environment, and provides the foundation for a more patient-centred built environment. The book includes organizational issues related to Lean adoption and provides a strategic plan for large companies in the construction industry that wish to implement Lean in multiple departments and/or projects. Scaling Lean isn't just about training; it's also about a culture shift and aligning company incentives to Lean measures, they say. The study provides practical solutions to institutional resistance and to make Lean part of the company's DNA instead of a set of isolated projects (Zegarra & Alarcón, 2019). In the paper "Enabling Lean Project Delivery through Robotics and Off-Site Prefabrication" (2022), Feldmann (2022) discusses how robotics and off-site prefabrication can be used to improve project delivery in the Lean process. The authors say automation is a powerful enabler of Lean by making work predictable and uniform. Construction companies can use robotics in a Lean context to be more precise, safer, and greatly decrease the "non-value-added" tasks of their traditional labor. The study indicates that prefabrication is not only a technology of construction, but also a discipline of Lean, as a strategy to move the production to controlled environments. Beyond cost and time measures of the success of Lean, Kalsaas (2013) offers some insights into other measures of Lean success, such as performance excellence and waste reduction efficiency. The author shares his philosophical journey of Lean implementation, highlighting the importance of making continuous improvements to work processes for achieving excellence. The research focuses on the concept of "flow" of work, the elimination of the eight wastes of Lean, and provides a way for organizations to measure how close they come to being "high-performing" organizations. In the study, Karim et al. (2024) discuss how to use IoT technology to get access to the 'real-time' data required to optimize the Last Planner System. Labor, equipment, and materials are now tracked with sensors and wearables, and project teams are able to pinpoint bottlenecks as they happen. The study reveals that although IoT does not replace human judgment, it is used as a 'ground truth' source of data that helps to make better progress planning decisions and coordinate the next day's work, leading to a 30X increase in Percentage of Plan Completed (PPC). The aim of the research by Mourmourakis et al. (2024) is to connect the concepts of Lean thinking and the Circular Economy, as they have a common objective to eliminate waste. According to the authors, it can be

used as a synergy for the reuse, recycling, and recovery of building materials in Lean processes. The construction industry is facing a critical juncture and is searching for new ways to overcome the static and mechanistic project management systems that are causing the industry to suffer from a productivity crisis, and to enter a more flexible and resilient project management system, which includes the principles of Lean Construction (LC) (Ziaei et al., 2026a). LC is a management philosophy aimed at optimizing the performance of a project by bringing a holistic approach to the lifecycle and concurrent engineering into play, and by emphasizing the value of the project's output and the objectives of the project's stakeholders. An integral component of this paradigm is the Last Planner System (LPS), which is a sociotechnical tool that increases the predictability of the system by giving more control over the system to the future (planning) instead of the past (results). These principles have been further refined with the advancements of the modern world – “Lean Intelligence” that includes Building Information Modeling (BIM), Digital Twins, and IoT. With its 3 pillars – Building Information Modeling (BIM), Digital Twins and IoT (“Lean Intelligence”) – Digital Transformation has contributed to these principles and brought real-time transparency and will also reduce the “digitalization of waste”. Ultimately, the goal of these methodologies is to create a whole cultural change; the consistent use of the “Lean Ideal” is put into practice to eliminate, one by one, those activities that are not adding value (Muda) and make custom-made products that meet the client's value requirements.

8.3 Professional Breakdown of the Synthesis

- Contextual Necessity: Recognizes the four-decade stagnation in industry productivity as the primary driver for lean adoption.
- The LPS Core: Highlights the shift from “Managing by Results” (MBR) to “Managing by Means” (MBM), which is the latest theoretical distinction in production control.
- Digital Integration: Incorporates recent 2023–2024 research regarding the synergy between Lean and digital tools like BIM and Digital Twins to ensure the paragraph is at the “latest edition” level.
- Operational Pillars: Focuses on the “4P” model (Philosophy, Process, People, and Problem Solving) as the structural foundation for organizational change.

Ziaei et al. (2026b) include a professional academic summary, with special emphasis on the advanced ‘Health-Check’ method for assessing the Last Planner System (LPS). Recent developments in production control systems have moved away from traditional performance indicators towards an advanced “Health-Check Framework for Assessing Last Planner System Implementation Using Social Network Analysis”. The main advantage of this framework is that it addresses the gap left by traditional Lean Construction, which does not have an effective means of measuring the quality of collaboration and the reliability of social ‘promises’.

Social Network Analysis (SNA), rather than the typical Percent Plan Complete (PPC) metrics, which are output indicators, is the foundation of the Health-Check Framework. The Health-Check Framework assesses the density, centrality, and dependability of communication between trade partners and project leads in contrast to the conventional Percent Plan Complete (PPC) measure, which solely takes output into account. A less fragmented commitment process can be achieved by examining these social interactions as a network to find “bottleneck” planners and commitment process problems before they affect the physical calendar. By using the diagnostic approach, project managers may become proactive organizational healers rather than reactive troubleshooters, ensuring that the LPS is a socio-technical project delivery machine rather than merely an administrative process.

- SNA Metrics: It utilizes a degree of orientation to discuss about critical project participants and also discusses the failure points in development phase.
- Commitment Quality: Evaluates not just if a task was completed, but the reliability of the network of promises (The “Social Circuit”) between the Last Planners.
- Predictive Diagnostics: Provides a “Health Score” for the project’s lean culture, allowing for targeted training interventions for specific trade teams.
- Digital Integration: It is a platform which operates by pairing with LPS to take out the important data for real-time network mapping.

9. Performance Improvement Process Model

The use of arrows to represent the areas where an antecedent act as a catalyst for a dependent variable is rendered in an innovative treatment of casual loop and it shows the mapping of systematic interactions in organizational development that are drives for this process. There are two cases in this situation, the negative case shows that relationship is reverse and positive shows that there is a significant increase in the first factor than the second. In order

to account for the difficulties of practical implementation, the model acknowledges that systemic effects are rarely instantaneous and use double-hatched lines to show temporal latencies.

The diamond-shaped convergence point presents an important structural constraint: On the one hand, it is a logical “AND” gate, meaning that the improvements of the elements that precede it must all be fulfilled, for the subsequent elements to take effect; on the other hand, it adds a special dimension to the development of operation: deliberate time allocation for iterative refinement, a higher level of technical competence and sophistication in the methods of improvement, strategic alignment of organizational perspectives with core objectives, all of them underlining the fact that although such strategic integrations can lead to measurable improvements in performance, they have a considerable development lag, meaning that if they are to be realized they need to become a fact within the organization, where patience is necessary to allow the “AND” gate to open.

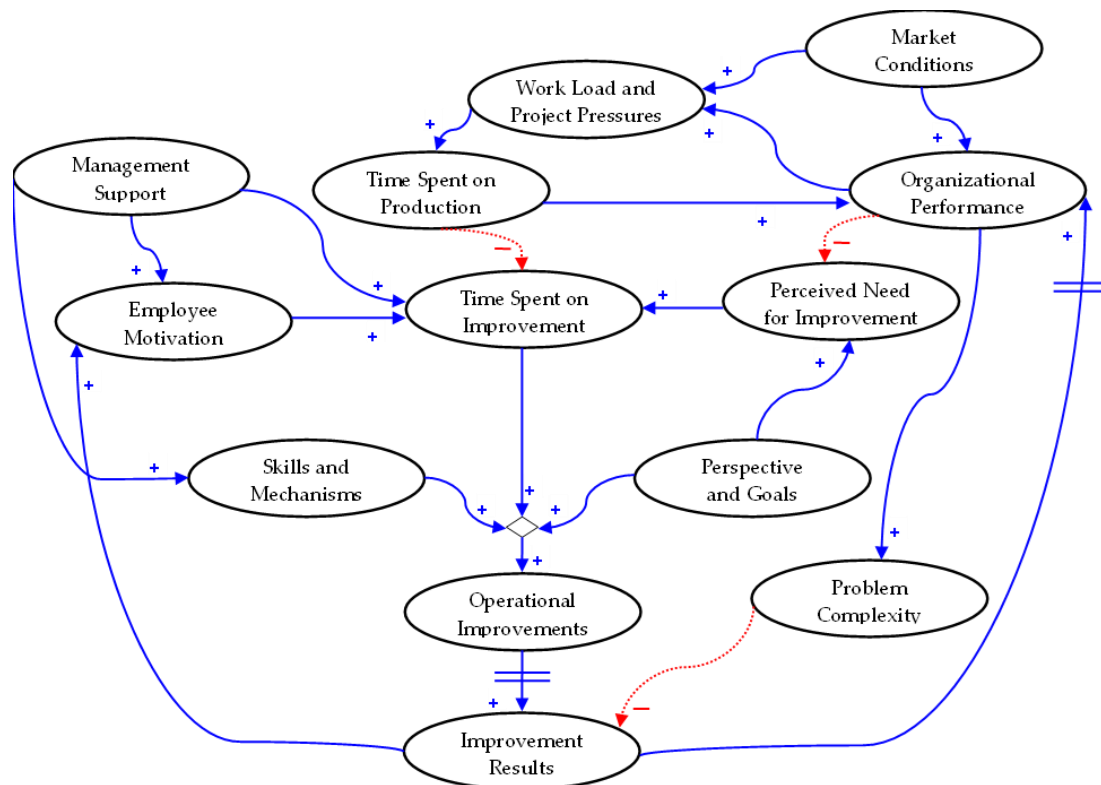


Figure 13: Framework for Performance Enhancement

9.1 Time Spent on Improvement

A common dilemma for organizations is whether to focus more on production or invest in long-term improvements – when there is a lot to do, the demand is high and there are staffing shortages, they are very likely to be doing almost all of their work on providing the product they are producing. This hurdle requires strong support from senior leadership, to be demonstrated by providing sufficient training budgets, rewarding innovative initiatives, measuring middle manager performance on their developmental impact, and allowing for strategic risk taking. This direct leadership support nurtures the necessary motivation of the people, who are contributing to the change and who may be reluctant or ambivalent, and can make the difference in helping to move people to become active promoters of change – particularly if their actions are promptly acknowledged and rewarded – even though the process of addressing complex, long-term operational issues has its inherent delays. Keeping this momentum going depends ultimately on having a sharp eye for what needs to be improved continuously, something that may not be as readily apparent during market upturns when flat or even up profit margins and project budgets seem to be hiding the problem of inefficiency. Therefore, it is crucial for leaders to counter the operational complacency by setting ambitious world class benchmarking targets and re-alignment of management thinking to truly recognise and tackle systemic problems at the core that exist in the market irrespective of the status of the market in that moment in time. In this module, students will acquire the performance improvement skills and mechanisms. The core of organizational performance improving is based on synergy generated between these two types of learning mechanisms and specialized analytical

competencies, which are supported by a firm management commitment. There are three main ways in which companies gain valuable knowledge: experiential learning, which comes after a thorough audit of current internal processes and a post-mortem analysis; picking up information on the latest technological and methodological developments in the market; and trying out new, untested production or management schemes. But, if an organization does not have the necessary skills to implement the three phase improvement process, these mechanisms are only viable for identifying potential operational improvements. This involves systematically gathering relevant performance information, critically analyzing this data to understand the underlying cause and effect relationships clearly, and practically implementing the information to improve performance for the launch of effective initiatives. In this cycle, the ability to master root cause and process analysis is crucial to make sure interventions address the underlying root causes instead of superficially treating the symptoms. In the end, management will have to work hard in-house training as well as with the help of external experts. In this way, the learning mechanisms and development of analytical skills are much reliable on leadership. So, management has to collaborate with the parties that developed and manage to take potential risks for innovations.

10. Performance Measurement and Continuous Improvement

Performance measurement is required to establish whether readiness-based planning benefits construction outcomes. Both the measures of quality of preparation indicators that are leading indicators such as percentage of work packages ready for the scheduled release date, time taken to resolve any constraint, number of constraints that are outstanding, and percentage of work packages cleared for their initial readiness check, and production results which are lagging indicators of past performance such as percent plan complete (PPC), labor productivity, installation time, waiting time, rework percentages, schedule variances, and delays caused by unmet prerequisites should form part of the assessment process. An example of this is a project team noticing that although most of the ductwork packages are on time, they are often late due to missing materials. This discovery would indicate that coordination of procurement should be improved in look-ahead planning. Alternatively, if the repeated failure is due to drawing revisions, it may be necessary to have earlier multidisciplinary design coordination. The planned readiness can be compared with the outcomes of the actual execution, and the causes of recurring failures can be investigated, which can lead to changes in the readiness conditions and in the coordination procedures, and create a continuous improvement cycle. This is conducive to learning at both the work-package and project level. Important, improvements to performance should be shown with specific project records or a clearly identified illustrative dataset. Numerical examples can be used to illustrate the functioning of the framework, but should not be considered as evidence of the framework unless observations of the phenomena have been made and verified.

10.1 Research Gap and Contribution of the Framework

Traditional project scheduling, lean construction production control, and constraint-based work preparation are three exceptional principles which are being provided by literature review. Readiness assessment offers a process to make decisions that are structured around these principles. While these complementary foundations are appropriate, a few practical concerns are relevant to HVAC installation management. One of the first is that there is no proper or uniform assessment of work readiness among teams. When no criteria are established, the decision as to whether a package can be released may vary from supervisor to supervisor. Secondly, indicators of readiness are not sufficiently linked to decisions on production control. A checklist is useful when some materials or drawings are missing; if the result of the checklist does not affect weekly work commitments, however, it is of little value. Third, readiness scores for aggregates may mask important deficits. A package could be approved with a score of +2 even if it does not have a necessary permit, approved drawing, or installation requirement. So, it is essential to have mandatory release gates. A comprehensive assessment is very important for evaluating the relationship between readiness and the results that may be achieved when it comes to manufacturing performance, in terms of schedule dependability, worker productivity, wait time, defect rates, and constraint elimination. Fifth, trade interfaces, location-based sequencing, equipment handling and commissioning requirements must be considered when implementing readiness based decision making for HVAC installations. These qualities are what set HVAC work packages apart from standard construction work. The decision framework is a mix of standardized readiness criteria, a weighted assessment, mandatory release gates, constraint ownership and lean short term production control that address these issues. The example worked can show the entire decision-making process, for example, evaluating individual work packages, choosing activities to do if they are feasible and using the results of subsequent performance to interpret. One of the key contributions is then the development of a structured and transparent relationship between work package preparation and production decision making at the field level. The framework is to be considered as an operational guidance tool that needs to be tested with project data, experts, or comparative case-study research.

11. Case Study

11.1 Implementing Lean Frameworks in a New Alamein City High-Rise Project

11.1.1 Project Context Name and Location: Strategic Investment Opportunities in New Alamein, Egypt.

- Type of project: Mixed use Residential & Commercial High-Rise Tower. Stakeholders: The General Contractor (GC) and various specialty subcontractors for Mechanical, Electrical, and Plumbing (MEP), and finishing trades involved in the project are the key stakeholders.
- Challenge: Typical of the region, the project experienced a "productivity crisis" with a lack of communication, supply chain delays for imported materials and a rigid "push based" schedule with the initial foundation phase being delayed by 20%. Apply the Paper's framework (10.1.2 The Lean Intervention). The project management team adopted a Lean Construction (LC) model in the wake of the paper that advocated for moving away from legacy systems to adaptive and resilient systems.
- Pivoting from top down master scheduling to collaborative 'Pull' system. Pull Planning:
- Rather than the GC setting the dates, the specialty contractors set dates backwards from the project milestones, creating a set of conditions or "precursors" that needed to occur before the specialists could complete their work.

11.1.2 Constraint Management

- It was created a weekly "Look-ahead" meeting to identify and take off constraints before they get to the critical path (e.g. pending site approvals, delayed material delivery from Alexandria port).
- B. Bridging the "Divergent Strategic Choices": The paper highlights a divergent strategic choice between GCs that pay attention to the aggregate outcome, and specialty contractors that pay attention to process productivity. To resolve this: The GC took an "holistic lifecycle approach" taking care of the overall project milestones.
- Specialty Contractors were encouraged to utilize "process-driven productivity studies" (Time-Motion studies) to best utilize their own processes with repetitive floor finishes. Integration: These two viewpoints were aligned by means of a daily huddle where process-level data fed into the overall project schedule.
- Using information technology to gain operational agility. One notable example of agility was when a sharp rise and fall in the Egyptian Pound (EGP) caused a disruption in the supply of specialized HVAC equipment.
- Traditional Approach: Without the ability to quickly execute the project with a clear path for re-approval, it would have been difficult to get it off the ground.
- Agile Operational Framework: The team re-created the sequence of interior finishing activities that were not sequential to the work being done by HVAC based on the Concurrent Engineering principle discussed in the paper. The complete shutdown of the site was avoided and labor productivity was kept thanks to this "agile" rescheduling. The state report card will include performance benchmarks and results.
- At the end of the structural phase, the results obtained were in line with the empirical data reported in the research: The project was able to recover the initial 20% delay and complete the basic structure 5 days early. Quality & Safety: A cleaner, more organized site (Lean methodology, "5S") reduced the number of incidents relating to the safety of workers. The capital expenditure was lowered significantly by reducing the "Muda" (waste) in particular by reducing double handling of materials on site.

11.1.3 Case Study Analysis

- This Egyptian case study confirms the paper's conclusion regarding the divergence of perspective. While the General Contractor in Alamein was initially skeptical of the "micro-level" productivity studies of the subcontractors, the integration of these studies into the broader Last Planner System created the "Operational Agility" necessary to navigate the volatile economic and logistical landscape of the Egyptian construction market.
- The success of this implementation supports the authors' call for future empirical validation of these models within the broader Middle Eastern construction landscape.

12. Conclusion

This research explores the integration of lean construction principles in holistic manner, focusing on how lean is operationalized, industry-specific waste identified and the lean construction practices' perceptions of professionals. A key element of this inquiry is the assessment of the Last Planner System as a key tool for waste minimisation, and more specifically its effectiveness to support the reliability of plans across the project. The study investigates how

lean approaches can be used in combination with programs for improving organizational performance to describe a specialized model that consists of 3 key components: time-consuming commitment, technical skills development mechanisms, and linking the view of improvement with organizational objectives. A key difference is made between outcome-based models, such as Critical Success Factors, and process-based models, such as Lean Construction, as it appears that some outcome-based models can actually hinder the integration of lean principles because they have limited ability to tackle complex, systemic inefficiencies. In addition, the study relies on a dynamic modeling method to illustrate how an organization's structural objectives shape the course of its improvement efforts and observes a stark difference in opinion: specialty contractors tend to think more along the lines of process and productivity studies, while general contractors continue to focus on the aggregate results of their projects. Finally, the study ends by pointing to the necessity of further empirical validation to identify the core factors that influence strategic decisions and to further develop the suggested model for improving performance in the broader construction context.

13. Recommendations

Based on the themes, orientations, and conclusions obtainable in the paper "Advancing Operational Agility Through Lean Frameworks," here are the premeditated and functioning recommendations for shareholders in the construction manufacturing, principally within the Egyptian and Saudi Arabian contexts mentioned:

13.1 Strategic Alignment: Bridging the "Divergence of Perspective"

The paper recognizes a gap where General Contractors (GCs') attention is on collective project consequences while specialty independents focus on process-driven productivity.

- Implement Integrated Project Delivery (IPD) contracts. Shifting away from old-style "Design-Bid-Build" to IPD inspires early participation of specialty servicers, aligning their process-level competences with the GC's overall project indicators.
- Develop Unified Performance Dashboards. Instead of tracking separate KPIs, use shared metrics that show how process-level efficiency (e.g., floor-to-floor cycle time) directly impacts aggregate project delivery dates.

13.2 Operational Agility: Implementing the Last Planner System (LPS)

The paper takes a serious and significant stance on the LPS as the solution for reliability, based on the orientation by Ballard and Tommelein (2021).

- Move from Push to Pull Planning. Site managers should encourage workers to run the work together in "Pull Sessions" so that the people who will do the work (the "Last Planners") collaborate to schedule the work and ensure that no work begins until all constraints have been taken away.
- Standardize Constraint Management. Establish a standard "Look-ahead" (usually 3-6 weeks ahead) process to pre-empt problems such as permit suspension, material shortages (particularly in the Egyptian market), or design clarifications that would otherwise affect the timeline.

13.3 Waste Elimination and Site Productivity

The paper highlights the importance of avoiding unnecessary capital expenditure by eliminating the 'Muda' (waste).

- Recommendation: Optimizing Operational Efficiency using 5S Methodology (Set, Sort, Shine, Standardize, Sustain). Organized sites eliminate "motion waste" and "transportation waste" in large-scale projects such as those in the city of New Alamein, and these wastes are directly attributable to improving the safety of the occupation.
- Recommendation: Carry out Gemba Walks. Management should periodically go to the "Gemba" (the real site where the work is done) to see the inefficiencies, and not merely via lagging reports.

13.4 Future Empirical Research

- The paper accomplishes this by calling for Empirical Endorsement. Companies should partner with academic institutions (like AIU/UBT) to conduct "Pilot vs. Control" project studies, documenting the specific ROI of Lean interventions to build a stronger business case for the Egyptian construction sector.

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