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Application of lean construction and last planner system in metro station excavation and construction

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Abstract

Metro station construction together with excavation works show substantial complexity due to the comprehensive planning requirements and coordination of resources and detailed safety protocols. Project execution difficulties lead to time delays as well as budget surges and reduced standards of finish. The research assesses how Lean Construction principles together with the Last Planner System (LPS) have become more significant for solving current project challenges. Lean Construction emerged from Toyota Production System (TPS) origins before adaptation in construction activities led to Last Planner System development as a collaborative planning tool. The study investigates how metro excavation projects benefit from applying three basic Lean principles which embrace waste elimination together with pull planning systems alongside continuous improvement methods. The document investigates the benefits of bringing BIM technology into partnership with LPS and Lean methods to achieve increased coordination and operational efficiency. The results indicate that Lean Construction together with LPS demonstrate major positive effects on project scheduling combined with resource management while simultaneously improving workplace safety and increasing stakeholder involvement. The study provides actionable recommendations and research opportunities for contractors and project managers together with urban planners to enhance Lean implementation in complex infrastructure projects.

Keywords: Lean Construction; Last Planner System; Metro Station Excavation; Scheduling Challenges; Resource Allocation; Safety Management; Digital Integration; Infrastructure Development; Construction Management

1. Introduction

1.1. Overview of Lean Construction and Last Planner System

The production management-based delivery method of Lean Construction produces projects by maximizing value through waste elimination. The production methods of lean manufacturing shape Lean Construction as it establishes project practices which unite stakeholders through continuous improvement and collaboration. The methodology achieves better workflow reliability through streamlined processes because it enhances team communication which produces efficient and effective project delivery. Rollout of the methodology occurs by developing foreseeable building outcomes through forward-minded scheduling combined with eliminating waste during all phases of construction work.

Lean construction began in the early 1990s as research circles recognized the inability of traditional construction management practices to handle complex alterations in construction projects. Researchers together with industry leaders expounded their search for applying automotive manufacturing lean production theories which Japanese producers developed to construction methods. The maturation of Lean Construction principles throughout time led to

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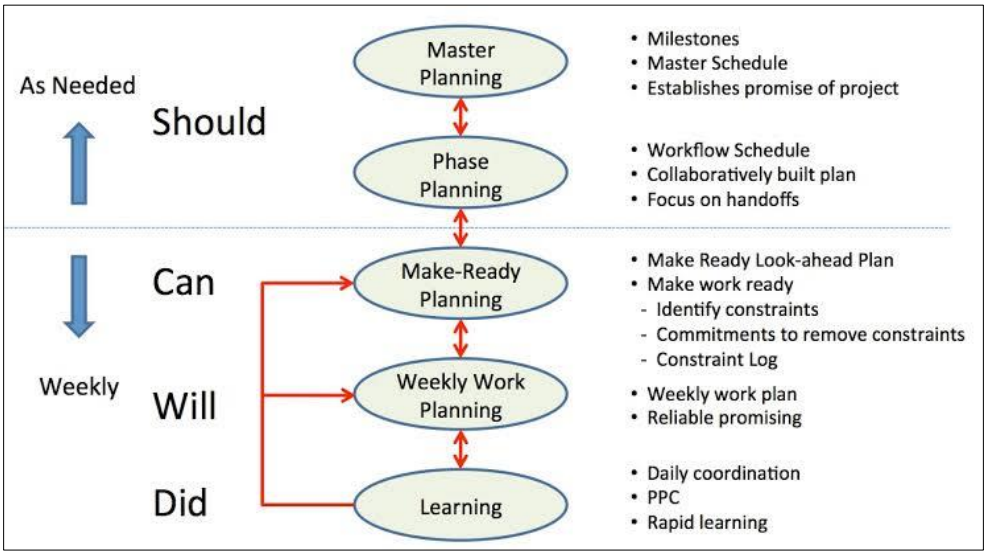
the inclusion of value stream mapping with pull planning and continuous flow as normal operating standards for projects worldwide.

The Last Planner System (LPS) exists as a practical Lean Construction implementation to resolve problems with unreliable project planning and execution. LPS functions as a group planning process that develops projects better through reliable and predictable planning and execution. The core principle of LPS depends on project team members offering promises about their responsibilities which results in transparent and accountable execution at every project stage. The system requires continuous work planning during weekly sessions and future planning and plan failure analysis to build a culture of continuous progress.

The Last Planner System emerged during the mid-1990s with the purpose of uniting broad project schedules with practical field operations. Continuous development of this system incorporated on-site observations together with research regarding planning inefficiency issues in construction operations. The Last Planner System has evolved into a central element for Lean Construction projects which enables teams to shift from management reactivity toward proactive delivery control. The program delivers successful results so it now appears in major infrastructure projects and residential and commercial development projects alike.

Modern construction project management heavily relies on Lean Construction together with the Last Planner System as essential components. Technological developments including digital scheduling software Building Information Modeling (BIM) and performance measurement data assist in their integration. Recent innovations have delivered enhanced precision through better responsiveness thus construction activities better match client needs and market requirements. These concepts continue to evolve because they ensure the development of sustainable and efficient client-centered construction practices.



Source: Richert, T. (2017, May 24). What is the Last Planner System? Lean Construction Bloghttps://leanconstructionblog.com/What-is-the-Last-Planner-System.html

Figure 1 Overview of the Last Planner® System components

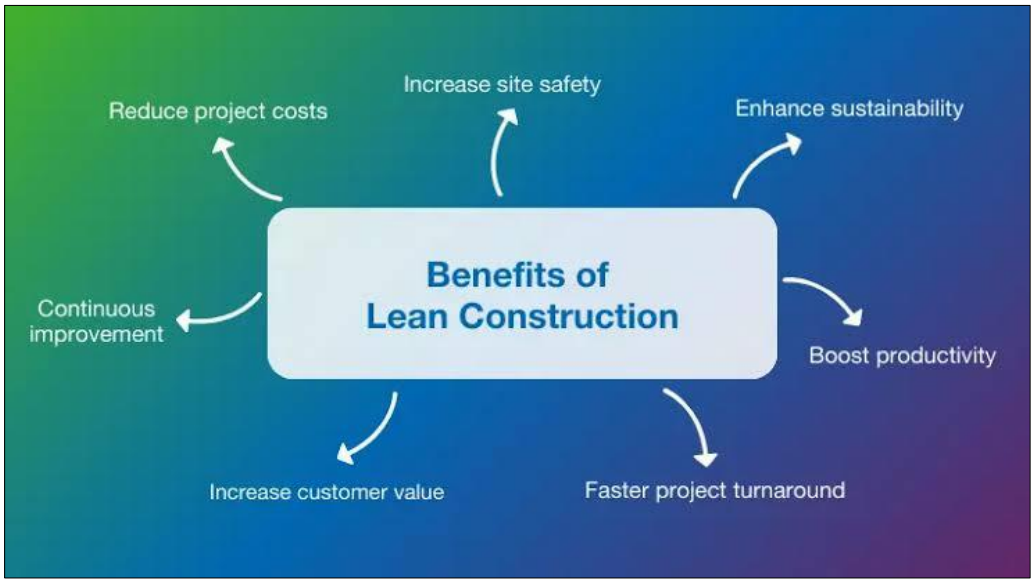
1.2. Importance of Lean Construction and Last Planner System in Metro Station Excavation and Construction

Metro station excavation together with construction work poses considerable difficulties because they require extensive underground digging in confined city areas and present elevated security threats and precise construction deadlines. Typical project management systems encounter difficulties with complex site conditions which results in project delays and expenditure increases together with safety problems. The systematic approach of Lean Construction enables the solution of project complications through enhanced workflow coordination and waste reduction and increased project valuation. Stakeholder collaboration under Lean Construction management results in efficient critical excavation practices that decrease urban population disturbances.

The Last Planner System functions as a vital element that advances scheduling and resource handling processes in metro station constructions. Weekly and daily field-based planning made possible through LPS allows project teams to anticipate project constraints and coordinate subcontractor activities for preparedness on upcoming tasks. During

excavation phases LPS facilitates early hazard detection while resolving complications ahead of time thereby it enhances operational reliability together with productivity levels. The model provides a commitment-based approach to planning that improves communications between engineers and contractors together with safety managers to develop resilient project environments.

Lean Construction and LPS implementation serve as a strategic requirement for metro systems development as urban facilities continue to grow in numbers. Through these methodologies projects achieve their deadlines and financial targets and workers stay safe and materials use fewer resources and environmental degradation remains low. Integration of Lean principles and Last Planner techniques enables metro builders to successfully handle diverse construction needs of excavation and station development thus achieving superior performance results alongside environmental sustainability.



Source: RIB Software. Lean Construction: Explore The Top Principles & Methods. from https://www.rib-software.com/en/blogs/lean-construction-principles-methods

Figure 2 Overview of Lean Construction principles and methods.

1.3. Objectives and Scope of the Study

The primary objective of this study is to investigate the application and impact of Lean Construction principles and the Last Planner System in the context of metro station excavation and construction. The research aims to evaluate how these methodologies improve scheduling reliability, resource efficiency, safety performance, and project delivery outcomes in complex underground projects. It will explore both theoretical frameworks and real-world applications to identify best practices and critical success factors.

The research investigates metro station projects with major excavation requirements along with their construction within heavily populated urban settings where execution challenges are most intense. Research evaluates how Lean Construction methods improve both the operational efficiency and safety standards during metro station excavation works. What methods does the Last Planner System use to enhance workflow predictability along with resource management? Which difficulties emerge from carrying out Lean and LPS methods in metro construction projects and how can project teams address them? The study performs targeted research to provide useful solutions for enhancing metro building performance.

1.4. Significance of the Study

Modern cities which experience quick urban growth need superior sustainable transportation systems that provide safety as never before. Urban transportation involves metro stations in their essential role to provide mobility solutions while cutting down congestion and environmental effects. The excavation together with construction of metro stations creates major technical along with logistical problems because of limited work areas and shifting soil conditions and elevated safety concerns. Urban projects suffer from serious delays as well as budget growth while experiencing operational difficulties that extend development periods for urban spaces.

This research takes on vital importance because it remedies the present necessity for superior construction management systems in metro project spaces. Lean Construction along with the Last Planner System provides transformative management solutions through facilitating organizational planning, waste reduction, resource optimization and workflow dependability enhancement. The integration of Lean Construction and the Last Planner System arrives at an opportune time because it fulfills rising demands for speedier and safer along with cost-efficient metro construction. The study provides valuable knowledge for urban infrastructure development through its systematic exploration of these methodologies for their application to metro station excavation work. The research findings will enable the development of superior practices through innovative solutions that create sustainable urban public transit systems for generations to come.

2. Literature Review

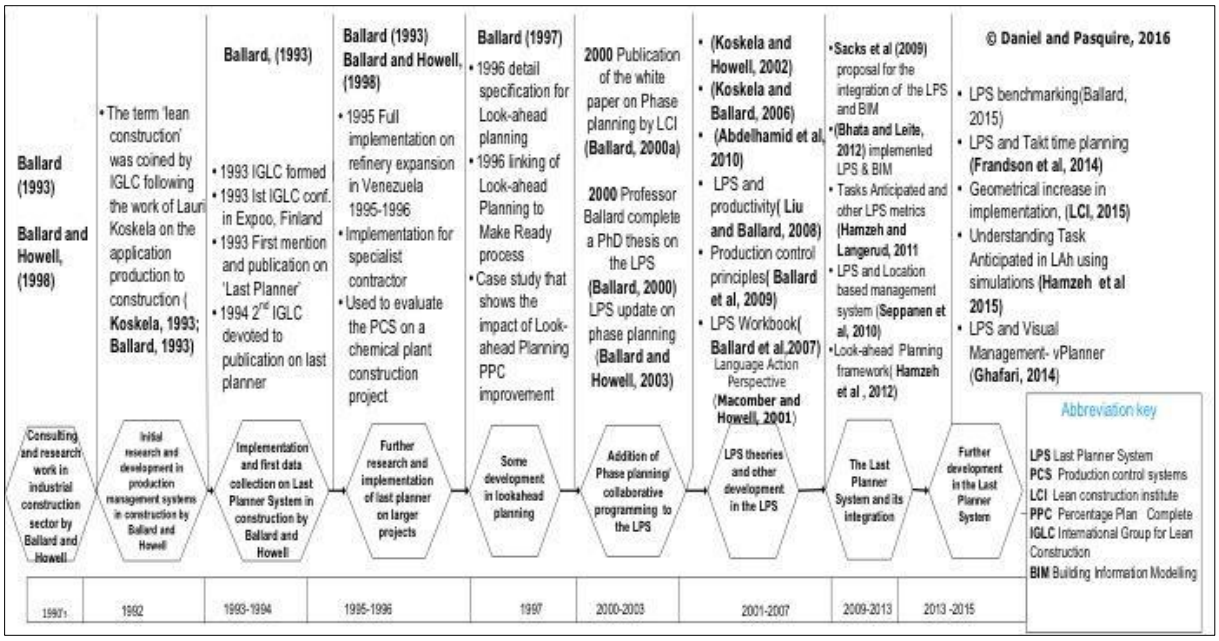
2.1. Historical Development of Lean Construction and Last Planner System

The history of Lean Construction started with the development of Toyota Production System (TPS) in post-World War II Japan. Under the leadership of Taiichi Ohno and Eiji Toyoda TPS brought forth manufacturing innovations that included the just-in-time production and waste elimination methods together with continuous improvement and respect for people. Research and professional practice can directly benefit from these concepts which dramatically enhanced automotive sector performance thus encouraging investigations about their adoption for different industries. During the early 1990s Lauri Koskela along with other scholars officially implemented TPS principles within construction because the industry encountered similar manufacturing-level inefficiencies and unpredictability and waste (Pellicer, Cerveró, Lozano, & Ponz-Tienda, 2015). The integration of manufacturing principles drew Lean Construction into existence as an independent philosophy which focuses on optimizing construction delivery processes by establishing value-added frameworks alongside productive flow enhancements.

Lean principles transformed the way construction operated when project management organizations needed to replace their previous typical scheduling and budget control systems. At its beginning Lean Construction explored production systems in construction and recognized workflow variability as the main cause of waste (Hamzeh, 2011). The International Group for Lean Construction (IGLC) serves to advance field research and development within Lean methodology thus encouraging international adoption of more efficient collaborative construction methods.

The Last Planner System emerged during the same period as Lean Construction development as an operational tool for implementing Lean principles within construction environments. The Last Planner System emerged in the early 1990s from the minds of Glenn Ballard and Greg Howell who developed it to enhance work planning reliability and production control capabilities. The authors Ballard and Howell developed their system to replace existing scheduling approaches by implementing collaborative planning with commitment management alongside continuous learning due to inefficiency of current methods in addressing real-time site conditions and workforce dynamics (Daniel & Pasquire, 2017).

Activities conducted through experimental projects combined with academic research enabled the Last Planner System to show its ability in improving workflow reliability and decreasing projects delays. A series of enhancements to the Last Planner System resulted from gathered field observations as well as research work (Hamzeh, 2011). The Last Planner System evolved into a primary principle of Lean Construction that obtained mass acceptance across diverse architectural domains like infrastructure along with healthcare and commercial construction. The construction sector uses Lean Construction and the Last Planner System to develop project management strategies that enable flexibility and promote teamwork alongside perpetual performance enhancement.



Source: Daniel, E. I., & Pasquire, C. The history of the development of the Last Planner® System. Lean Construction Blog. https://leanconstructionblog.com/The-History-of-The-Development-of-the-Last-Planner-System.html

Figure 3 Timeline of the development of the Last Planner® System. (Zoom in)

2.2. Core Theories and Models Related to Lean Construction and LPS

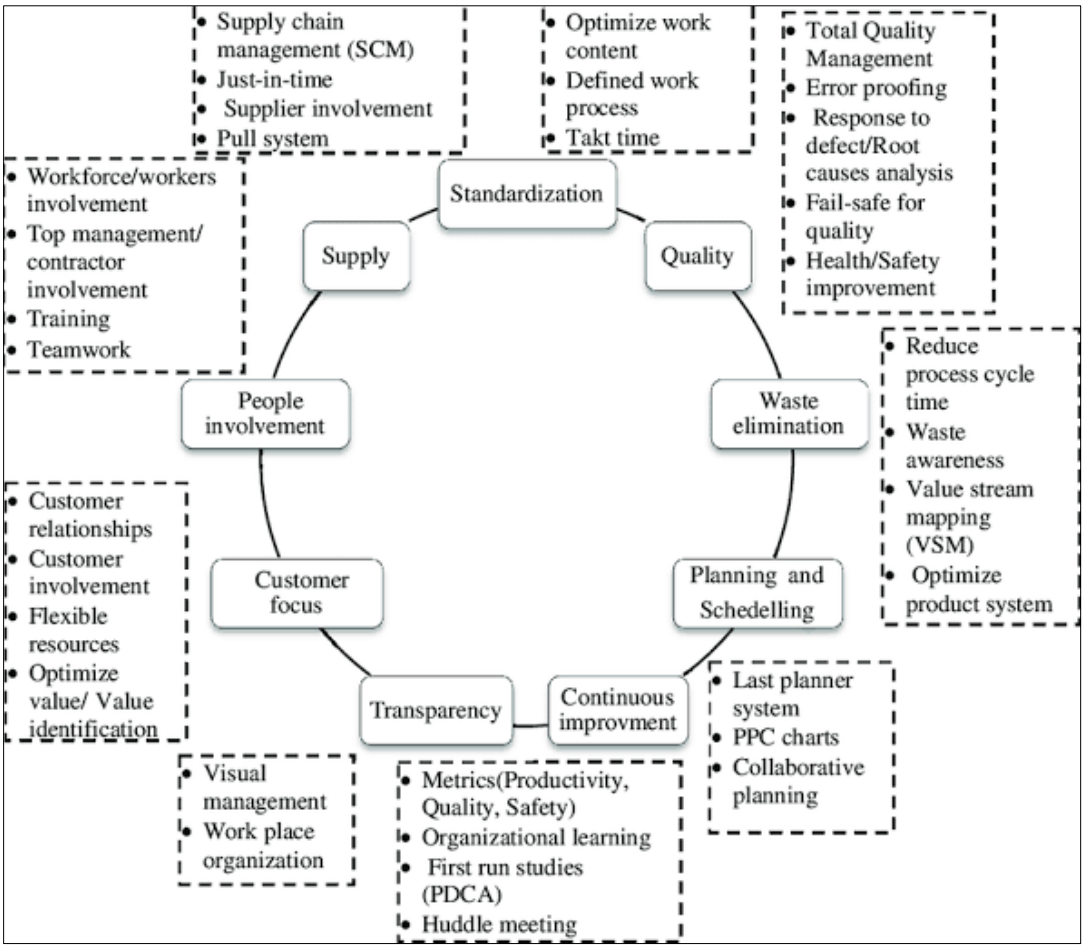
Production theory provides Lean Construction with its foundation through principles which focus on waste elimination and continuous improvement and delivering maximum customer value. Its central theoretical construct involves identifying seven types of waste characterized in manufacturing primarily from defects then proceeding with systematic waste removal consisting of defects, overproduction, waiting, non-utilized talent, transportation, inventory, motion, and extra-processing. Construction-related wastes appear in project delays and increase the need for repetitive work and material transport inefficiencies and inefficient project information exchange. The Lean Construction approach takes specific lessons from manufacturing to enhance the reliability of project workflows and maximize resource effectiveness while establishing beneficial activities across project durations (Conte & Gransberg, 2001).

Pull planning stands as the essential concept of Lean Construction because it functions oppositely to traditional push-based scheduling systems. A pull system contains signals that downstream units use to confirm their readiness to accept work while adapting to favorable work conditions. The application of this system eliminates system slowdowns and cuts down unproductive periods while improving project adaptability. Coordination and communication formed on pull planning platforms match effectively with the collaborative characteristics of construction work areas especially metro station excavation projects that need sequential participation of multiple specialized teams.

The Last Planner System utilizes Lean principles by developing practical planning and control methods from them. The Last Planner System draws its theoretical foundation from learning theory focusing on social learning methods and feedback processes for improvement. Within the Last Planner System, the scheduling process happens through direct involvement of workers who execute the work since they function as planners. The method implements various systems including look-ahead planning together with constraint analysis and weekly work planning and percent plan complete (PPC) measurements to construct stronger planning predictability (Kalsaas, 2012). Through these practices the organization maintains accountability structures and gains a culture that learns from deviations as it continuously optimizes its processes.

The implementation of Plan-Do-Check-Act (PDCA) cycle as an essential model results from combining Lean Construction principles with the Last Planner System by establishing a structured format for recurring planning and control activities. Construction teams enhance performance through continuous execution of planning, task execution and outcome assessment followed by adjustments to practice systems. The Last Planner System has integrated with Building Information Modeling (BIM) digital tools to enhance the visualization and tracking abilities of construction activity coordination (Schimanski, Marcher, Pasetti Monizza, & Matt, 2020).

These frameworks serve complex construction environments by allowing teams to enhance both efficiency and collaboration and predictability because of their robust design in uncertain high-dependency situations. Such time-sensitive approaches work best in fluctuating project environments because they enable building teams to achieve certain outcomes while maximizing value delivery.



Source: Bajjou, M. S., Chafi, A., & Ennadi, A. (2018). Development of a conceptual framework of lean construction principles: An input-output model. Malaysian Construction Research Journal, 26(3), 67–86. https://doi.org/10.22452/mcrj.vol26no3.5

Figure 4 Conceptual model of Lean Construction principles**.**

2.3. Previous Research and Findings

For the past two decades researchers have developed a substantial collection of academic and industry knowledge about Lean Construction and the Last Planner System (LPS). Research by Conte and Gransberg (2001) introduced the foundation for transferring Lean manufacturing principles into construction sites. The researchers established that project success depends foremost on workflow variability management alongside process waste elimination. The initial research became the basis for future evaluations about detailed outcomes of Lean and LPS practices across multiple project types encompassing significant infrastructure ventures.

Hamzeh (2011) conducted an extensive analysis of both the difficulties and rewards which occurred during Last Planner System implementation. Field case studies in his research revealed the value of involving stakeholders early and showing how work constraints need identification and elimination followed by the benefits of weekly work planning meetings. Hamzeh determined LPS effectively improved workflow reliability yet its success required both project teams to maintain consistent commitment alongside their members continuously learning through the entire construction process. According to his research the implementation of LPS needed teams to modify their project management behaviors towards openness and teamwork.

AlSehaimi along with Tzortzopoulos Fazenda and Koskela (2014) used LPS to resolve persistent delivery issues within Middle Eastern construction operations. The authors documented positive results from their study through better subcontractor coordination and improved schedule compliance and enhanced site operations. Weekly coordination

meetings together with look-ahead planning proved essential to early detection and elimination of risks according to their findings. The research findings from different cultural and project conditions strengthened understanding about LPS as an important construction management method for metro station builds that need multiple trades and advanced sequencing.

Today's research investigates how digital technologies link together Lean Construction and LPS practices. The authors Schimanski and colleagues Marcher and Pasetti Monizza and Matt (2020) evaluated the combination of Building Information Modeling and LPS applications in construction execution. The authors developed a conceptual design which explained that bringing together BIM visualization and data control functionalities with LPS planning teamwork would produce better site decisions while minimizing ambiguity. The combined application brings benefits especially when executing metro excavations due to the intricate nature of underground construction environments which requires precise planning and immediate modifications.

The research shows that Lean Construction together with the Last Planner System leads to enhanced project performance as long as practitioners use them intelligently. The examined studies identify three essential topics regarding collaborative planning methods and learning culture development alongside digital tools implementation. Research results create an excellent basis to analyze how Lean and LPS enhance outcomes during metro station excavation projects.

2.4. Research Gaps and Emerging Issues

Studies have confirmed the advantages of Lean Construction and the Last Planner System across different industries but additional research is needed for their direct application in metro station excavation and construction projects. All current research studies analyze vertical building construction alongside highway projects but fail to address the specific challenges encountered in metro tunnel excavation that includes restricted working areas and difficult geological situations along with complicated stakeholder settings. A limited focus between research studies impedes a complete understanding how Lean and LPS principles adopt to the changing and high-risk environment of metro projects.

The implementation of Lean concepts requires new integration with Building Information Modeling (BIM), Internet of Things (IoT) sensors in addition to real-time data analytics. Early studies show promising advantages of digital integration with Lean planning but empirical research fails to demonstrate systematic ways digital enhancement supports Lean practices in real construction sites that are highly congested and complex. Few studies exist that provide systematic methods for combining the different interests of stakeholders including contractors and consultants and their clients into a single Lean framework. Effective resolution of these gaps must take place to make Lean Construction and LPS applicable to extensive urban infrastructure projects.

3. Key Challenges and Issues in Metro Station Excavation and Construction

3.1. Project Complexity and Scope Management

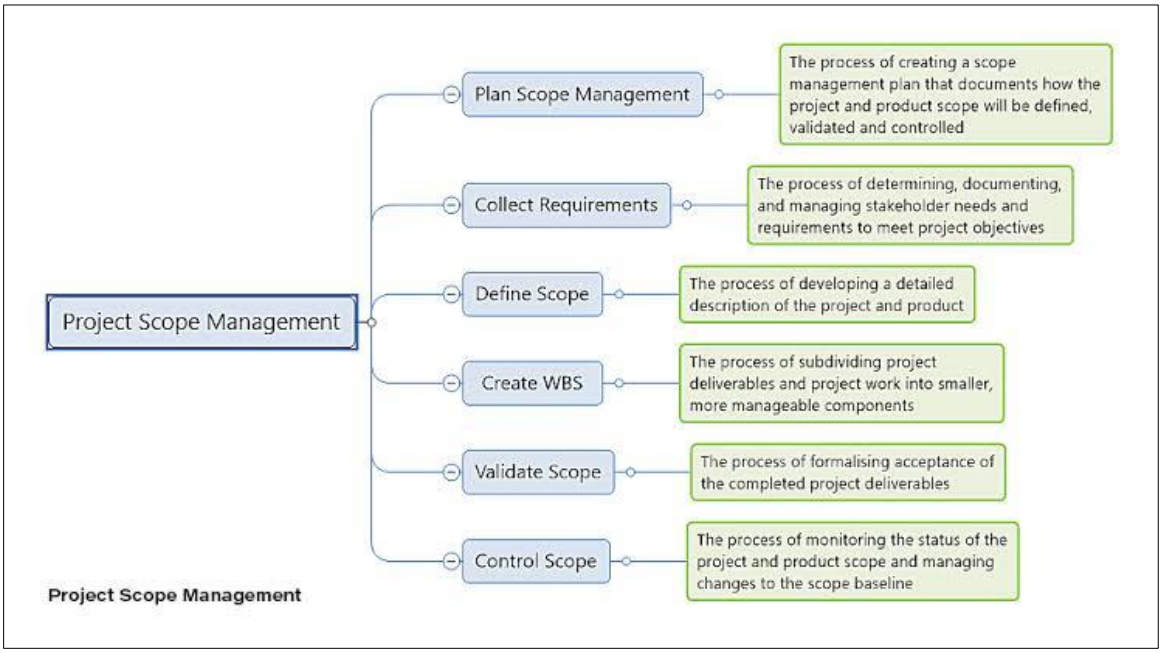
Urban infrastructure development requires the most challenging task to be executed when building metro stations at excavation sites. Such projects execute complex tunnel operations which demand combined civil, structural and electrical and mechanical solutions in tight restricted environments (Jiju, 2015). Construction scope management faces high obstacles caused by unrevealed subsurface ground patterns along with shifting design needs and stringent regulations and ongoing access needs demanding safety for public persons. Project success depends heavily on thorough planning and coordination because unanticipated factors create substantial scope expansion problems as well as delayed schedules and increased costs (Khosravi & Kähkönen, 2015).

The Last Planner System and Lean Construction provide organizations with systematic ways to deal with project complexity. The main principles of lean construction support early stakeholder participation while performing constant team collaboration together with focused elimination of activities which do not add value to projects. Relying on this methodology helps smooth out project definitions at the beginning through early identification of potential ambiguities that could cause larger problems while work takes place. Through their approach to transparent communication and iterative planning Lean methodologies let changes in scope get rapidly detected and integrated into workflows with minimal project disruption (Khosravi & Kähkönen, 2015).

Through its planned approach the Last Planner System solves the issue of workflow coordination between multiple stakeholders alongside the management of job relationship dependencies. The Last Planner System implements look-

ahead planning combined with constraint identification to achieve weekly work plan sessions which builds participation from all actors to establish practical and dependable commitments. The collaborative approach provides participants with complete understanding about their specific duties while showing them exactly how their work affects upcoming operations (Jiju, 2015). The emphasis on planning reliability and accountability through LPS helps prevent the typical issues of rework and miscommunication together with unplanned modifications which affect complicated metro projects.

Research highlights that applying Lean Construction and LPS significantly improves adaptability to the uncertainties inherent in metro excavation projects. The emphasis on visual planning tools, daily huddles, and real-time feedback loops supports dynamic scope management, enabling project teams to respond swiftly to unforeseen challenges such as ground instability, utility interferences, or unexpected environmental regulations (Khosravi & Kähkönen, 2015). As metro systems expand globally to meet urban transportation demands, adopting these Lean approaches becomes increasingly vital for delivering projects efficiently, safely, and within the defined scope.



Source: Project Management Path. The planning process in project scope management. https://projectmanagementpath.com/the-planning-process-in-project-scope-management/

Figure 5 Overview of the planning process in project scope management.

3.2. Scheduling and Resource Allocation Challenges

To build a metro station effectively scheduling and allocating resources represent crucial issues that lead to substantial financial losses alongside operational impairments. The combination of strict time constraints together with multiple task interdependencies and exact contractor cooperation occurs in underground stations throughout short construction durations. Work delays become especially problematic in resource management due to unexpected problems such as unstable soil or underground utilities or weather-related interruptions which cause work stoppages and create costly schedule bottlenecks. Specialized resources which require scheduling coordination extend the complexity level of the procedure because skilled labor, machinery together with materials need precise scheduling.

The Last Planner System (LPS) together with Lean Construction strategies address these problems effectively because they lead to higher resource usage performance and decreased stoppages. Lean principles reduce time-based waste by implementing efficient processes which combine ongoing improvement initiatives. Under Lean Construction a fundamental principle requires controlling resource distribution effectively to match supply with demand in order to avoid both excess and insufficient resources. The prevention of resource hoarding combined with flow enhancement results from this method by reducing periods of waiting and cutting down empty resource periods.

The pull-based scheduling approach of LPS functions harmoniously with Lean principles to improve collaborative activities between all project members. LPS adopts "look-ahead" planning to determine restrictions ahead of time thus

resources receive allocation according to their real capacities and accessibility. The scheduling system only books work when it confirms that essential elements are available to maintain efficient workflow throughout.

Through combined usage of weekly planning sessions with schedule tracking meetings LPS enhances early analytics of potential problems like resource shortages or delays which enables teams to implement proactive solutions before they become significant issues. The integrated system based on weekly planning and regular meetings lowers the project downtime risk and maintains construction activities in alignment with project objectives which prevents schedule extensions and improves operational efficiency (Gautam et al., 2024). Lean Construction and LPS successfully help direct metro station construction projects through their resource scheduling challenges.

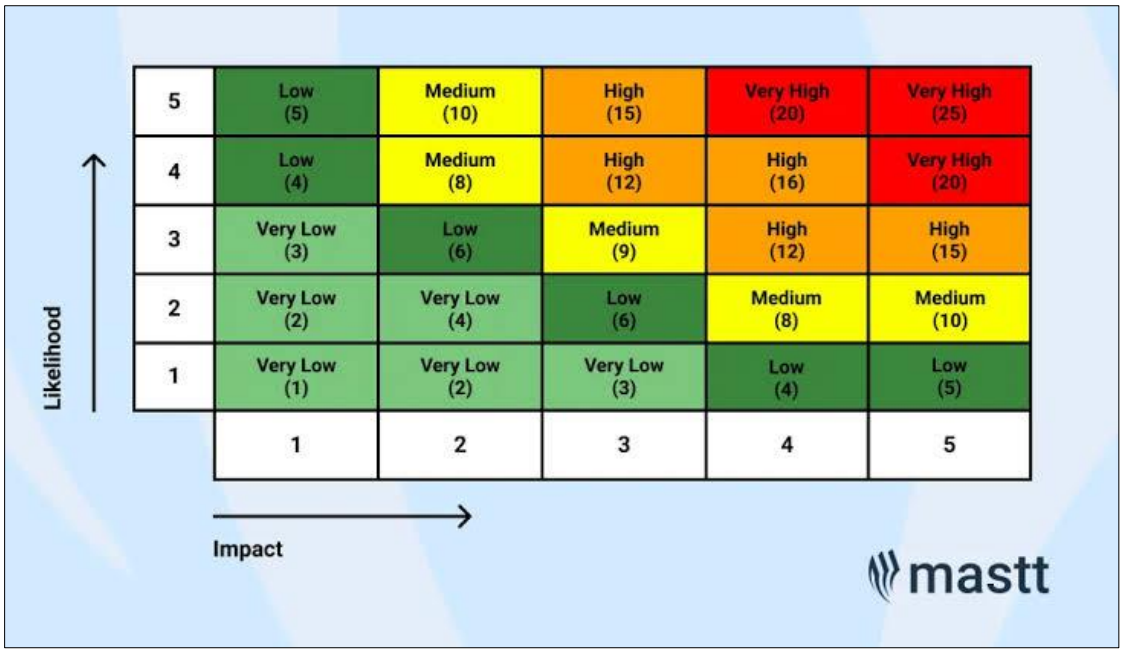
3.3. Safety and Risk Management in Underground Construction

The hazardous characteristics of underground construction tasks increase numerous safety challenges during metro station excavation work. Underground operations for tunnel excavation and metro station construction endanger workers through earthquakes and equipment breakdowns in addition to dangerous substances exposure and dangers that rise from narrow spaces. The combination of exposure to physical dangers and environmental threats such as groundwater inflows and gas leaks and poor air quality leads to safety complexities in management operations. Multiple teams working in tight quarters experience increased risks of accidents because proper communication and supervision become challenging when coordinating complex operations.

Minimizing safety risks in construction projects can be achieved through the effective utilization of Lean Construction together with the Last Planner System (LPS). The reduction of waste which Lean emphasizes naturally extends toward safety by striving to eliminate time-wasting and resource-consuming unsafe practices. Lean implementation includes efficiency elimination criteria which in safety practice means discovering potential risks and resolving them before incidents occur. Visual management systems from the Lean toolset enable organizations to show safety rules in an understandable manner which ensures workers continuously stay aware of threats in their work environment. Standard operating procedures (SOPs) and regular safety meetings jointly promote safe practices through which institutions reduce human errors and unsafe behaviors.

LPS helps reduce project safety risks through its key function to build effective stakeholder coordination. LPS implements pull planning and look-ahead planning methods which schedule work tasks based on resource availability and site conditions jointly for reducing hazardous situations caused by poor or hurried planning activities. LPS helps risk management throughout planning by converting projects into workable packages that reveal potential hazards before planning begins. Continuous improvement happens through weekly planning meetings which enable safety issues detection followed by discussion and action within ongoing operations (Qian & Lin, 2016).

The incorporation of Lean and LPS in underground metro station construction maintains safety excellence through organized planning standards and open communication practices together with active risk control methods that lead to safer workplaces and decreased accident occurrences (Singh, 2015).



Source: Cerexhe, J. What is a Risk Matrix? [Examples + Free Template]. Mastt. https://www.mastt.com/blogs/what-is-a-risk-matrix

Figure 6 Risk matrix illustrating likelihood versus impact levels**.**

4. Solutions and Mitigation Strategies

4.1. Lean Construction Application in Metro Station Projects

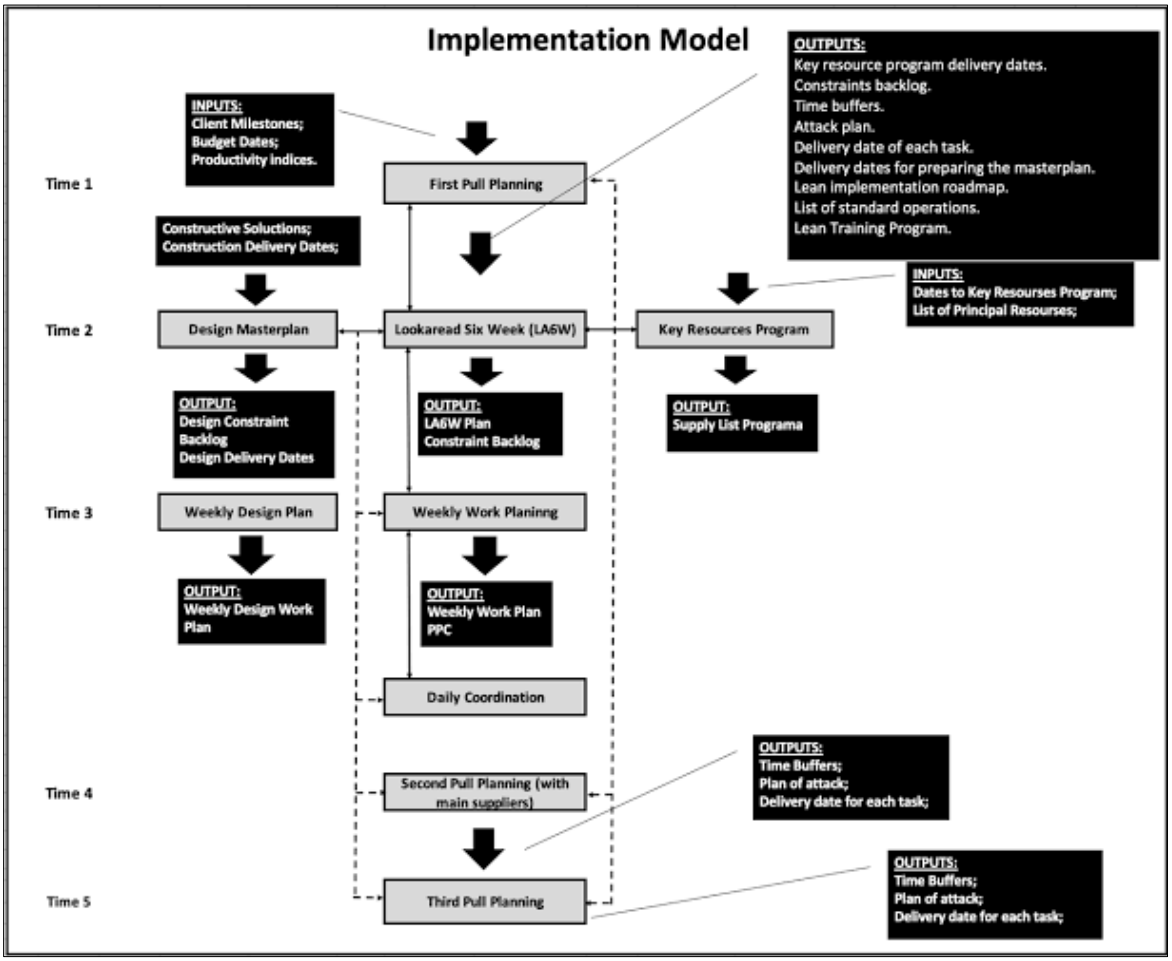
Velocities within metro station construction enhance their efficiency through Lean Construction application which streamlines operations and reduces waste throughout the project duration. Station-building operations become complicated because they necessitate wide-ranging stakeholders combined with elaborate engineering plans and demanding tunnel-digging activities. The systematic methods of Lean Construction enable project completion at higher speed with better safety and reduced costs through waste reduction together with value stream mapping and just-in-time (JIT) delivery practice.

The foundational principle of Lean Construction includes waste reduction as a means to deal with inefficient activities that could occur during any construction project. The construction of metro stations needs to minimize all delays while reducing the delivery of extra materials as well as transportation between sites and storage of excessive supplies. The implementation of Lean methods at a Saudi Arabian metro project optimized material use by managing construction material stockpile amounts effectively which allowed reduced storage requirements and minimized material decay risks (Allouzi & Al jaafreh, 2023). By using this delivery method projects receive materials right when they need them which reduces both time-based and money-based consequences of stockpiling.

Value stream mapping serves as a successful Lean tool which identifies activities that add no value during metro project development and implementation. Value stream mapping allowed project teams to identify workflow bottlenecks especially when teams responsible for structural and electrical work delayed communication with each other. Value stream mapping enabled the project team to see the complete process and identify unproductive areas that allowed them to restructure their workflow and implement solutions which cut down project delays and strengthened stakeholder coordination (Ivina & Olsson, 2020).

Metro station construction needs the Just-in-Time (JIT) delivery principle because of restricted site spaces and scarce resources. Through JIT delivery materials as well as equipment and workforce arrive precisely when needed thus avoiding project delays while minimizing storage needs. The London metro station construction project managed prefabricated component delivery through JIT methods so they arrived on time for swift installation that cut down construction labor requirements and waste generation (Bataineh, 2019). Such efficient delivery methods decreased operation costs while speeding up the project timeline.

In conclusion, the integration of Lean Construction principles in metro station projects results in enhanced efficiency, better resource utilization, and reduced waste. By employing strategies such as waste reduction, value stream mapping, and JIT delivery, metro construction projects can overcome challenges associated with complex planning, coordination, and resource management. The success of these principles in real-world projects demonstrates their value in delivering infrastructure efficiently and sustainably.



Source: Soares, A. Implementation Model of Lean Construction Concepts in Fast Building Projects. Lean Construction Blog. https://leanconstructionblog.com/Implementation-Model-of-Lean-Construction-Concepts-in-Fast-Building-Projects.html

Figure 7 Implementation model for Lean Construction in fast-track projects

4.2. Utilizing Last Planner System for Improved Coordination and Scheduling

The Last Planner System (LPS) establishes itself as a fundamental solution to enhance scheduling operations in metro station excavation work and construction development. Metro projects feature multiple stakeholders performing complex work schedules within shortened periods which results in major work interruptions when delays occur. The Last Planner System solves project execution problems through improved communication methods and enhanced planning accuracy which leads to work completion according to schedules.

The LPS depends primarily on collaborative scheduling because it promotes effective communication between every project member. Traditional scheduling methods implement top-down approaches because they make decisions independently from operational realities. As a result of LPS workers actively taking part in planning enhances their empowerment to contribute their direct task expertise. The actual capabilities together with constraints of the teams become visible through this process which makes schedules more realistic. The LPS planning system includes weekly consultative meetings between foremen and subcontractors which helps them identify upcoming project obstacles and modify schedules to resolve them in a metro station excavation project. The project reached smoother execution through a combined effort of both planners and the team members who provided input (Gautam et al., 2024).

The main benefit of LPS arises from its implementation of continuous improvement using regular feedback systems. Look-ahead planning as part of LPS asks teams to spot impediments to workflow in advance of task conduct. Through proactive measures teams can recognize potential obstacles including delivery delays or manpower deficits to execute prevention measures before operational problems emerge. The procedure of scheduling refinement alongside work plan adjustments through real-time feedback helps LPS generate precise project timeline forecasts while decreasing delay instances. LPS enabled smooth communication between excavation personnel and structural engineers during a metro project construction which resulted in uninterrupted completion of each construction phase (Castillo, Alarcón, & Salvatierra, 2018).

The planning stages benefit from LPS since it provides better accuracy to fulfill assigned tasks by focusing on reliable planning. The system demands team members to establish work plans while monitoring their achievement of set aims. The team can analyze the causes of any task deviation from planning to make suitable modifications for future projects. The process completes the project schedule enhancement by reducing delays and maintaining schedule reliability.

The Last Planner System enhances metro station excavation projects through better stakeholder coordination by improving team collaboration and through enhanced scheduling predictability and communication. Last Planner System delivers a structured framework that gives metro construction projects their required completion dates while maintaining budgets and reducing construction interruptions.

4.3. Integration of Lean and LPS with Digital Tools

Metro station construction projects experience revolutionary transformations through the combination of BIM and project management software with Lean Construction principles and Last Planner System (LPS). By implementing these tools, the coordination between teams enhances along with improved data precision to make construction processes more efficient resulting in overall process optimization. Project teams who implement synergies between Lean, Last Planner System and digital tools achieve simplified planning process along with minimized waste and better outcome predictability.

Through Building Information Modeling (BIM) professionals generate 3D digital models which showcase every component in an entire metro station project starting from design through to construction. The BIM system works in perfect harmony with Lean Construction by showing detailed visual representations that let teams spot problems before the design phase to lower the risk of construction issues. Constructors who use BIM together with LPS can maintain schedule alignment between project models and physical project requirements because BIM integrates with LPS. The use of BIM lets project teams find early design conflicts which helps prevent building-related waste during the construction phase (Allouzi & Al jaafreh, 2023).

The combination of Project management software with Lean and LPS generates a unified platform which enables central management of team tasks as well as resource distribution and task scheduling. The integration allows stakeholders to receive current information in order to enhance their communication and teamwork. Project teams achieve better task tracking capabilities through software real-time update features which help them adjust their strategies in real time. Homemade software solutions supporting LPS provide teams the ability to actively monitor "look-ahead" progress checkpoints as well as track task performance statistics against scheduled outputs. The system enables both improved forecasting accuracy and rapid issue response thus minimizing both equipment downtime and better usage of available resources (Belayutham et al., 2022).

When implemented correctly digital tools expose project data to all stakeholders including contractors and subcontractors as well as clients so they remain up to date with project progress. This project transparency enables smooth progression through Lean and LPS because all stakeholders base their decisions on shared information. Through integration of Lean and LPS with digital tools metro station construction projects acquire better efficiency and stronger adaptability for their building process.

The integration of BIM and project management software with Lean Construction and LPS enhances metro station construction projects by increasing their efficiency and making predictions more certain. The digital tools improve planning functions along with communication capabilities and coordination functions and at the same time minimize waste and delays to produce optimized construction outcomes.

5. Conclusion

The research demonstrates how Lean Construction (LC) with its Last Planner System (LPS) addresses critical issues in metro station tunneling as well as construction procedures. Planning and delivery of construction projects become faster and more efficient through Lean Construction methods which reduce waste while enabling continuous development and mapping out value streams. Lean principles operate to cut resource waste through their emphasis on just-in-time delivery and strengthened team coordination and goal alignment processes of all stakeholders.

The Last Planner System builds upon project performance excellence by establishing leading methods to manage scheduling and communication systems between project stakeholders. LPS facilitates planning collaboration which leads teams to produce realistic schedules and ensures reliable task performance and enhances project timeline prediction. Researchers discovered that LPS reduces project delays because it develops responsible work cultures which enable staff to share problems beforehand to enhance operational plans. The system achieves project control and improvement through its forward-thinking planning strategy which operates within real-time monitoring loops to detect potential issues before taking corrective actions.

Building Information Modeling (BIM) and project management software combined with LPS and Lean helped organizations optimize their resource coordination operations. Digital tools showed real-time analysis but this brought about better clarity for all stakeholders during their interactions. By integrating Lean along with LPS and digital technologies the construction sector receives an advanced solution which guides project management through metro station complexities thus enabling swifter progress with superior resource handling and enhanced efficiency.

The combination of Lean Construction and LPS methods proves incredibly successful at improving the efficiency and performance results in metro excavation and construction works. Digital integration enhances the performance of these methods by resolving scheduling problems and resource management issues and safety and coordination requirements present in contemporary subway projects.

5.1. Implications for Stakeholders

The outcomes presented in this study deliver key practical applications for both contractors and project managers and city planners who work in metro station construction. Contractors should implement Lean Construction principles which minimize inefficiencies through reducing waste and optimizing workflow management and material delivery time. Project completion times shorten while costs decrease when contractors adopt this approach so they can strengthen their position in the difficult market environment.

Project managers can leverage the Last Planner System to foster better communication and collaboration among different teams. By involving workers in the planning process and using weekly planning meetings, they can ensure that tasks are completed on time and address potential issues before they become roadblocks. This system’s focus on continuous feedback and adaptation helps maintain the project's momentum and ensures that any delays or disruptions are swiftly dealt with.

For city planners and government agencies, understanding the benefits of Lean and LPS is crucial for setting realistic project timelines and expectations. By incorporating these methodologies into planning processes, they can ensure that metro projects are completed more efficiently, with fewer cost overruns and delays. Moreover, their understanding of the importance of digital tools in project coordination allows for better oversight, transparency, and management of public resources.

Lean and LPS implementation in upcoming metro platform construction will create efficient results and enhance project quality because they unite stakeholders around common objectives. Urban infrastructure development will become more sustainable while delivering projects faster and using lower costs because of effective methodology implementation.

5.2. Recommendations and Future Research Directions

The implementation of Lean Construction principles as well as the Last Planner System should be adopted by professionals in the industry for their metro station projects according to the research findings. The achievement of these strategies relies on contractors and project managers who train all stakeholders about Lean methodologies and Last Planner System core principles. Regular team participation in planning meetings at collaborative sessions represents a necessary approach for keeping projects on schedule. Proficient use of digital tools incorporating BIM

together with project management software lets contractors conduct efficient workflows which facilitate real-time communications among all stakeholders.

Future research should analyze Lean and LPS implementation effects on metro station projects across extended periods to determine total cost benefits and time efficiencies together with safety performance values. Studies moving forward should work on creating complex digital solutions which unite with Lean and LPS to achieve better construction process optimization. The investigation should analyze how these methodologies function in combining multiple stakeholder management for complex private-public projects across different cultural settings. Additional research investigates the implementation of Lean and LPS across diverse geographic areas. The research would enhance the usefulness of Lean and LPS principles across all metro station projects worldwide.

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