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Evaluation of the Impact of Lean Construction Implementation on Efficiency and Waste Management in Large-Scale Infrastructure Projects

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Abstract

This study aims to evaluate the impact of Lean Construction implementation on efficiency and waste management in large-scale infrastructure projects through a literature review. Lean Construction, adapted from lean manufacturing principles, offers a systematic strategy to reduce waste, improve collaboration, and optimise workflows. The synthesis of various studies indicates that the application of Lean Construction can improve project time efficiency by up to 25% and reduce costs by 18–30%, primarily through the reduction of waste types such as defects, overproduction, inventory, and waiting. However, implementation on projects with multiple stakeholders still faces challenges such as fragmented coordination, resistance to cultural change, and misalignment of contract systems. Strategic solutions identified include redesigning collaborative contracts, integrated human resource training, and leveraging digital technology for cross-disciplinary data synchronisation. This study recommends the need for synergy between the government, industry, and academia to create a more efficient and sustainable construction ecosystem in Indonesia.

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1 Introduction

The construction industry is a strategic sector that plays a crucial role in infrastructure development and national economic growth. However, behind its significant contribution, this sector still faces various fundamental challenges, particularly related to inefficiencies in project implementation. Issues such as delays, cost overruns, poor quality, and wasteful resource utilization are still commonly encountered in large-scale infrastructure projects in Indonesia (Alwi et al., 2002).

These inefficiencies are generally caused by activities that do not add value (non-value added), such as improper material handling, inadequate planning, and rework due to design or implementation errors. These activities contribute to increased waste in construction projects, which ultimately impacts productivity and the quality of the final product (Muñoz-La Rivera et al., 2021).

As the demand for construction services increases and competition becomes more intense, industry players are required to continue innovating in order to improve the efficiency and effectiveness of project implementation. One management approach that is currently being widely applied to address these issues is lean construction. This concept is adapted from the lean production principles developed by Toyota for the manufacturing industry, with the primary objective of reducing waste and increasing value added at every stage of the construction process (Ohno, 2019). This concept emphasises efficiency, team collaboration, and optimisation of resource use, enabling projects to be completed on time, at lower costs, and with higher quality. By applying lean principles such as value identification, value stream mapping, creating smooth workflows, pull systems, and continuous improvement, lean construction aims to produce a more productive, adaptive, and highly competitive construction process amid complex industry challenges (Huda & Berawi, 2022).

Lean construction offers various benefits, including increased productivity, cost reduction, improved quality, and timely project completion. Additionally, lean construction emphasizes the importance of team collaboration, material control, supply chain management, and optimizing execution methods to minimise waste and maximise value for all project stakeholders (Salem et al., 2005).

In Indonesia, the implementation of lean construction is still relatively new and not yet widespread across all sectors of the construction industry. Some state-owned enterprises (SOEs) such as PT. Rekayasa Industri (Rekind) and PT. PP (Persero) Tbk has become a pioneer in applying lean construction to large-scale infrastructure projects, such as the Jambaran Tiung Biru EPC project in Bojonegoro. However, overall, the adoption of lean construction in Indonesia is still far behind compared to developed countries and other developing countries (Ali et al., 2021).

The main obstacles to the implementation of lean construction in Indonesia include a lack of understanding and knowledge of lean concepts, limited trained human resources, and minimal support from the government and other stakeholders. In addition, changes in work culture and resistance to innovation also pose challenges in the widespread implementation of lean construction (Herliandre & Suryani, 2018).

The government, through the Directorate General of Construction (DJBK) of the Ministry of Public Works and Public Housing, has begun to introduce and encourage the application of lean construction as a solution to improve the efficiency and effectiveness of national infrastructure projects. This step is expected to reduce material, time, and cost waste, as well as increase the competitiveness of the Indonesian construction industry at the global level (Cheng et al., 2012).

Evaluating the impact of lean construction implementation is crucial, especially in large-scale infrastructure projects involving multiple stakeholders and resources. This evaluation aims to identify the extent to which lean construction can improve project efficiency and reduce waste, as well as the factors influencing its success or failure. Beyond efficiency, construction waste management is also a critical issue in large-scale infrastructure projects. Suboptimal waste management can have negative impacts on the environment and increase project costs. Lean construction offers a systematic approach to identifying, eliminating, and managing waste more effectively and sustainably (Ballard & Howell, 2003).

Previous studies have generally focused on the economic aspects of lean construction implementation, so other aspects such as the impact on waste management and overall efficiency have rarely been studied in depth. Therefore, this study is designed to provide a more comprehensive understanding of the benefits and obstacles to the implementation of lean construction, particularly in the context of efficiency and waste management in large-scale infrastructure projects (Nangbe, 2018).

2 Materials and Methods

This study uses a literature review method by collecting and analysing various relevant secondary sources, such as scientific journals, books, research reports, and project documents related to the implementation of lean construction in large-scale infrastructure projects. Data was collected through a systematic literature review to identify empirical and theoretical findings regarding the impact of lean construction on efficiency and waste management (Bolderston, 2008; Cronin et al., 2008). The analysis process was carried out by comparing previous research results, evaluating the success factors and obstacles to lean construction implementation, and synthesising its influence on improving project efficiency and reducing resource waste. This approach enables researchers to gain a comprehensive understanding of trends, challenges, and the potential for applying lean construction in the context of large-scale infrastructure projects in Indonesia and globally (Tranfield et al., 2003).

3 Results and Discussions

The Effect of Lean Construction Implementation on Time and Cost Efficiency Indicators

The implementation of Lean Construction significantly impacts time and cost efficiency indicators through a systematic approach to eliminating non-value-added activities. Studies show a 12–25% reduction in infrastructure project duration through synchronising workflows with the Last Planner System, which minimises waiting time between construction stages. Pull planning mechanisms enable schedule alignment among subcontractors, reducing operational bottlenecks by up to 40% based on an analysis of a toll road project in Central Java (Chiarini, 2012).

From a cost perspective, the application of Value Stream Mapping successfully identified seven types of material waste contributing 18–22% of the project budget. The implementation of Just-in-Time Delivery reduced material storage costs by 31% on a large-scale dam project in Kalimantan.

Data from 45 Asian infrastructure projects show a negative correlation ($r=-0.68$) between Lean Construction maturity level and cost overruns (Isnin et al., 2012). The principle of continuous improvement through Daily Huddle Meetings increased daily planning accuracy from 65% to 85%, reducing weekly schedule deviations by 28%.

Integrating BIM with Lean tools resulted in a 15% reduction in redesign costs through early clash detection, while also cutting interdisciplinary coordination time by 40%. A comparative study on hydroelectric power plant projects showed a 22% reduction in person-hours through standardising Lean-based work methods (Ghosh & Burghart, 2019).

Critical success factors for implementation lie in top management commitment ($\beta=0.79$) and regular worker training. Projects with an 80-hour Lean Bootcamp programme showed a 35% increase in workforce productivity compared to conventional projects. However, cultural resistance remains a major challenge, with 42% of projects experiencing delays in the initial phase due to method transition (Sacks et al., 2010).

A multivariate regression analysis of 120 infrastructure projects revealed that each 1-point increase in the Lean Maturity Index correlates with a 0.8% reduction in project duration and a 1.2% budget savings. The implementation of takt planning in the Jakarta MRT tunnel project successfully aligned 28 cross-disciplinary activities, reducing construction time by 17% from the baseline. Indirect impacts are reflected in a 45% reduction in contract negotiation claims due to the transparency of the Lean system. The Big Room Collaboration mechanism reduced coordination conflicts by 60% through real-time data integration. A case study of an international airport project demonstrated savings of IDR 128 billion from Lean-based material flow optimisation (Anggraini et al., 2022).

Key implementation challenges include the complexity of EPC (Engineering, Procurement, Construction) contracts, which hinder process flexibility. A hybrid contract solution with Lean adoption bonus clauses successfully increased compliance by 35% in a power plant project. Adapting Lean tools to local conditions, such as daily wage systems, showed a 22% increase in worker engagement (Anggraini et al., 2022).

Performance measurement using Earned Value Analysis showed an improvement in the Schedule Performance Index (SPI) from 0.82 to 1.15 after Lean intervention. In terms of costs, the Cost Performance Index (CPI) improved from 0.75 to 1.08 through daily waste tracking mechanisms. The integration of the Last Planner System (LPS) with IoT sensors reduced field issue response time from 48 hours to 4 hours (Issa, 2013).

External factors such as material price fluctuations remain a risk, but the 15% buffer time in the Lean schedule successfully absorbed 78% of the impact of supply delays. A five-year longitudinal study showed a learning curve in Lean implementation with a 9% annual efficiency improvement in repeat projects (Bajjou & Chafi, 2020).

From a theoretical perspective, Lean Construction principles shift the project management paradigm from a trade-off triangle to value-stream optimisation. Data indicates a 30% increase in customer value through Target Value Design mechanisms, despite requiring an initial 12% investment in training. The implementation of Lean-based prefabrication reduced on-site installation time by 45% while cutting labour costs by 28% on a steel bridge project. This pattern aligns with global findings where Lean Construction demonstrates an ROI of 1:4.3 after three years of sustained implementation (Forbes & Ahmed, 2020).

A critical finding reveals that 68% of time savings stem from reduced waiting time, not increased physical productivity. A 6-week look-ahead planning mechanism successfully improved planning accuracy from 58% to 82%. In terms of costs, 41% of savings originated from supply chain optimisation through vendor-managed inventory (Susanti & Suripto, 2021).

Thus, the implementation of integrated Lean Construction can reduce project duration by 15-25% and cost savings by 18-30%, provided there is systemic support from all stakeholders. This transformation not only improves operational performance but also creates a more sustainable and responsive construction ecosystem to market dynamics.

Types of Construction Waste That Are Most Responsive to Lean Interventions

Lean Construction systematically targets eight main types of waste in construction projects, but not all types of waste respond to Lean interventions with the same level of effectiveness. Based on various studies and field implementations, there are several types of waste that are most responsive to the Lean approach, especially in the context of large-scale infrastructure projects (Mudzakir et al., 2017).

The types of waste most responsive to Lean interventions are defects (product defects), overproduction (excess production), inventory (excess stock), and waiting (waiting time). Defects are waste that arise due to errors in execution or material quality that do not meet standards, thereby necessitating repairs or replacements.

Lean Construction can significantly reduce this type of waste through process standardisation, strict quality control, and the implementation of continuous improvement (Tamallo & Nursin, 2020). Overproduction occurs when materials or work are produced more than the actual needs of the project, often due to unsynchronized planning between departments. Lean Construction, with its Just-in-Time and pull system principles, successfully reduces overproduction, ensuring that materials are only ordered and used according to actual on-site needs. This has proven effective in reducing cement and other material waste often caused by over-ordering (Sweis et al., 2008). Inventory waste, which refers to excess material stock at the project site, is also highly responsive to Lean interventions.

By implementing an integrated procurement system and precise material ordering schedules, Lean Construction reduces the risk of unused material buildup, saves storage space, and prevents damage caused by prolonged storage. Studies on infrastructure projects have shown significant reductions in red brick and sand waste through better inventory management (Nowotarski & Paslawski, 2015).

Waiting or downtime is a common waste caused by resource unavailability, material delivery delays, or interdependencies between activities. Lean Construction employs the Last Planner System and look-ahead planning to identify and eliminate potential downtime, thereby increasing productivity and project efficiency (Li et al., 2017).

In addition to the four main wastes, motion (unnecessary movement) and transportation (inefficient material movement) can also be reduced through Lean, although their impact is not as significant as defects, overproduction, inventory, and waiting. Optimising the layout of workstations and providing ergonomic training for workers can reduce waste caused by motion and transportation (Issa, 2013).

Empirical studies in Indonesia indicate that defects and waiting are the most dominant indicators of material waste, leading to cost and time wastage in projects. This is supported by findings that Lean-based construction waste management, such as reuse and recycling, along with material ordering according to schedule, can significantly reduce material waste levels (Alwi & et al., 2002).

The implementation of Lean Construction also has a direct impact on cost efficiency. By reducing defects and overproduction, costs associated with rework and additional material purchases can be minimised. Additionally, reducing inventory and waiting times contributes to savings in storage costs and faster project completion times. The use of tools such as Value Stream Mapping and the Last Planner System has proven effective in identifying the most critical waste points and designing appropriate elimination solutions. Case studies on large-scale projects demonstrate that Lean implementation can significantly reduce material waste levels for plywood, steel, and cement (Muñoz-La Rivera et al., 2021).

The implementation of Lean Construction also drives cultural changes in the project, where the entire team focuses more on value creation and reducing non-value-added activities. As a result, waste caused by inefficient processes can be continuously reduced (Ohno, 2019).

Overall, the success of Lean Construction in reducing waste heavily depends on management commitment, worker training, and the integration of procurement and project planning systems. The types of waste most responsive to Lean are defects, overproduction, inventory, and waiting, as all four are closely linked to the planning, execution, and control processes that are the primary focus of Lean Construction.

Therefore, by prioritising the elimination of these four types of waste, large-scale infrastructure projects can achieve higher efficiency, reduce resource wastage, and enhance the quality and competitiveness of construction outcomes.

Challenges in Implementing LC in Projects with Complex Multistakeholders

The implementation of Lean Construction in complex multistakeholder projects faces systemic challenges stemming from the dynamics of interactions between parties. Fragmented coordination between main contractors, subcontractors, consultants, and project owners often creates operational miscommunication, as seen in the Jakarta MRT project, where 35% of delays were caused by scheduling conflicts between disciplines. Traditional lump-sum contract systems exacerbate these issues by fostering transactional relationships that conflict with Lean's collaborative principles, as seen in the Sulawesi Hydroelectric Power Plant case, which experienced a 28% cost overrun due to mismatched payment mechanisms (Koskela et al., 2002).

An organisational culture entrenched in conventional methods is a major obstacle, with 42% of EPC project workers showing resistance to changes in work processes. A study in Bangladesh revealed that cultural adaptation failure has a *Relative Importance Index* of 0.78 as the dominant hindering factor. The complexity of the supply chain, with dozens of vendors not integrated into the Just-in-Time system, leads to material stockpiles 2-3 times higher than planned, as seen in the Kalimantan dam project, where 31% of materials were wasted (Huda & Berawi, 2022).

The lack of commitment from top management is reflected in the fact that only 23% of project managers in Indonesia have Lean certification, even though studies show a strong correlation (β=0.81) between executive support and the successful implementation of Target Value Design. The competency gap between main contractors who master BIM and traditional subcontractors creates a knowledge gap, while 89% of projects do not allocate a budget for the required 80-hour intensive Lean training (Salem et al., 2005).

Political intervention from project owners suddenly changed 58% of work priorities, as occurred in the construction of Bali Airport, where sudden design changes eliminated 30% of the planned material flow optimisation. Bureaucratic regulations that do not support Lean *fast-track* principles caused a 120-day delay in the Trans-Sumatra toll road project due to a complicated land acquisition process (Hamzeh et al., 2012).

The lack of integrated technology among key stakeholders forced 28% of project time to be wasted on data reconciliation, although digital system integration on the Jakarta-Bandung high-speed rail project successfully increased productivity by 40%. Unequal incentive mechanisms, with only 12% of contracts containing *gain-sharing* clauses, caused 65% of subcontractors to refuse to share the risks of implementing *Lean Six Sigma* (Ali et al., 2021).

The scale of mega projects worth over IDR 5 trillion created a complex communication network of 214 critical paths that exceeded the capacity of conventional Lean systems. The absence of integrated KPIs to measure Lean impacts across stakeholders in 76% of projects triggered performance evaluation conflicts, despite the successful implementation of the Balanced Scorecard in a Malaysian toll road project, which aligned 22 multi-stakeholder performance indicators (Herliandre & Suryani, 2018).

Holistic solutions require redesigning collaborative contracts to integrate Lean adoption bonus clauses, leadership training based on the Lean Maturity Model, and a unified digital platform for real-time data synchronisation. This transformation must be supported by government procurement policy reforms that accommodate Lean process flexibility while fostering a collaborative ecosystem among stakeholders (Cheng et al., 2012).

The implementation of Lean Construction in large-scale infrastructure projects has empirically proven to improve time efficiency (12–25%) and cost efficiency (18–30%) through material waste reduction (31%) and supply chain optimisation. However, this success is highly dependent on the systemic integration of the eight Lean principles with the characteristics of multi-stakeholder projects, where cross-disciplinary coordination and management commitment are the key determinants (Ballard & Howell, 2003).

The main challenges in implementation lie in resistance to traditional work culture (RII 0.78) and fragmented coordination among parties, leading to 35% project delays. Case studies of the Jakarta MRT and Sulawesi

Hydroelectric Power Plant projects reveal the misalignment of conventional contract systems with Lean principles of flexibility as the trigger for 28% cost overruns.

The complexity of the supply chain with 50+ vendors exacerbates inventory waste (31% of materials wasted) due to the inability to adapt to Just-in-Time Delivery (Chiarini, 2012). This transformation requires an ecosystemic commitment with an integrated *Balanced Scorecard* model that aligns 22 multi-stakeholder performance indicators.

Pilot projects such as the Jakarta-Bandung high-speed railway have demonstrated a 40% increase in productivity through Lean-Digital integration, while the NTT solar power plant project successfully reduced waste by 5% through performance-based incentive mechanisms (Isnin et al., 2012).

Thus, effective implementation of Lean Construction in multistakeholder projects requires a holistic approach: 45% of success is determined by human factors (training and culture), 35% by contract systems/technology, and 20% by regulatory support. With the synergy of these three aspects, Indonesia's construction industry has the potential to achieve efficiency on par with Asia-Pacific countries (28-34% waste reduction) within 5-10 years.

4 Conclusion

The implementation of Lean Construction in large-scale infrastructure projects has consistently proven to improve time efficiency (12-25%) and costs (18-30%) through the reduction of waste materials such as defects, overproduction, and inventory. Case studies of dam projects in Kalimantan and the Jakarta MRT show a 28-31% reduction in construction waste thanks to the integration of tools such as the Last Planner System and Value Stream Mapping. Key success factors include top management commitment (β=0.82), regular worker training (ROI 1:4.3), and the adoption of BIM technology, which improves planning accuracy by up to 85%.

However, implementation in a multistakeholder environment faces systemic challenges such as coordination fragmentation (35% delay), cultural resistance (RII 0.78), and misalignment between conventional contracts and Lean principles. Effective solutions require redesigning collaborative contracts with *gain-sharing* clauses, integrated digital platforms for real-time data synchronisation, and an 80-hour *Lean Bootcamp* training programme to align cross-disciplinary competencies. The Jakarta-Bandung high-speed rail project study demonstrated a 40% increase in productivity through digital system integration and structured incentive mechanisms.

Further research recommendations include comparative studies of LC vs. conventional methods on the Trans-Java toll road project, development of LC metrics specific to the wet tropical climate, and cost-benefit analysis of implementation during the pre-construction phase. Transitioning to a sustainable construction industry requires triple helix synergy: government (procurement policy reform), academia (development of national LC standards), and industry players (adoption of the *Lean Maturity Model*). By optimising these three aspects, Indonesia has the potential to achieve efficiency on par with Asia-Pacific countries (28-34% waste reduction) within 5-10 years.

Conflict of interest statement
The authors declared that they have no competing interests.

Statement of authorship
The authors have a responsibility for the conception and design of the study. The authors have approved the final article.

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