

Strategies for achieving sustainable infrastructure through lean construction optimization in the Indonesia Dam Project

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Abstract. Dams are critical infrastructure that support water security, energy production, food resilience, and disaster risk reduction in Indonesia's rapidly developing regions. However, conventional delivery of dam projects still suffers from delays, cost overruns, and waste arising from fragmented planning and low workflow reliability. This study investigates how Lean Construction, particularly the Last Planner System (LPS) integrated with Building Information Modeling (BIM), can enhance performance in the Tiga Dihaji Dam Project Package 4. An explanatory sequential mixed-methods design was adopted, combining document review, site observations, and structured discussions with project stakeholders, followed by quantitative evaluation of schedule and productivity indicators. The results show that collaborative planning, weekly coordination, constraint removal, and visual control through BIM support more reliable task commitments, reduce rework and waiting, and improve information flow. Lean implementation also decreased non-value-adding activities such as overproduction, excessive inventory, and unnecessary material handling on site. Overall, Lean-LPS implementation contributed to measurable performance gains, including significant schedule acceleration ($R_a \approx 96.7\%$; $R_i \approx 97.2\%$), while reinforcing sustainable infrastructure outcomes, organisational learning, and alignment with national dam development policies and Sustainable Development Goals targets. The findings provide practical guidance for scaling Lean practices to other Indonesian dam projects and large infrastructure programs.

1 Introduction

Indonesia relies heavily on dams and related water infrastructure to secure raw water supply, irrigation, hydropower generation, and flood control in the face of rapid urbanisation, population growth, and climate variability [1,3]. National strategic dam programmes are expected to strengthen water security, food resilience, and regional development in line with SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy), and SDG 13 (climate action) [2,3]. However, the delivery of large dam projects still faces recurring schedule delays, cost overruns, and productivity losses driven by high

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technical complexity, dispersed locations, multi-contract structures, and resource constraints [2,4,6]. Recent studies on Indonesian infrastructure projects also reveal persistent waste in the form of waiting, rework, unnecessary material movements, and other non-value-adding activities [5,8,11]. Lean Construction (LC) has been promoted as a systematic approach to minimize waste, stabilize flow, and maximize value for clients and users, with empirical evidence showing improvements in time performance, efficiency, and sustainability outcomes in public-sector and large-scale projects [7,8,10,12]. Within LC, the Last Planner System (LPS) functions as a practical planning and control tool that enhances workflow reliability through collaborative look-ahead planning, constraint removal, and commitment-based weekly planning [5,9,13]. The integration of LPS with digital technologies such as Building Information Modeling (BIM) further strengthens visualization, coordination, and data-driven decision-making on complex infrastructure projects [14,15]. Significant studies have highlighted that megaproject environments, such as dam construction, are particularly vulnerable to planning instability, inadequate constraint identification, and inefficient communication flows, which collectively hinder sustainable performance outcomes. This paper examines how LPS, supported by BIM, can be implemented in the Tiga Dihaji Dam Project Package 4 to improve schedule performance, reduce waste, and support sustainable dam infrastructure development in Indonesia. Combining LPS and BIM supports real-time production control, early clash detection, and more accurate forecasting on infrastructure megaprojects, such as Dam Project.

2 Review of key concepts and practices in dam construction

2.1 Sustainable infrastructure development

Sustainable dam development integrates environmental, economic, and social objectives across the asset life cycle—preserving ecosystems, using resources efficiently, and supporting community well-being—while contributing to SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy), and SDG 13 (climate action) [3]. In Indonesia, national strategic dam programmes are expected to enhance water security and resilience, yet implementation is still constrained by resource inefficiencies, cost overruns, and fragmented stakeholder coordination [2,4,6]. Lean Construction (LC) offers a process-oriented pathway to address these challenges by minimising waste, stabilising flow, and maximising value for users and affected communities [7,8,10,11,13]. In dam projects, LC practices such as collaborative planning, constraint removal, and reliable work structuring help synchronise civil works, electro-mechanical installation, and environmental mitigation, while LC–BIM integration strengthens visualisation, communication, and data-driven decision-making in support of long-term sustainability and resilience goals [5,7,8,10,11,14,15].

2.2 The last planner system (lps) in construction projects

Lean Construction (LC) adapts principles of the Toyota Production System to the built environment by eliminating non-value-adding activities, stabilising flow, and

maximising value from the client’s perspective [10,13]. In construction, waste includes rework, waiting, unnecessary transport, and other activities that consume resources without contributing to the final product, and empirical studies in Indonesian projects show that LC can reduce these wastes while improving productivity and sustainability outcomes [7,8,10,12]. LC promotes the integration of design, procurement, and construction processes to enhance workflow reliability, collaboration, and project predictability [7,10,11,13]. Within this framework, the Last Planner System (LPS) is a key production-control tool that increases planning reliability through commitment-based, collaborative planning, combining master scheduling, phase planning, look-ahead planning, and weekly work planning so that only “ready” tasks are released to site [5,9,13]. Evidence from various project settings indicates that LPS improves schedule adherence, productivity, and communication among stakeholders, but successful implementation requires cultural and organisational change, including strong leadership support and continuous training [5,9,12,13]. In Indonesia, empirical applications of LPS in large-scale infrastructure, including dam projects, are still emerging [5,6,12], so integrating LPS into dam construction management offers an opportunity to systematically reduce process waste, improve workflow reliability, and support national goals for sustainable infrastructure development.

3 Research methodology

3.1 Research design

This study employed a sequential mixed-methods case study design to explore strategies for achieving sustainable infrastructure through Lean Construction optimisation in an ongoing dam project in Indonesia. The research began with a qualitative phase, including semi-structured interviews, site observations, and document analysis, to capture current planning and control practices, implementation challenges, and opportunities for applying lean principles in sustainable dam construction.

Insights from the qualitative phase were then used to guide a follow-up quantitative assessment of schedule and productivity indicators in order to examine how lean implementation related to observable performance improvements. Triangulation of interview, observational, documentary, and numerical data enhanced the credibility and validity of the findings. This design was chosen to capture both the technical and contextual dimensions of lean implementation, providing a comprehensive understanding of its role in supporting sustainable infrastructure development in Indonesia.

3.2 Case study

The Tiga Dihaji Dam Project Package 4 is a major infrastructure initiative in Indonesia, designed to enhance water security, flood control, and energy generation (see Fig. 1). The project involves multiple contractors and subcontractors, complex construction phases, and intensive stakeholder coordination, making it an ideal case for evaluating LPS

implementation. Key performance aspects, such as: time, cost, productivity, and quality, were monitored to assess improvements associated with Lean practices.



Fig. 1. Technical Data 3Dihaji Dam.

3.3 Data collection and analysis

Qualitative data were collected to deepen understanding of LPS implementation and its perceived effects on project performance. Data sources comprised semi-structured interviews with project managers, supervisors, contractors, subcontractors, and consultants, on-site observations of look-ahead and weekly work planning meetings, and document analysis of project schedules, reports, and LPS records. Thematic analysis was used to identify recurring patterns, challenges, and success factors in LPS adoption, and these findings were then triangulated with quantitative project data on schedule and productivity. This integration enabled a more robust explanation of how LPS contributes to workflow reliability, waste reduction, and sustainable project delivery in the Tiga Dihaji Dam Project Package 4, while capturing both measurable outcomes and stakeholder experiences in evaluating Lean Construction practices.

4 Results and discussion

4.1 Lean implementation practices in tiga dihaji dam project package 4

In the Tiga Dihaji Dam Project Package 4, Lean Construction principles were implemented through a structured application of the Last Planner System (LPS) to enhance workflow reliability, minimise waste, and strengthen stakeholder collaboration. Key practices included master schedule and milestone planning, pull planning and rolling schedules, daily huddle meetings, make-ready and weekly planning, joint surveys, waste material control, mock-up concrete optimisation, and joint inspections. The master schedule provided an overall coordination framework, while pull planning enabled collaboratively sequenced tasks driven by downstream demand. Daily huddles supported short-term coordination and constraint removal, with Percent Plan Complete (PPC)

improving from about 65% to over 85% during implementation. Make-ready planning, supported by a biweekly readiness checklist, reduced stoppages and delays, and weekly planning meetings reinforced accountability and continuous improvement through regular review of commitments. Joint surveys and inspections fostered integration among contractors, consultants, and the owner, reducing rework and improving quality, while lean waste-control strategies and mock-up concrete trials optimised material use and work accuracy. Overall, these practices collectively improved coordination, reduced variability, and supported more sustainable project delivery.

The main Lean practices applied in the Tiga Dihaji Dam Project Package 4 consisted of master schedule and milestone planning, pull planning with rolling schedules, daily huddle meetings, make-ready and weekly planning, joint surveys, control of waste materials, mock-up concrete optimisation, and joint inspections. Together, these practices aimed to align key deliverables, increase workflow reliability, ensure task readiness, and reinforce accountability. Their implementation was associated with improved coordination among disciplines, higher Percent Plan Complete (PPC), fewer stoppages and measurement errors, measurable reductions in material wastage, and a stronger learning and collaboration culture across project teams

4.2 Waste reduction through lps and bim integration

The implementation of the Last Planner System (LPS) in the Tiga Dihaji Dam Project Package 4 significantly reduced construction waste, particularly waiting time, rework, and material overuse. A key enabler was the integration of Building Information Modeling (BIM) for clash detection, which allowed design conflicts between structural, mechanical, and civil works to be identified and resolved before construction (Fig. 2). By visualising potential clashes and their impacts on sequencing, BIM-supported planning meetings helped the team adjust workflows, manage constraints more effectively, and prevent resource-intensive rework. Interviews with project managers and observations of planning sessions confirmed that BIM-based clash detection improved the reliability of task completion and reduced non-value-adding activities. This LPS-BIM combination is consistent with previous studies that highlight the synergy between Lean Construction and digital technologies in enhancing planning reliability, visualising workflow, and controlling variation to achieve waste reduction [14,15].

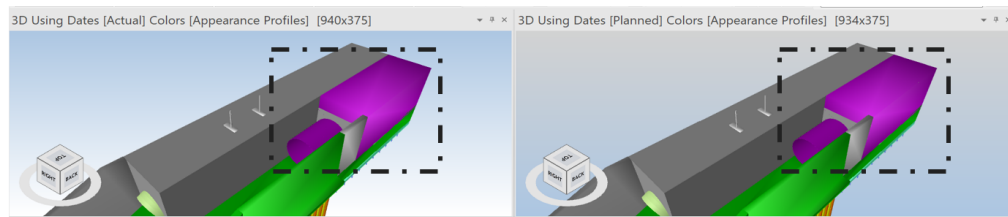


Fig. 2. BIM and Lean Construction Integration.

design stages, provide structured training and strong leadership support, and continuously monitor performance metrics so that Lean Construction and digital technologies can consistently reinforce high-performance, sustainable project delivery.

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