# Assessing Lean Construction Implementation in Excavation Operations of a Large-Scale Dam Project

**Dedi Chandra Lumbantoruan**
Department of Civil Engineering, Hasanuddin University, Gowa, Indonesia
dedi.chandra@wikamail.id

**Rosmariani Arifuddin**
Department of Civil Engineering, Hasanuddin University, Gowa, Indonesia
rosmarianiarifuddin@unhas.ac.id (corresponding author)

**Asad Abdurrahman**
Department of Civil Engineering, Hasanuddin University, Gowa, Indonesia
asad@unhas.ac.id

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## ABSTRACT

**This study applies Lean Construction principles to excavation work, analyzes the effectiveness of Lean tools in maintaining workflow stability, and identifies key factors influencing operational efficiency. Through quantitative descriptive methods, this research uses a case study of the Jenelata Dam Project in South Sulawesi, Indonesia, with primary data obtained from 42 respondents directly involved in excavation operations. The results indicate that Lean Construction is effectively implemented, with the Last Planner System (LPS) and Daily Huddle Meetings (DHMs) being the key factors, achieving Relative Importance Index (RII) values of 0.93 and 0.90, respectively. These findings indicate that daily coordination and structured planning can mitigate common obstacles, such as workflow instability and field coordination challenges, which often occur in dam projects in Indonesia. Furthermore, the analysis shows that supply chain integration and real-time evaluation of obstacles through short coordination meetings are determining factors in reducing wasted time. It is concluded that project management interventions should prioritize strengthening the participatory planning system and standardizing daily communication to improve excavation productivity. These results provide practical guidance for stakeholders to accelerate construction and strengthen the Lean Construction implementation in large-scale water resource infrastructure development.**

***Keywords-lean construction; dam excavation; dam engineering; workflow stability; Last Planner System; daily huddle meetings; relative importance index; construction productivity***

## I. INTRODUCTION

Water resource infrastructure, including dams, is designed to regulate, store, and distribute water to support flood control, irrigation systems, and the overall management of water resources that underpin regional development [1]. In gravity dam construction, meticulous planning and precise execution during foundation excavation are significant, as excavation accuracy and slope stability are decisive factors for long-term structural integrity [2]. There is a need to develop excavation methods that are not only safe but also efficient to support the rapid development of water resource infrastructure [3]. Excavation activities on dam projects are characterized by high variability and complex coordination, which often leads to inefficiencies if not properly managed [4]. The demand for efficient execution of construction projects poses significant challenges. This is due to the construction industry's highly fragmented, project-based nature and slow technology adoption. This lack of integration directly impacts inefficiency, project delays, and cost overruns [5]. In the Indonesian context, a gap has been identified between actual infrastructure implementation and construction sustainability, primarily due to poor construction practices and commercial restraints. These challenges are further intensified by human resource factors, which hold the highest Internal Factor Score (IFSC) of 1.6, indicating their critical role in successful construction strategies [6]. Despite their importance, projects often face a lack of technical knowledge and motivation among local labor, which hinders the adoption of efficient methodologies. Without the proper tools to manage uncertainty and opportunity, large-scale projects often fail to optimize resource use and proactively mitigate risks [7]. One of the main obstacles to professional development, especially in public works projects, is the lack of knowledge regarding modern management techniques. The lack of technical knowledge among construction personnel and the high construction costs are often cited as reasons for the limited adoption of efficiency methodologies [8]. In this context, Lean Construction provides a structured approach to support excavation activities by improving process organization and reducing inefficiencies in construction operations. The application of Lean principles reduces process variability through more collaborative and transparent planning [9].

Lean Construction focuses on value creation, waste elimination, and continuous process improvement. Workflow visualization is crucial because it allows teams to understand how tasks align with project demands. Successful implementation depends heavily on top management support and effective communication and coordination between all parties [10]. The systematic implementation of Lean tools enables better team coordination and more adaptive managerial processes in the face of project complexity [11]. Techniques such as Just-In-Time (JIT) and Value Stream Mapping (VSM) can be used to analyze the entire manufacturing cycle and schedule resources exactly when they are needed [12]. However, the implementation of Lean Construction in dam projects, particularly in excavation work, remains underexplored in the academic literature. Much of the existing Lean Construction literature emphasizes the application of Lean tools and techniques in building and industrial construction projects, primarily to enhance overall project management performance [13]. Considering the complexity and variability of excavation processes, such as haul distance, equipment synchronization, geological uncertainty, and weather conditions, there is a need to evaluate how Lean tools can improve workflow efficiency in dam construction environments.

The present study examines Lean Construction implementation in the excavation phase of the Jenelata Dam Project in South Sulawesi, Indonesia. The research identifies the most influential Lean tools, evaluates workflow performance using the Relative Importance Index (RII), and highlights barriers that hinder Lean application. The findings aim to provide practical insights for improving excavation efficiency and strengthening Lean adoption in large-scale dam projects.

## II. METHODOLOGY

### A. *Research Framework*

This study employed a descriptive quantitative method to evaluate Lean Construction implementation in the excavation works of the Jenelata Dam Project. The research framework was developed to answer the following research objectives:

- Assessing the level of implementation of six Lean Construction tools—Last Planner System (LPS), Daily Huddle Meetings (DHMs), JIT, SMART Goals, VSM, and 5S (Sort, Set in Order, Shine, Standardize, and Sustain).
- Comparing the relative dominance of these tools based on their influence on excavation workflow performance.

The research process involved several stages, including variable identification, development of Lean indicators, distribution of structured questionnaires, and quantitative data analysis using validity tests, reliability tests, and the RII. These stages ensured that the findings aligned with the study objectives and provided an understanding of Lean Construction performance in excavation operations. A summary of the research strategy and expected outcomes is presented in Table I.

TABLE I. RESEARCH OPERATIONAL FRAMEWORK

| Research questions | Strategies | Expected outcomes |
|---|---|---|
| RQ1: What is the level of implementation of the six Lean Construction tools (LPS, DHM, JIT, SMART, VSM, 5S) in the excavation works of the Jenelata Dam Project? | i) Data collection: Literature review and structured questionnaires | a) Identification of the implementation level of each Lean tool<br>b) Classification of Lean tools into "High," "Moderate," and "Low" implementation categories<br>c) Establishment of a baseline performance profile for Lean Construction in excavation works<br>d) Quantitative mapping of Lean practices already functioning in the project |
| | ii) Data analysis: Validity test and reliability test (Cronbach's Alpha) | |
| RQ2: How dominant is each Lean Construction tool in influencing excavation workflow efficiency? | i) Data collection: Questionnaire results from RQ1 | a) Ranking of Lean tools based on their influence on workflow efficiency<br>b) Identification of the strongest contributors (e.g., LPS, DHM) and the least influential tools (e.g., SMART, 5S)<br>c) Determination of key impact factors such as productivity, cycle time, coordination, and stability of excavation activities<br>d) Evidence-based prioritization of Lean tools that should be strengthened in the project |
| | ii) Data analysis: RII and ranking | |

### B. *Data Collection*

Primary data were collected using structured questionnaires distributed to personnel directly involved in excavation work, including engineers, supervisors, equipment coordinators, and field inspectors. Secondary data were obtained from project reports, scientific journals, prior studies, and documentation related to Lean Construction practices and excavation operations. The structured questionnaire consists of indicators representing six Lean tools: LPS, DHMs, JIT, VSM, SMART Goals, and 5S.

### C. *Population and Sample*

The population of the study consisted of construction personnel participating in excavation activities within the Jenelata Dam Project. A purposive sampling technique was applied, resulting in 42 qualified respondents. Selection criteria included a minimum of five years of field experience and at least a diploma (D3) or a bachelor's degree (S1) in engineering.

The respondents represented key stakeholders, including supervisors, engineers, equipment operators, subcontractor coordinators, and site managers. This composition ensured that the data reflected actual operational conditions in excavation workflows.

### *D. Data Analysis*

#### *1) Validity Test*

Instrument validity was assessed using the item–total correlation method to determine whether each indicator appropriately measured the research construct. An item was considered valid if its correlation coefficient exceeded the critical r-value from the r-table at 5% significance level [14].

#### *2) Reliability Test*

Instrument validity was assessed through item-total correlation, with all indicators exceeding the minimum r-table value for $N = 42$. Reliability testing was conducted using Cronbach's Alpha, with all constructs achieving values above 0.70, indicating acceptable internal consistency for quantitative analysis [14].

#### *3) RII Analysis*

The RII method was used to rank Lean indicators by their influence level. RII values range from 0 to 1, where higher values indicate a stronger influence on workflow performance. This approach enables identifying dominant Lean tools and critical factors affecting excavation efficiency [15]. To quantify the importance of each factor, respondents' perceptions were captured using a five-point Likert scale. The responses were weighted accordingly, and the RII was calculated to normalize the influence level of each factor:

$$RII = \frac{\Sigma \mathrm{W}}{A \times N} \tag{1}$$

where W refers to the maximum attainable scale value, and $N$ is the total number of responses.

## III. RESULTS AND DISCUSSION

### *A. Identification of Lean Construction Factors Affecting Excavation Performance*

Based on an extensive literature review, several factors related to Lean Construction practices that influence excavation workflow efficiency, productivity, and project performance were identified. These factors represent key dimensions of Lean implementation commonly applied in construction projects, particularly in earthwork and dam construction activities. The identified factors were classified into six main Lean Construction tools and are presented in Table II.

TABLE II. LEAN CONSTRUCTION INDICATORS FOR EXCAVATION WORKFLOW EFFICIENCY

| Tools | Code | Indicators | Reference |
|---|---|---|---|
| LPS | X1.1 | Master schedule: The excavation execution schedule is developed comprehensively from the beginning to the completion of the excavation works. | [16, 17] |
| | X1.2 | The team records and analyzes weekly causes of excavation delays and implements corrective actions for subsequent work plans. | [16, 17] |
| | X1.3 | Lookahead planning: Potential constraints affecting excavation works are identified and mitigated during planning stages. | [16, 17] |
| | X1.4 | Weekly work plan: Excavation volume targets and work locations are determined through weekly planning. | [16, 17] |
| | X1.5 | Percent Plan Complete (PPC): Excavation progress is monitored daily and compared with weekly plans. | [16, 17] |
| VSM | X2.1 | The excavation workflow (cutting, loading, hauling, dumping) is clearly mapped using process diagrams. | [12, 18] |
| | X2.2 | Heavy equipment utilization is planned according to actual needs without overuse. | [12, 18] |
| | X2.3 | All personnel understand their roles and work sequence within the excavation process flow. | [12, 18] |
| JIT | X3.1 | Subcontractor mobilization is conducted on time and aligned with the excavation schedule. | [12, 19] |
| | X3.2 | Supporting materials for excavation works, such as fuel and spare parts, are consistently available when needed. | [12, 19] |
| | X3.3 | Heavy equipment arrives on-site according to daily schedules without causing excavation delays. | [12, 19] |
| SMART Goals | X4.1 | Specific: Daily excavation volume targets are clearly and precisely defined. | [9] |
| | X4.2 | Measurable: Excavation outputs are measured quantitatively, such as m³/day or working hours per volume. | [20] |
| | X4.3 | Achievable: Excavation targets are realistic and achievable with available resources. | [20] |
| | X4.4 | Relevant: Excavation goals align with the main objectives of the dam project (e.g., critical schedule and area readiness). | [20] |
| | X4.5 | Time-bound: Each excavation task has a clearly defined completion deadline communicated to all teams. | [20] |
| DHMs | X5.1 | DHMs are conducted every day before excavation activities commence. | [17] |
| | X5.2 | Technical problems encountered on the previous day are discussed, and follow-up solutions are determined during daily meetings. | [17] |
| | X5.3 | Field teams (foremen, heavy equipment operators, and site engineers) actively participate in DHMs. | [17] |
| 5S | X6.1 | Sort: Unnecessary tools and materials are promptly removed from excavation work areas. | [21] |
| | X6.2 | Set in order: Heavy equipment, auxiliary tools, and safety signs are placed in designated locations. | [21] |
| | X6.3 | Shine: Excavation work areas are cleaned daily after work completion. | [21] |
| | X6.4 | Standardize: Cleanliness and orderliness of excavation areas are consistently maintained by all teams. | [21] |
| | X6.5 | Sustain: Field personnel are accustomed to maintaining workplace organization according to 5S standards. | [21] |

Table II presents the principal Lean Construction indicators identified through an extensive literature review, classified according to the six core Lean tools applied in this study. This classification serves as the foundation for/contributes to the development of the questionnaire used to assess Lean Construction implementation in excavation works. The selected indicators have been supported by multiple prior studies and are relevant and applicable to dam excavation projects.

### *B. Validity Test*

To ensure that the measurement instrument accurately represents the research constructs, a validity test was conducted to evaluate the appropriateness of the questionnaire items. Validity assessment is essential to confirm that each indicator effectively measures aspects of Lean Construction implementation in excavation works. The instrument's validity was examined using the item–total correlation method, in which indicators with correlation coefficients exceeding the critical r-value at the 5% significance level were considered valid. The results of the validity test are presented in Table III.

TABLE III. VALIDITY TEST RESULTS FOR LEAN CONSTRUCTION INDICATORS (ITEM-TOTAL CORRELATION)

| Tools | Code | r-value |
|---|---|---|
| LPS | X1.1 | 0.615 |
| | X1.2 | 0.713 |
| | X1.3 | 0.567 |
| | X1.4 | 0.659 |
| | X1.5 | 0.662 |
| VSM | X2.1 | 0.695 |
| | X2.2 | 0.651 |
| | X2.3 | 0.565 |
| JIT | X3.1 | 0.568 |
| | X3.2 | 0.749 |
| | X3.3 | 0.642 |
| Smart Goals | X4.1 | 0.686 |
| | X4.2 | 0.549 |
| | X4.3 | 0.757 |
| | X4.4 | 0.706 |
| | X4.5 | 0.583 |
| DHMs | X5.1 | 0.565 |
| | X5.2 | 0.704 |
| | X5.3 | 0.676 |
| 5S | X 6.1 | 0.646 |
| | X 6.2 | 0.607 |
| | X 6.3 | 0.690 |
| | X 6.4 | 0.566 |
| | X 6.5 | 0.692 |

As displayed in Table III, all questionnaire items demonstrated satisfactory validity, with item–total correlation coefficients exceeding the critical r-table value (0.304) for each indicator. These results confirm that all variables adequately represent the constructs measured in this study and are appropriate for subsequent analysis.

### *C. Reliability Test*

To ensure the measurement instrument's consistency, a reliability test was conducted to assess the internal consistency of the questionnaire items for the six Lean Construction tools applied in excavation work. Reliability was evaluated using the Cronbach's Alpha coefficient. The results of the reliability test are illustrated in Table IV, demonstrating that all Lean Construction indicators used in this study achieved Cronbach's Alpha values greater than 0.60. This confirms that the questionnaire items exhibit acceptable internal consistency and are reliable for further statistical analysis, including the RII evaluation. Therefore, the instrument is considered suitable for assessing the implementation level.

TABLE IV. RELIABILITY TEST RESULTS FOR LEAN CONSTRUCTION INDICATORS (CRONBACH'S ALPHA)

| Tools | Code | Cronbach's Alpha |
|---|---|---|
| LPS | X1.1 | 0.94 |
| | X1.2 | 0.93 |
| | X1.3 | 0.94 |
| | X1.4 | 0.94 |
| | X1.5 | 0.94 |
| VSM | X2.1 | 0.93 |
| | X2.2 | 0.94 |
| | X2.3 | 0.94 |
| JIT | X3.1 | 0.94 |
| | X3.2 | 0.93 |
| | X3.3 | 0.94 |
| Smart Goals | X4.1 | 0.93 |
| | X4.2 | 0.94 |
| | X4.3 | 0.93 |
| | X4.4 | 0.93 |
| | X4.5 | 0.94 |
| DHMs | X5.1 | 0.94 |
| | X5.2 | 0.93 |
| | X5.3 | 0.94 |
| 5R | X 6.1 | 0.94 |
| | X 6.2 | 0.94 |
| | X 6.3 | 0.93 |
| | X 6.4 | 0.94 |
| | X 6.5 | 0.93 |

### *D. Calculation of RII*

The procedure for calculating the RII is demonstrated using sub-variable X1.1 as an example:

$$RII = \frac{5(n_5)+4(n_4)+3(n_3)+2(n_2)+1(n_1)}{A\ x\ (n_5+n_4+n_3+n_2+n_1)}$$

$$RII = \frac{5(28)+4(13)+3(1)+2(0)+1(0)}{5\ x\ (28+13+1+0+0)}$$

$$RII = 0.93$$

TABLE V. RII ANALYSIS RESULTS FOR LEAN CONSTRUCTION INDICATORS

| Tools | Code | RII |
|---|---|---|
| LPS | X1.1 | 0.93 |
| | X1.2 | 0.92 |
| | X1.3 | 0.92 |
| | X1.4 | 0.96 |
| | X1.5 | 0.93 |
| VSM | X2.1 | 0.88 |
| | X2.2 | 0.91 |
| | X2.3 | 0.92 |
| JIT | X3.1 | 0.93 |
| | X3.2 | 0.88 |
| | X3.3 | 0.87 |
| Smart Goals | X4.1 | 0.91 |
| | X4.2 | 0.89 |
| | X4.3 | 0.88 |
| | X4.4 | 0.91 |
| | X4.5 | 0.90 |
| DHMs | X5.1 | 0.92 |
| | X5.2 | 0.91 |
| | X5.3 | 0.90 |
| 5R | X 6.1 | 0.87 |
| | X 6.2 | 0.88 |
| | X 6.3 | 0.86 |
| | X 6.4 | 0.86 |
| | X 6.5 | 0.86 |

The RII analysis, presented in Table VI, provides a quantitative overview of the implementation level of Lean Construction tools in excavation works. Based on the interpretation criteria, all indicators recorded RII values greater than 0.80, indicating a very high level of Lean Construction implementation across the six evaluated tools. This result demonstrates that Lean principles have been comprehensively adopted during the excavation phase of the project.

TABLE VI. RII VALUE INTERPRETATION CRITERIA

| **RII value** | **Interpretation** |
|---|---|
| 0.8 – 1 | Very high (excellent level of implementation) |
| 0.6 – 0.79 | High |
| 0.4 – 0.59 | Moderate |
| 0.2 – 0.39 | Low |
| 0 – 0.19 | Very low |

The LPS exhibits the strongest implementation performance, with RII values ranging from 0.92 to 0.93. This complies with existing research, according to which the implementation of the Final Planning System (as one of the main pillars) has been proven to significantly reduce project duration by 15.57% [16]. Indicators related to master scheduling, weekly delay analysis, lookahead planning, weekly work planning, and PPC consistently achieved very high RII scores. These findings show that structured planning, early identification of constraints, and continuous progress monitoring are effectively implemented and play a crucial role in ensuring schedule reliability and workflow stability in excavation works.

Similarly, VSM recorded very high RII values of 0.88-0.92, indicating that excavation workflows, such as cutting, loading, hauling, and dumping, have been clearly mapped and understood. High RII values for equipment utilization and role clarity suggest that process visualization significantly reduces inefficiencies and improves coordination between the workforce and heavy equipment. The implementation of JIT principles also demonstrates strong performance, with RII values ranging from 0.87 to 0.93. High RII scores for indicators related to subcontractor mobilization, fuel and spare parts availability, and the timely arrival of heavy equipment confirm that supply-chain reliability is significant for maintaining continuous excavation operations and minimizing equipment idle time.

For SMART Goals, RII values ranged from 0.88 to 0.91, reflecting a very high level of implementation. These results indicate that excavation targets are clearly defined, measurable, achievable, relevant to project objectives, and time-bound. The consistently high RII values suggest that SMART-based goal setting supports effective performance monitoring and enhances accountability among field teams. The DHM tool also achieved very high RII values of 0.90-0.92, highlighting the effectiveness of daily coordination meetings in improving communication, resolving technical issues, and ensuring active participation by field personnel. High RII values confirm that DHMs are a substantial mechanism for maintaining information flow and operational responsiveness in excavation activities.

Finally, the 5S (workplace organization) tool recorded RII values ranging from 0.86 to 0.88, which, although slightly lower than planning- and coordination-related tools, still range within the very high implementation category. These findings indicate that practices related to sorting, organizing, cleaning, standardizing, and sustaining workplace discipline have been consistently applied in excavation areas. However, the relatively lower RII values suggest that continuous reinforcement is required to fully embed the 5S culture in daily excavation operations.

Overall, the RII results confirm that Lean Construction implementation in excavation works is dominated by tools related to planning (LPS), coordination (DHM), and resource availability (JIT), which achieved the highest RII values. Tools associated with process visualization (VSM), goal setting (SMART Goals), and workplace organization (5S) also demonstrate strong implementation but still offer opportunities for further optimization to support continuous improvement.

This study adds to the current body of knowledge by demonstrating that the LPS and DHMs act as significant stabilizing agents in excavation workflows characterized by geological uncertainty and equipment synchronization challenges. While existing knowledge suggests that Lean is effective for repetitive manufacturing. The present research extends this understanding by demonstrating that structured daily coordination (RII = 0.92) can effectively mitigate the non-repetitive risks inherent in dam foundation work. Furthermore, the findings introduce a new localized performance profile for the 5S culture in Indonesian dam projects, revealing that while planning tools are easily adopted, workplace organization requires more intensive reinforcement to achieve the same level of impact.

This study is limited to excavation works at the Jenelata Dam Project. It relies primarily on questionnaire-based data, which may not fully capture the dynamic conditions of construction sites or variations across different infrastructure projects. Future research may expand the scope to other dams or infrastructure projects in different regions and incorporate qualitative methods, such as in-depth interviews or case studies, to obtain a greater understanding of Lean Construction implementation.

## IV. CONCLUSION

This study examined the implementation of Lean Construction in the Jenelata Dam Project excavation work. The implementation was highly effective, as evidenced by the Relative Importance Index (RII) values exceeding 0.80 for all evaluated indicators. The Last Planner System (LPS) and Daily Huddle Meetings (DHMs) were identified as the key factors with the greatest influence on workflow stability, achieving RII values of 0.93 and 0.92, respectively.

The results indicate that structured daily coordination and participatory planning can mitigate field constraints and improve operational schedule reliability. This research contributes to existing knowledge by providing empirical evidence regarding the application of Lean Construction tools, specifically during the excavation phase of dam construction projects in Indonesia. In contrast to previous studies that generally focus on building construction projects, this study specifically analyzes the implementation of six Lean tools in large-scale infrastructure projects, thereby enriching the understanding of Lean Construction implementation within the unique and complex environment of dam construction.

Furthermore, successful supply chain integration through Just-in-Time (JIT) principles proved crucial in minimizing wait times for heavy equipment and ensuring the timely availability of supporting resources. Although other tools, such as 5S (Sort, Set in Order, Shine, Standardize, and Sustain), also demonstrated very high levels of implementation, further reinforcement is needed to deeply internalize a culture of work discipline in the excavation area. For field application, this study proposes that project management should prioritize standardizing daily communication and visualizing processes to maintain productivity and support the sustainability of Lean implementation in other large-scale water resource infrastructure projects.

## DECLARATION OF COMPETING INTERESTS

The authors declare no competing interests.

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## DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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