

# Navigating the "Vital Few": Prioritizing Waste in Concrete Work for Mega-Dam Projects Using Relative Importance Index and Pareto Analysis

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Received: 9 February 2026 | Revised: 4 March 2026 and 26 March 2026 | Accepted: 28 March 2026

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## ABSTRACT

Mega-dam projects involve complex concrete operations where non-value-adding activities undermine cost, schedule, and quality. This study investigates waste in concrete work at the Jenelata Dam Project in Indonesia using the DOWNTIME (Defects, Overproduction, Waiting, Non-utilized human potential, Transportation, Inventory, Motion, Extra processing) framework. A descriptive, quantitative survey involving 59 practitioners was conducted to evaluate 48 indicators across eight categories. The Relative Importance Index (RII) was used to rank the criticality, and Pareto analysis identified the "vital few" drivers. All indicators were critical (RII = 0.7627–0.9763). Defects emerged as the most critical aspect, with rework from poor workmanship and design/drawing changes ranking first (RII = 0.9763). Material-related factors were the next most critical, including over-ordering (RII = 0.9492) and hidden inventory (RII = 0.9220), as well as waiting losses from equipment scheduling and downtime. The study proposes prioritized actions, including strengthened quality control and work-readiness checks, design freeze with BIM clash detection before IFC release, pull/make-ready planning, Just-in-Time (JIT) delivery with digital tracking, and preventive maintenance with backup equipment for critical pours.

**Keywords-**lean construction; waste management; mega-dam projects; Relative Importance Index (RII); Pareto analysis; concrete works

## I. INTRODUCTION

Infrastructure development significantly contributes to economic growth and equal development in Indonesia. However, the construction sector is inherently complex, fraught with uncertainty, and vulnerable to inefficiencies that manifest as waste. Within this framework, the concept of waste extends beyond mere physical scrap or debris. It includes all non-value-adding operations, such as idle time, redundant motion, overproduction, defects, and surplus inventory. These forms of waste directly affect project performance, leading to cost overruns, schedule delays, and quality degradation [1]. In response to these widespread inefficiencies, lean construction principles were established to optimize value creation by

systematically eliminating waste. Yet practice shows that waste elimination is frequently weakened by implementation barriers, most notably the lack of waste identification and control, which directly contradicts lean construction's core intent [2]. The application of lean tools in the precast industry has been explored [3]. However, there is a gap in specific analyses of on-site concrete works in conventional dam construction [4]. The Jenelata Dam Project in Gowa Regency, South Sulawesi, is a large-scale strategic project designed as a Concrete Face Rockfill Dam (CFRD). With a reservoir capacity of 223.6 million m<sup>3</sup> and significant investment, the project faces high risks of waste due to its long duration and complex coordination. Concrete work serves as the primary impermeable layer (facing concrete) and is a significant path of

activity where waste generation is most prevalent. This study investigates dominant waste factors using the Relative Importance Index (RII) and develops mitigation strategies based on the "Vital Few" factors identified through Pareto analysis.

Lean construction seeks to enhance process efficiency and deliver maximum value to project stakeholders by systematically eliminating non-value-adding activities [5]. Within this paradigm, waste is commonly categorized into eight types—often summarized using the DOWNTIME acronym [6]:

1. **Defects:** Errors, nonconformities, or unmet specifications that trigger rework and corrective actions.
2. **Overproduction:** Producing earlier, faster, or in greater quantities than needed, creating excess output and additional storage/handling burdens.
3. **Waiting:** Unproductive time when workers, materials, information, or equipment are idle due to poor coordination, delays, or unbalanced workflows.
4. **Non-utilized human potential:** A systemic underuse of workforce capabilities, knowledge, and creativity, which constrains innovation, problem-solving, and continuous improvement.
5. **Transportation:** Unnecessary movement of materials, resources, or equipment between locations, increasing handling time and risk of damage.
6. **Inventory:** Excess or poorly managed stock (materials, components, or work-in-progress) that ties up capital and increases deterioration, obsolescence, and space requirements.
7. **Motion:** Avoidable worker movement caused by ineffective site layout, poor ergonomics, or inefficient work sequencing.
8. **Extra processing:** Performing work beyond what is required by specifications or client needs (i.e., "gold plating"), leading to additional time and cost without proportional value gain.

Figure 1 illustrates the eight types of waste in lean construction (DOWNTIME framework). The core philosophy of the lean approach rests on minimizing waste—specifically by curtailing activities that add no value—while simultaneously amplifying output value tailored to client specifications. To achieve this, the proposed methodology prioritizes reducing process variability and cycle durations, alongside simplifying operational steps. It also calls for enhanced output flexibility and process transparency. Control mechanisms are redirected towards the overall workflow rather than individual sub-processes. This is sustained by a commitment to continuous iteration, maintaining an equilibrium between flow and conversion, and validating performance through external benchmarking [7]. Based on these lean principles, this study addresses the need to optimize waste in large-scale hydraulic infrastructure. While the

DOWNTIME framework provides a comprehensive waste classification, not all factors contribute equally to project degradation. Therefore, this study bridges the specific gap between theoretical waste identification and practical mitigation in the Jenelata Dam Project. Using the RII, this study quantifies the perceived impact of various waste factors in on-site concrete works, specifically for dam face elements. Furthermore, Pareto analysis is used to provide a prioritized decision-support framework and targeted mitigation strategies to site management, ensuring that resources are focused where they are most effective to increase productivity and project value in mega-dam construction in Indonesia.



Fig. 1. Types of waste in Lean construction (DOWNTIME framework).

## II. METHODOLOGY

### A. Research Design

This study is structured around two research questions, RQ1 and RQ2. RQ1 investigates the most dominant waste factors occurring during construction by synthesizing project evidence from documentation, observations, and interviews, complemented by relevant literature, and then the RII is applied to quantify and rank waste drivers by their criticality. RQ2 translates the ranked results from RQ1 into actionable lean construction interventions by applying Pareto analysis to isolate the "vital few" waste contributors and using descriptive interpretation to formulate targeted improvement strategies for effective waste reduction at the Jenelata Dam Project. Table I presents the detailed research question, tools/methods, and expected outcomes of the research.

### B. Data Collection

The survey instrument was developed through a systematic adaptation of 48 specific waste indicators derived from an extensive review of the literature. The rationale for selecting and adapting these indicators was to ensure their technical relevance to the unique operational complexities of mega-dam concrete works, which differ significantly from those of general building construction. Data acquisition was facilitated by a structured survey instrument grounded in the 8 distinct waste categories of the 8 DOWNTIME framework, which were further divided into 48 specific indicators. The questionnaire utilized a 5-point Likert scale ranging from "Very No Effect" (1) to "Very Influential" (5).

TABLE I. RESEARCH FRAMEWORKS

Research question	Tools/method	Expected outcomes
What are the most dominant waste factors in the project?	Input/data collection: project data, literature study, previous research, observation, project documentation, interview	Analysis of the types and factors of waste that occur during the construction process
	Data analysis: RII method, critical analysis	
What is the strategy for applying lean construction practices to minimize waste in the Jenelata Dam Project?	Input/data collection: output/result from RQ 1	Formulating improvement strategies for effective waste reduction via lean construction
	Data analysis: Pareto analysis, descriptive analysis	

C. Population and Sample

The target population was expert respondents involved in the project, meeting criteria such as a minimum bachelor's education and direct experience in dam construction. A total of 59 respondents participated, comprising contractors (64%), consultants involved in planning and supervision (19%), owner/client team (9%), and subcontractors (8%). The respondents were highly qualified, with 89% holding a Bachelor's (D4/S1) or Master's (S2) degree, and 44% having 11–15 years of professional experience.

CONSTRUCTION INDUSTRY WORK EXPERIENCE  
59 RESPONSES

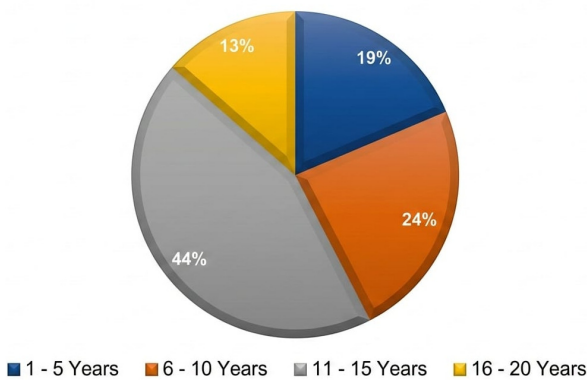


Fig. 2. Respondents' work experience.

D. Data Analysis Techniques

The data analysis followed a structured flow:

1) Validity and Reliability Tests

Statistical data processing was conducted using IBM SPSS v27. To ensure instrument quality, validity was assessed using the Pearson product-moment correlation, with a critical value of  $r = 0.2564$  at  $df = 57$ . At the same time, internal consistency was measured using the Cronbach's alpha coefficient [8].

2) Relative Importance Index

The RII is a robust statistical instrument that hierarchizes variables based on respondent feedback. The dominance of various waste factors was calculated using the RII [9]. Widely recognized in construction research, this method translates qualitative Likert-scale feedback into a prioritization metric (0–1). In this context, an elevated RII value indicates a factor with a significantly stronger negative influence on project performance:

$$RII = \frac{\sum w}{A \times N} \tag{1}$$

where  $\sum w$  is the aggregate summation of the respondent scores,  $A$  is the upper limit of the measurement scale ( $A = 5$ ), and  $N$  represents the total sample size of evaluators.

3) Pareto Analysis (20:80)

Pareto analysis is used to filter the RII results to identify the top 20% of indicators that contribute to the majority of waste issues, guiding the strategic recommendations [10].

III. RESULTS AND DISCUSSION

A. Identification of DOWNTIME Waste Indicators

After the literature review, 48 indicators were identified, as shown in Tables II-IX.

TABLE II. WASTE INDICATORS OF DEFECTS

Code	Indicators	Reference
X1	Defects	
X1.1	Rework due to poor workmanship or deviation from specifications.	[11, 12]
X1.2	Design or drawing revisions that trigger demolition and rework.	[13-15]
X1.3	Defective/damaged/nonconforming materials or components leading to rework.	[12-16]
X1.4	Nonconformances identified during inspection/testing requiring corrective work.	[11-15]
X1.5	Extensive punch-list findings at handover, indicating repeated rectification.	[16]
X1.6	Incomplete/unclear technical information (e.g., delayed RFIs) causing errors and rework.	[11]

TABLE III. WASTE INDICATORS OF OVERPRODUCTION

Code	Indicators	Reference
X2	Overproduction	
X2.1	Producing/fabricating elements too early or too fast (ahead of schedule), increasing surplus and rework risk.	[17, 18]
X2.2	Producing components in quantities exceeding demand, creating surplus stock and extra cost.	[18, 19]
X2.3	Over-ordering materials due to inaccurate planning/estimation.	[17-19]
X2.4	Over-finishing/over-spec work beyond required quality standards (extra processing).	[18]
X2.5	Executing work before required approvals (premature release), leading to potential dismantling/rework.	[18]
X2.6	Duplicated administrative outputs (repeated drawings/documents) that do not add value.	[18]

TABLE IV. WASTE INDICATORS OF WAITING

Code	Indicators	Reference
X3	Waiting	
X3.1	Waiting for materials/equipment due to supplier or logistics delays.	[18-20]
X3.2	Waiting for heavy equipment/plant/operators due to poor coordination and scheduling.	[18-20]
X3.3	Waiting caused by slow approvals/inspections or delayed RFI responses.	[18-21]
X3.4	Crew idle time due to trade interference or predecessor-work delays.	[18-22]
X3.5	Downtime from equipment breakdowns or unplanned maintenance.	[21, 22]
X3.6	Waiting for managerial instructions/decisions at the workforce.	[18-21]

TABLE V. WASTE INDICATORS OF NON-UTILIZED HUMAN POTENTIAL

Code	Indicators	Reference
X4	Non-utilized human potential	
X4.1	Skill-task mismatch from inappropriate workforce placement, reducing productivity and quality.	[18-23]
X4.2	Limited worker involvement in problem-solving/Kaizen, weakening learning and improvement.	[17, 18-23]
X4.3	Insufficient training/certification, increasing errors, and reducing productivity.	[17, 18-23]
X4.4	Underuse of frontline feedback and lessons learned, causing repeated mistakes.	[18-23]
X4.5	Unclear roles/authority and weak communication, slowing down decisions and coordination.	[18-23]
X4.6	Rigid hierarchical structure that constrains site-level improvement and innovation.	[18-23]

TABLE VI. WASTE INDICATORS OF TRANSPORTATION

Code	Indicators	Reference
X5	Transportation	
X5.1	Unnecessary material movement caused by poor site layout and long haul distances.	[18]
X5.2	Double-handling due to inefficient storage and repeated relocations.	[18, 19]
X5.3	Material retrieval from stockyards/warehouses located too far from work areas.	[18, 24]
X5.4	Excess personnel movement between zones due to inefficient task allocation.	[18]
X5.5	Return shipments/re-delivery due to wrong or defective materials.	[18, 19]
X5.6	Supply-chain fragmentation (many suppliers/subcontractors) increasing internal logistics movements.	[18, 19-24]

TABLE VII. WASTE INDICATORS OF INVENTORY

Code	Indicators	Reference
X6	Inventory	
X6.1	Excess on-site inventory without clear consumption planning, increasing damage/obsolescence risk.	[25]
X6.2	Stockpiling of finished components awaiting installation, congesting the workspace.	[26]
X6.3	Prolonged/poor storage that causes deterioration, expiry, or damage to materials.	[26]
X6.4	Excess WIP queues between trades/work packages, reducing productivity.	[22]
X6.5	Material obsolescence due to design changes, resulting in unused inventory.	[22]
X6.6	Hidden/unrecorded inventory that undermines material control and planning.	[26]

TABLE VIII. WASTE INDICATORS OF MOTION

Code	Indicators	Reference
X7	Motion	
X7.1	Excessive worker walking due to non-strategic locations of materials/tools.	[18]
X7.2	Time spent searching for tools/materials/documents due to weak 5S/visual management.	[18-27]
X7.3	Non-ergonomic repetitive motions (bending, reaching, twisting) that slow work and increase risk.	[18-28]
X7.4	Poor workstation layout causing repeated pick-and-place movements for tools/equipment.	[18]
X7.5	Repeated relocation of ladders/scaffolds for small work areas, prolonging minor tasks.	[18]
X7.6	Repeated vertical travel (up/down floors) for minor tasks due to inefficient workforce design.	[18]

TABLE IX. WASTE INDICATORS OF EXTRA PROCESSING

Code	Indicators	Reference
X8	Extra processing	
X8.1	Repeated measurement/inspection due to low data confidence and lack of standardization.	[18-27]
X8.2	Repeated data entry/documentation across multiple systems (duplicate documentation).	[18-27]
X8.3	Gold plating: specifications/inputs exceeding customer requirements, adding time and cost.	[18]
X8.4	Unnecessary finishing to overly tight tolerances beyond requirements.	[18]
X8.5	Layered approval/authorization flows that add time without adding value.	[18]
X8.6	Repeated prototyping/sampling due to unclear acceptance criteria.	[18]

### B. Validity and Reliability

Based on the results of data processing through validity and reliability tests, it was found that the questionnaire instrument used to measure the eight DOWNTIME waste categories namely (X.1) Defects, (X.2) Overproduction, (X.3) Waiting, (X.4) Non-utilized talent, (X.5) Transportation, (X.6) Inventory, (X.7) Motion, and (X.8) Extra processing in concrete works was proven to be valid and reliable. The validity test results showed that all 48 waste indicators had  $r\text{-counts} > r\text{-table}$  (0.2564), confirming that all items were valid. With a Cronbach's alpha of 0.961, the instrument demonstrated reliability significantly exceeding the minimum cut-off of 0.60. This attests to the robust nature and consistency of the data collection tool.

### C. Results of RII - Ranking of Dominant Waste Factors

With an RII of  $\approx 0.98$ , the study identified quality-induced rework and design-related alterations as the primary contributors to project waste. This was followed by over-ordering of materials, defective materials, a high number of punch list items, hidden stock, and excessive inventory at the project site (RII  $\approx 0.92\text{-}0.95$ ). Other indicators with relatively high RII values include delays in heavy equipment availability, downtime due to equipment failure, delays in material delivery, waiting for managerial instructions, weak communication and workforce involvement, and extra processing activities such as repeated measurements and multi-layered approval workflows. The RII analysis revealed that all indicators were perceived as critical, with values ranging from 0.7627 to 0.9763. The top 10 dominant waste factors are presented in Table IV.

TABLE X. TOP 10 WASTE INDICATORS BASED ON RII

Rank	Code	Waste indicator	RII	Reference
1	X1.1	Rework due to poor workmanship or deviation from specifications.	0.9763	[7, 8]
2	X1.2	Design changes causing rework or demolition.	0.9763	[9-11]
3	X2.3	Over-ordering of materials due to inaccurate planning.	0.9492	[13-15]
4	X1.3	Defective or damaged materials causing rework.	0.9390	[8-12]
5	X1.5	Excessive punch-lists after handover.	0.9254	[12]
6	X6.6	Hidden inventory not recorded in inventory control systems.	0.9220	[22]
7	X6.1	Excess material inventory without clear usage plans.	0.9186	[21]
8	X3.2	Waiting for equipment availability due to poor scheduling.	0.9153	[14-16]
9	X3.5	Downtime caused by equipment breakdown or unplanned maintenance.	0.9153	[17, 18]
10	X1.6	Unclear technical information or late RFLs causing execution errors.	0.9119	[7]

TABLE XI. TOP 20% PARETO ANALYSIS

Code	Waste indicator	RII	Percentage	Cumulative percentage
X1.1	Rework due to poor workmanship or deviation from specifications.	0.9763	2.32%	2.32%
X1.2	Design changes causing rework or demolition.	0.9763	2.32%	4.64%
X2.3	Over-ordering of materials due to inaccurate planning.	0.9492	2.26%	6.89%
X1.3	Defective or damaged materials causing rework.	0.9390	2.23%	9.13%
X1.5	Excessive punch-lists after handover.	0.9254	2.20%	11.33%
X6.6	Hidden inventory not recorded in inventory control systems.	0.9220	2.19%	13.52%
X6.1	Excess material inventory without clear usage plans.	0.9186	2.18%	15.70%
X3.2	Waiting for equipment availability due to poor scheduling.	0.9153	2.17%	17.87%
X3.5	Downtime caused by equipment breakdown or unplanned maintenance.	0.9153	2.17%	20.05%

#### D. Pareto Analysis Results

Pareto analysis was applied to isolate the top 20% cumulative factors. The analysis indicates that addressing the top-ranked issues (rework, design changes, over-ordering) would have the most significant impact on the project. The percentage contribution of each waste indicator in the Pareto analysis was calculated by dividing its RII value by the total RII for all 48 indicators. The cumulative percentage was then derived by sequentially summing these individual percentages from the highest to the lowest rank to identify the 'vital few' factors that account for approximately 20% of the total cumulative impact.

#### E. Strategies for Lean Construction Implementation to Minimize Waste in Concrete Works

Defects (X.1) emerged as the most critical waste category, with rework due to poor workmanship and design changes jointly ranked first (RII = 0.9763). For a CFRD dam, rework on the concrete face slab is both cost-intensive and technically risky, indicating that quality-at-the-source and design coordination are persistent challenges despite lean adoption. This is consistent with evidence that rework absorbs substantial resources in large infrastructure projects [8], and reinforces the need for sustained coordination and communication across design, construction, and commissioning to prevent miscommunication-driven rework [29]. In practice, a design-freeze milestone and BIM-based clash detection before issuing "For Construction" drawings—integrated with the Last Planner System discipline—can reduce design-originated rework.

Material-related wastes also ranked high: over-ordering (Rank 3, RII = 0.9492) and hidden inventory (Rank 6, RII = 0.9220) indicate misalignment between planning and field execution. Unrecorded on-site stock can create a false sense of availability and ultimately generate waste through damage, quality degradation, and obsolescence. While pull planning is

crucial in lean construction, these results highlight that material logistics requires tighter control mechanisms, including Just-in-Time (JIT) delivery to reduce buffers and simple digital tracking (e.g., barcoding) to eliminate hidden inventory.

To address waiting losses during critical concreting activities, the study prioritizes equipment reliability through preventive maintenance for concrete pumps and vibrators and the use of a daily equipment readiness checklist to confirm operability, spare-part readiness, and key pre-pour parameters [16]. For time-sensitive pours, providing backup equipment is also proposed to maintain flow continuity and minimize interruption-related waste when primary equipment fails or requires corrective maintenance.

#### F. Limitations and Future Research

While this research provides practical insights into waste management in large-scale infrastructure projects, several methodological limitations should be acknowledged. First, this research is a single case study focused exclusively on concrete work at the Jenelata Dam Project. Therefore, the findings and resulting indicator rankings may have limited statistical generalizability when applied to other work packages or geographic regions with different industry characteristics.

Second, the sample size of 59 expert respondents, while adequate for the case study and RII analysis in construction management, is a noteworthy methodological limitation. The very high concentration of RII values (0.76 to 0.98) across indicators also demonstrates potential response bias from practitioners who view nearly all listed issues as critical, which can sometimes obscure nuanced differences between types of waste.

Given these limitations, future research is proposed to expand the sample size to include additional national strategic projects to validate this "Vital Few" ranking more broadly.

Additionally, deeper integration of qualitative data or the use of other multi-criteria decision-making methods could be conducted to provide a more efficient interpretation of the root causes of waste. Finally, future research could evaluate the effectiveness of more specific digital technology applications, such as 4D BIM or IoT-based material tracking, in reducing the waste identified in this study.

#### IV. CONCLUSION

Lean construction-based waste management in concrete works at the Jenelata Dam Project confirms that waste remains a major performance constraint across the DOWNTIME taxonomy (Defects, Overproduction, Waiting, Non-utilized human potential, Transportation, Inventory, Motion, Extra processing), with all indicators rated highly critical with Relative Importance Index (RII) between 0.7627–0.9763; however, these conclusions are limited to concrete-related activities in a mega-dam context and should not be generalized to other work packages without further validation. The dominant drivers are primarily quality and planning failures—poor-workmanship rework, design/drawing changes, inaccurate material planning leading to over-ordering, nonconforming materials, and extensive post-handover punch lists—supported by additional losses from excess/hidden inventories and waiting due to heavy-equipment scheduling and downtime, indicating weak integration between planning, QA/QC, and logistics. Consequently, improvement efforts should target the "vital few" wastes using RII–Pareto prioritization by reinforcing quality-at-the-source and work-readiness controls, strengthening pull and make-ready planning to prevent overproduction and premature releases, applying Just-in-Time (JIT) with integrated material control to reduce inventory waste, improving equipment reliability via preventive maintenance to cut waiting/downtime and enhancing workforce capability and participation through training, clear roles, and continuous improvement practices.

#### DECLARATION OF COMPETING INTERESTS

The authors declare no competing interests.

#### ACKNOWLEDGEMENT

The authors express sincere appreciation to the Department of Civil Engineering of Hasanuddin University for the invaluable support rendered during the course of this research. Sincere appreciation is also extended to all parties involved in the Jenelata Dam Project who contributed valuable insights, technical assistance, and constructive feedback towards the successful conclusion of this research.

#### DATA AVAILABILITY

The data supporting the findings of this study are available within the paper. Raw data that support the findings of this study are available from the corresponding author upon reasonable request.

#### AI USE AND DECLARATION OF GENERATIVE AI USE

The authors used ChatGPT for language editing and readability improvement. The authors take full responsibility

for the content of the manuscript and have reviewed and verified all results and conclusions.

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