Implementation of Lean Construction and Risk Management for Waste Identification in the Jragung Dam Construction Project Package 2

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Abstract. PT Wijaya Karya (Persero) Tbk, a leading state-owned construction enterprise, faces significant waste management challenges that have caused financial losses in previous projects. This study applies lean construction and risk management to identify waste and risks in the Jragung Dam Construction Project Package 2. Waste identification began with brainstorming sessions with the project management team, followed by a borda questionnaire to prioritize waste using the pareto principle. 5-whys discussions were then used to determine the risks causing critical waste. These risks were categorized using the Risk Breakdown Structure (RBS) and analysed through Failure Mode and Effect Analysis (FMEA), with risks plotted on a cartesian diagram based on Risk Priority Number (RPN) and Risk Severity Value (RSV). The four critical waste types identified were defects (20.05%), waiting (19.80%), over-processing (17.79%), and overproduction (14.04%). The highest-priority risks were unfinished diversion channels (RPN 108, RSV 36), geological issues found (RPN 105, RSV 35), and design revision (RPN 96, RSV 32). The benefit of this research is a systematic approach for identifying waste through lean construction and risk management principles, facilitating targeted waste identification. This process is expected to help the company make informed decisions, enhancing project efficiency and reducing potential financial losses.

1 Introduction

PT. Wijaya Karya (Persero) Tbk, as a State-Owned Enterprise (BUMN) operating in the construction sector, is renowned for its reliability in completing various large-scale infrastructure projects. However, despite its extensive experience and expertise, the company faces several operational challenges, particularly related to waste that frequently occurs in previous projects. This waste can arise from various sources, such as unpredictable natural conditions, obstacles in land acquisition processes, and delays caused by vendors and subcontractors. The accumulation of these identified forms of waste has the potential to result in significant financial losses. Therefore, the company needs a comprehensive management

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approach to identify and analyse potential waste at each stage of the infrastructure projects undertaken. By appropriately integrating lean construction concepts with risk management, waste can be reduced from the early planning phase through to the final stages of the project [1].

This research was conducted on the Jragung Dam Construction Project Package 2, which is being executed by PT. Wijaya Karya (Persero) Tbk - PT. Basuki Rahmanta Putra, KSO. The project faces several issues, such as the need for re-planning the dam due to unsuitable geological conditions, material that has been stockpiled but does not meet technical specifications, and waiting time caused by incomplete work on other packages. In response to these issues, the author identifies waste and analyses potential risks that may cause waste in the future. The methods employed in this study include lean construction, utilizing the 5-Why Method to determine the root causes of waste, and Risk Breakdown Structure (RBS) and Failure Mode and Effect Analysis (FMEA) to identify risks resulting from waste in the Jragung Dam Construction Project Package 2.

2 Literature review

2.1 Lean construction

Lean construction is a modern philosophy focused on managing construction production [2]. It was emphasized that lean construction can deliver beneficial effects on the construction industry by addressing the shortcomings of traditional methods. It aims to enhance client value by eliminating waste and utilizing project management tools to promote collaboration, as part of a comprehensive and systematic strategy for continuous improvement [3].

Recently, the lean approach has become widely recognized in the construction sector as an effective project management. The five core principles of lean construction are value, pull, value stream mapping, flow, and pursuit of perfection [4]. Lean aims to optimize the use of materials, resources, and personnel.

The continuous effort to eliminate waste remains as crucial today as it was when Taiichi Ohno identified the key sources of waste, known as "The Seven Deadly Wastes" [5]. Those are transportation, inventory, motion, waiting, over-processing, over-production, and defect [6]. Many scientists and professionals believe that neglecting these seven types of waste by stakeholders during the construction phase is a major contributor to cost overruns and project delays in the construction industry [7]. The explanation of the seven types of waste can be found in Table 1.

Table 1. Seven wastes and their explanations.

Waste	Explanation
Transportation	Unnecessary movement of products, materials, or information
Inventory	Holding raw materials, work-in-progress, or finished goods beyond what is necessary to meet customer demands and maintain process stability
Motion	Excessive movement of individuals, such as walking, reaching, or stretching
Waiting	Any pause between the completion of one process and the initiation of the next task
Over-processing	Expending more energy or effort than needed to produce a product, or adding more value than the established standard
Overproduction	Creating more than what is immediately required
Defect	Any production that necessitates rework or leads to waste

The five whys is a lean construction tool designed to efficiently identify the root cause of a problem [8]. It involves repeatedly asking the question "why" in response to the previous answer, helping to uncover the underlying issue. This practice closely resembles the fishbone method commonly used in quality management systems [9]. Clearly defining the problem and accurately addressing each "why" question are crucial for this approach to be effective.

2.2 Risk management

Risk management can be defined as the process of systematically identifying, analysing, and managing risks across all business activities with the goal of enhancing efficiency and effectiveness [10]. It involves the logical and systematic identification, quantification, and assessment of risks, developing strategies to address them, and continuously monitoring and reporting these risks. The ultimate objective is to improve the company's value by comprehensively addressing organizational challenges.

The evaluation of potential risks within a project is determined based on the identification of critical waste and is organized using the risk breakdown structure (RBS). The RBS is employed to highlight the significance of each risk and to enhance the understanding of organizational or project risks within a logical, systematic, and structured framework [11]. Additionally, RBS aids in comparing projects and compiling lessons learned, which can be applied to future projects.

FMEA aids in pinpointing and addressing vulnerabilities during the initial stages of developing product and service concepts. In FMEA risk assessment, Risk Priority Number (RPN) and Risk Score Value (RSV) are used as metrics. This method ranks risk factors by identifying risk categories, potential risks, the severity of each failure mode's impact (S), the likelihood of failure (O), and the difficulty in detecting the cause of each failure mode (D) [12]. It then calculates the RPN and RSV for each risk and determines the prioritization of all risk factors [13]. The RPN formula is as follows:

$$RPN = S \times O \times D \tag{1}$$

The higher the RPN value, the more significant the failure or risk mode, and the greater the potential impact on the project, necessitating appropriate preventive measures and corrective actions. To calculate the Risk Score Value (RSV), the values for Severity and Occurrence are required, leading to the following formula for determining the RSV [14]:

$$RSV = S \times O \tag{2}$$

3 Methodology

The research methodology adopts a quantitative approach, beginning with an extensive literature review on lean construction and risk mitigation. The objective of this review is to apply foundational concepts and methodologies of lean construction and risk mitigation in the identification of waste and risk management within construction projects.

The first step involves determining the research focus, specifically identifying tasks or activities within the construction project that are particularly susceptible to waste. To achieve this, the researchers utilize the pareto diagram, a powerful analytical tool that assists in recognizing the primary factors contributing to the majority of issues within the project. The pareto principle, also known as the 80/20 rule, asserts that a significant portion of outcomes (80%) originates from a small set of causes (20%) [15]. By leveraging the pareto principle (80/20), the researchers are able to concentrate their efforts on the 80% of tasks that contribute most significantly to costs, thereby enhancing the efficiency and effectiveness of the research [16].

After establishing the research focus, data collection is conducted using three main methods: brainstorming, borda questionnaire, and discussions. Brainstorming sessions are held with the project management team to identify potential waste that may not be immediately apparent. The borda questionnaire is employed to gather quantitative data from individuals with relevant knowledge and experience. The borda method is used to identify critical waste by assigning weights to various alternatives [17]. While the analytic hierarchy process (AHP) method involves complex calculations, the borda method is preferred for its simplicity [18]. In-depth discussions are then conducted to further explore each finding and ensure that all perspectives are considered.

For data analysis, the researchers utilize several well-established tools in lean construction. One of the key tools employed is root cause analysis (RCA), which is used to identify the underlying causes of waste. In this context, the 5 Whys method is applied, where the researchers repeatedly ask "why" in response to each answer until the true root cause of the waste is uncovered.

Subsequently, potential future risks are identified based on previous waste data. The researchers use the risk breakdown structure (RBS) to categorize and organize these risks into logical groupings that facilitate further analysis. Finally, failure mode and effect analysis (FMEA) is applied to evaluate the criticality of the identified risks, considering three main factors: severity (the impact's severity), occurrence (the frequency of the occurrence), and detection (the difficulty in detecting the risk).

4 Analysis and result

4.3 Analysis of tasks

The initial step in our research analysis involves identifying the tasks within the construction project that are most vulnerable to waste. The application of the Pareto diagram begins by sequentially summing the cumulative percentage of task costs, starting with the most expensive ones [19]. The analysis focuses on tasks that account for 80% of the cumulative cost percentage.

Six tasks were identified, with a total weight of 77.306%. These tasks include random rock fill (42.797%), mechanical soil excavation (9.947%), fine filter fill (7.495%), coarse filter fill (7.230%), core clay fill (5.359%), and cement-treated base (4.478%). The analysis is then concentrated solely on these six tasks to focus the research findings on the most significant sources of waste.

4.4 Critical waste

To identify waste in the Jragung Dam Construction Project Package 2, a brainstorming session was conducted with the project management team, including the Project Manager, Heads of QA/QC, Finance and Administration, Commercial, and Technical Functions, as well as the Chief Executive. The brainstorming session revealed indications of waste in six tasks that were analysed. It also resulted in the selection of 19 respondents to fill out a borda questionnaire.

The questionnaire was used to rank each type of waste. Rank one represents the most critical waste in the Jragung Dam Construction Project Package 2, while rank seven indicates the least critical waste. Subsequently, a pareto diagram was constructed, ranking the waste from the highest to the lowest scores. The pareto diagram of critical waste is illustrated in Figure 1.

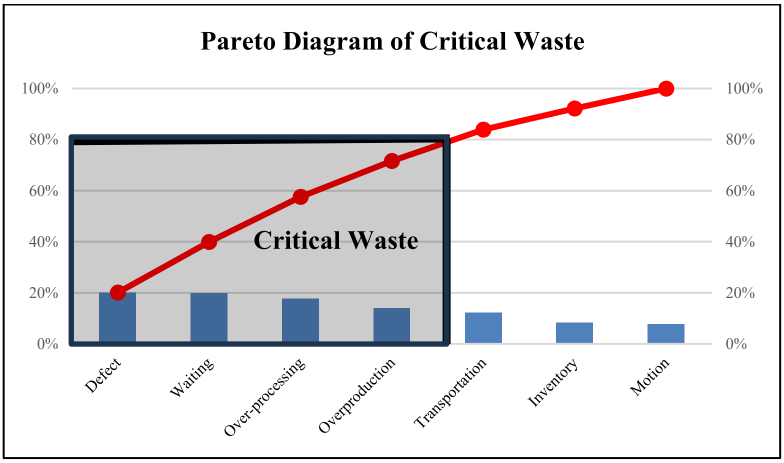

Fig. 1. Pareto diagram of critical waste.

Based on the Pareto diagram, four types of critical waste were identified. Critical waste was determined based on scores with a cumulative percentage weight of 80%. These four critical wastes include defect (20.050%), waiting (19.799%), over-processing (17.794%), and overproduction (14.035%), resulting in a total cumulative percentage weight of 71.678% for all identified critical wastes.

4.5 Causes of waste

The next stage of analysis involves identifying the causes of critical waste using the 5 Whys method. This analysis was conducted through discussions with 19 respondents, during which the question "why?" was repeatedly asked for each identified issue until the underlying root cause was determined. Through this approach, the direct causes of critical waste were uncovered, and potential future risks that may impact the overall efficiency of the project were identified. The causes of critical waste are presented in Table 2.

Table 2. Causes of critical waste.

Waste	Sub-waste	Why 1	Why 2	Why 3	Why 4	Why 5
Defect	Rework on random rock fill	Density below spec	Lack capacity of vibrator roller	No equipment inspection	Equipment arrived late	Urgency not informed
	Rework on core clay fill	Porosity below spec	Lack of watering	Hot weather		
Waiting	Delay in random rock fill	Material arrived late	Quarry area relocation	Rejection by resident		
	Delay in core clay fill	Lack of available land	Sunken fill zone	Unfinished diversion channel		
	Delay in cement treated base	Equipment and material arrived late	Doubt schedule	Design revision	Geological issues found	

Waste	Sub-waste	Why 1	Why 2	Why 3	Why 4	Why 5
Over-processing	Re-grooving of core clay fill	Flat surface	Used as dump truck path	Lack of available land	Sunken fill zone	Unfinished diversion channel
Over production	Excessive random rock fill	Differences between technical and executive teams	No use of drawings in meeting	Design revision	Geological issues found	

4.6 Risk mapping

Risk mapping is carried out by organizing and categorizing various types of risks that may impact the project using the risk breakdown structure (RBS). All possible sources of risk have been thoroughly analysed to determine whether additional risk identification activities are necessary. The RBS for the Jragung Dam Construction Project Package 2, is illustrated in Figure 2.

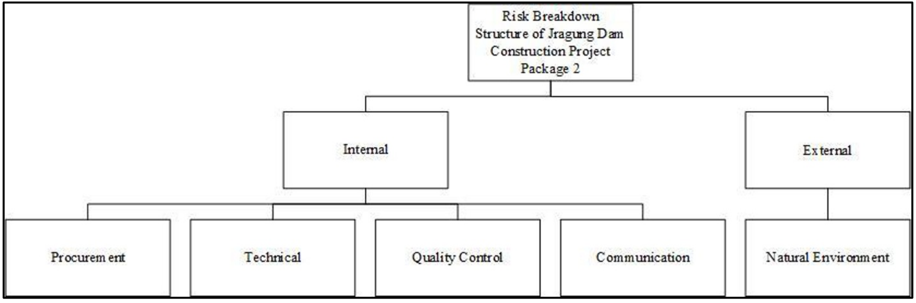

Fig. 2. RBS of Jragung Dam Construction Project Package 2.

Risk identification is conducted to determine the categories of risks that could lead to waste in future projects. This process involves organizing risks according to the categories established in the Risk Breakdown Structure (RBS). The identified potential risks are presented in Table 3.

Table 3. Identification of possible risk.

Source of Risk	Category	Explanation
Internal	Procurement	Equipment arrived late
		Quarry area relocation
	Technical	Unfinished diversion channel
		Design revision
		Geological issues found
	Quality Control	Density below spec
		Porosity below spec
	Communication	Urgency not informed
External	Natural Environment	Hot weather

4.7 Risk scoring

Risk scoring is a stage for measuring and prioritizing risks based on their potential impact on the project. In the context of Failure Mode and Effect Analysis (FMEA), two primary methods used for risk scoring are the Risk Priority Number (RPN) and Risk Severity Value (RSV). The risk scoring process is illustrated in Table 4.

Table 4. Identification of possible risk.

Code	Risk	S	Effect (S)	O	Effect (O)	D	Effect (D)	RPN	RSV
R1	Unfinished diversion channel	9	Hazardous with warning	4	Unlikely	3	High	108	36
R2	Geological issues found	5	Low	7	High	3	High	105	35
R3	Density below spec	7	High	2	Very low	7	Very low	98	14
R4	Design revision	4	Very low	8	Very high	3	High	96	32
R5	Porosity below spec	6	Moderate	3	Low	5	Moderate	90	18
R6	Quarry area relocation	10	Hazardous without warning	1	Remote	3	High	30	10
R7	Urgency not informed	1	None	8	Very high	2	Very high	16	8
R8	Equipment arrived late	7	High	1	Remote	2	Very high	14	7
R9	Hot weather	4	Very low	3	Low	1	Almost certain	12	12

5 Discussion

The plot of RPN and RSV scores provides a clear visualization of the risk distribution within the project. By mapping the risks on a two-dimensional graph, where the x-axis represents RSV and the y-axis represents RPN, the distribution of each risk can be observed based on its priority [20]. Utilizing Pareto's 80/20 Principle, the critical value for RPN is 86.4 (80% of 108) and the critical value for RSV is 28.8 (80% of 36), which are used as reference lines in the scatter diagram. The risk scatter diagram can be seen in Figure 3.

Risks located in the upper right quadrant of the scatter plot have both high priority and severity. Risks situated in the upper left and lower right quadrants of the scatter plot have moderate priority. Meanwhile, risks in the lower left quadrant of the scatter plot are characterized by low priority.

The results indicate that risks R1, R2, and R4 are located in the upper-right quadrant. This suggests that the unfinished diversion channel, geological issues found, and design revision are high-priority risks. These three risks originate from the technical risk category. These high-priority risks are identified as key priorities, with a recommendation for the company to focus more attention on these critical risks.

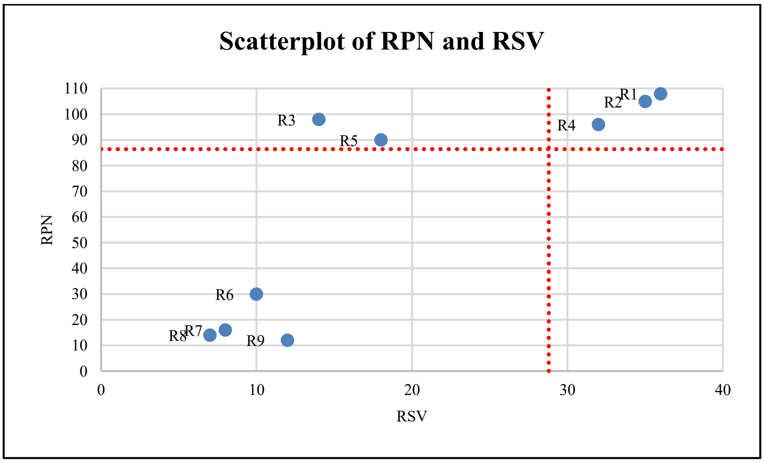

Fig. 3. Risk scatter diagram.

6 Conclusion

The waste identification process was conducted by analysing pareto tasks such as random rock fill, mechanical soil excavation, fine filter fill, coarse filter fill, core clay fill, and cement treated base. Based on brainstorming results and borda questionnaires that prioritized the types of waste in the project, the analysis identified four critical waste types: defect (20.05%), waiting (19.80%), over-processing (17.79%), and overproduction (14.04%). These critical waste categories include rework on random rock fill, rework on core clay fill, delay in random rock fill, delay in core clay fill, delay in cement treated base, re-grooving of core clay fill, and excessive random rock fill.

Risk identification was performed using the 5 whys method, revealing that the causes of critical waste stemmed from categories such as procurement, technical issues, quality control, communication, and the natural environment. Based on Failure Mode and Effect Analysis (FMEA) and pareto analysis through a scatter plot, three high-priority risks requiring further attention were identified: unfinished diversion channels (RPN 108, RSV 36), geological issues found (RPN 105, RSV 35), and design revision (RPN 96, RSV 32). These three risks originate from the technical risk category.

The benefit of this research lies in providing a systematic approach for identifying waste through the application of lean construction and risk management principles, enabling a more targeted waste identification process. The results of this waste and risk identification are expected to assist the company in making more informed decisions, preventing negative impacts on project efficiency, and reducing potential financial losses in the future.

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