International Journal of Economics, Business and Innovation Research
https://e-journal.citakonsultindo.or.id/index.php/IJEBIR
E-ISSN : 2964-0865
IJEBIR

Planning And Control Of Construction Projects Using Critical Chain Project Management And Lean Construction To Minimize Waste

Hendik Waluyo[1], Ridho Bayuaji[2]
[1,2]Master of Technology Management Study Program, Interdisciplinary School of Technology Management, Sepuluh Nopember Institute of Technology (ITS)

Corresponding Email:hendykwaluyo87@gmail.com,bayuaji@its.ac.id

Abstract

Large-scale infrastructure projects, such as the Cabean Dam, are often faced with the risk of schedule delays and cost overruns. This study aims to (1) analyze the implementation of Critical Chain Project Management (CCPM) and Lean Construction in project planning and control, and (2) analyze their impact on waste, time, costs, and implementation challenges. The research method is carried out by integrating the CCPM approach to manage schedule uncertainty through buffer management and resource constraint control, and the Lean Construction approach to eliminate waste through the Last Planner System and field layout improvements. Time and cost performance evaluations are analyzed using the Earned Value Management (EVM) method. The results of the study indicate that under existing conditions, the project experiences delay constraints as indicated by a Schedule Performance Index (SPI) value of 0.42 with a physical delay deviation of 7.03%. Nevertheless, the integration of CCPM and Lean Construction has proven effective in acting as a fluctuating early warning system in maintaining schedule control limits. From a cost perspective, this implementation successfully maintained budget efficiency with a Cost Performance Index (CPI) value of > 1 (under budget). The measure of success in minimizing waste was demonstrated through the elimination of idle time due to waiting for iron distribution, the elimination of rework costs through early formwork quality control, and the reduction of transportation time and costs through rearranging the layout of the construction material warehouse. The conclusion of this study shows that the integration of CCPM and Lean Construction can significantly improve the visibility of project control. Although it has not completely eliminated delays to the initial plan, this method has been scientifically proven to reduce cost waste in the field and ensure the efficient use of the project budget.

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

International Journal of Economics, Business and Innovation Research
https://e-journal.citakonsultindo.or.id/index.php/IJEBIR
E-ISSN : 2964-0865
IJEBIR

Keywords: Critical Chain Project Management (CCPM), Lean Construction, Waste, SPI, CPI.

INTRODUCTION

Amidst globalization and rapid technological advancements, the construction sector faces increasingly complex challenges. Infrastructure projects, such as dams, require effective planning and control strategies to ensure timeliness, cost, and quality. According to the Project Management Institute(IEEE standards 1490–2011, 2011)This condition shows that the conventional project management approach has not been fully able to overcome uncertainty, resource limitations, and the high potential for waste in construction projects.(Koskela, 1992)

Data obtained from one of the state-owned construction companies, PT X, stated that within a seven-year period, namely 2019 to 2025, there was an increase in the number of completed natural resource construction projects (dams) that were over budget from the budget plan that had been made and agreed upon before the project started, which can be seen in the following table:

Table 1 Number of Completed Natural Resources Construction Projects (Dams) by PT. XYZ from 2019 to 2025

KONDISI BUDGETING PROYEK KONSTRUKSI DIVISI SDA PT. X	TAHUN PENYELESAIAN							TOTAL 2019 SD 2025
	2019	2020	2021	2022	2023	2024	2025	
UNDER BUDGET	3	1	5	1	3	1	0	**14**
OVER BUDGET	0	0	2	1	3	5	2	**13**
JUMLAH	**3**	**1**	**7**	**2**	**6**	**6**	**2**	27

Source: PT. XYZ data, processed by researchers, 2025

In the table above, it can be seen that the completion of PT. XYZ's SDA (Dam) construction projects that experienced a decrease in profit from the plan or over budget were 13 projects out of 27 projects that had been completed in the 2019 - 2025 period, where the percentage reached 48.15% of all completed projects, with a decrease in projects that experienced profit achievement each year based on the number of projects per year.

Table1Annual Overbudget Increase for PT. XYZ's Natural Resources (Dam) Construction Project from 2019 to 2025

KONDISI BUDGETING PROYEK KONSTRUKSI DIVISI SDA PT. X	TAHUN PENYELESAIAN							TOTAL 2019 SD 2025
	2019	2020	2021	2022	2023	2024	2025	
UNDER BUDGET	100,00%	100,00%	71,43%	50,00%	50,00%	16,67%	0,00%	**14**
OVER BUDGET	0,00%	0,00%	28,57%	50,00%	50,00%	83,33%	100,00%	**13**
JUMLAH	**3**	**1**	**7**	**2**	**6**	**6**	**2**	27

Source: PT. XYZ data, processed by researchers, 2025

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

International Journal of Economics, Business and Innovation Research
https://e-journal.citakonsultindo.or.id/index.php/IJEBIR
E-ISSN : 2964-0865
IJEBIR

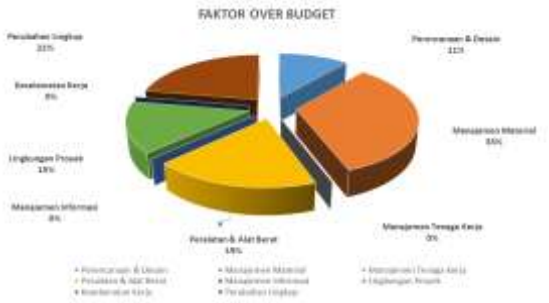


Figure 1. Over Budget Factor

Tables 1, 2, and Figure 1 show that Material Management is the biggest cause of overbudget, with a value of 33%. This indicates that waste related to material management remains a dominant problem in dam projects. This condition provides the basis for researchers to mitigate the risk of overbudget in the Cabean Dam Project, which will begin implementation in 2025.

The Cabean Dam Project, located in Karanganyar Village, Todanan District, Blora Regency, Central Java Province, is a national strategic project aimed at improving water security and supporting the agricultural sector. However, the work, dominated by concrete, has the potential for high waste, both in terms of materials, waiting time, and resource coordination. Furthermore, data from the Ministry of Public Works and Public Housing (PUPR) (2022) shows that dam projects in Indonesia still face challenges in schedule and cost control. Therefore, the application of CCPM and Lean Construction to this project is expected to provide an effective solution to address these issues.

CCPM focuses on identifying and managing uncertainty in projects by optimizing resources and time, while Lean Construction aims to reduce waste and increase customer value (Elshaer et al., 2020). The combination of these two methods is expected to be a powerful strategy to increase efficiency and effectiveness in dam construction projects. This study aims to explore the application of both methodologies in the context of the Cabean Dam project. The integration of CCPM and Lean Construction is expected to not only be able to control time uncertainty through buffer management but also systematically reduce material waste and non-value-added activities. Therefore, this study aims to analyze the application of Critical Chain Project Management and Lean Construction in the planning and control of the Cabean Dam Project to minimize waste and reduce the potential for overbudget.

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

International Journal of Economics, Business and Innovation Research
https://e-journal.citakonsultindo.or.id/index.php/IJEBIR
E-ISSN : 2964-0865
IJEBIR

METHOD

This research uses a mixed methods method with a case study approach on the Cabean Dam Construction Project.in Karanganyar Village, Todanan District, Blora Regency, Central Java Province. Mixed methods were chosen because this study combines quantitative and qualitative analysis in evaluating the implementation of Critical Chain Project Management (CCPM) and Lean Construction.

Quantitatively, this study analyzes project schedule and cost data to measure the impact of CCPM and Lean Construction implementation on time and cost efficiency. The data collection technique in this study uses a mixed method approach, namely a combination of quantitative and qualitative methods to obtain comprehensive data regarding the implementation of Critical Chain Project Management (CCPM) and Lean Construction in minimizing waste in the Cabean Dam Project. Data collection was carried out through documentation studies, field observations, questionnaires, in-depth interviews, and process mapping using Big Picture Mapping. The documentation study was conducted by collecting various project documents related to project planning and control, such as the time schedule (baseline CPM), S-curve, Cost Budget Plan (RAB), weekly and monthly progress reports, time and cost deviation data, material usage data, and rework reports. This documentation data is used to simulate rescheduling using the CCPM method, calculate and analyze buffers, and evaluate project time and cost deviations.

Field observations were conducted directly at the project site to identify activities that fall into the categories of value-adding activities, non-value-adding activities, and non-value-adding but necessary activities. These observations aimed to identify forms of waste such as waiting, rework, excess inventory, multitasking, and other waste that occurred during project implementation. A questionnaire was developed to identify waste frequency based on the E-DOWNTIME classification, measure waste-causing factors based on the 5M approach (man, machine, material, method, management), and assess the risks of CCPM and Lean Construction implementation through likelihood, impact, and detection measurements which were then calculated using the Risk Priority Number (RPN) method. To deepen the analysis, in-depth semi-structured interviews were conducted with project management to gather information related to obstacles to CCPM and Lean Construction implementation, factors causing overbudget, and challenges in controlling project time and costs. The interview results were used to support the Root Cause Analysis (RCA) analysis in identifying the root causes of waste and project deviations. Respondents in this study were selected using purposive sampling techniques, namely experts and project management directly involved in the planning, control, and implementation of the project, such as Project Managers, Site Managers, Project Control, Cost Control, Supervisors, Quality Control, as well as the logistics and

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

International Journal of Economics, Business and Innovation Research
https://e-journal.citakonsultindo.or.id/index.php/IJEBIR
E-ISSN : 2964-0865
IJEBIR

procurement department. All data collection techniques were analyzed using data triangulation and method triangulation approaches, so that the research results obtained are more comprehensive, consistent, and can be scientifically accounted for. In general, there are four stages: the identification stage, the data collection and processing stage, and the data analysis and conclusion stage.

RESULTS AND DISCUSSION

Existing Conditions of Project Planning and Control

Based on the results of observations in the spillway casting area of the Cabean Dam Project on May 12, 2026, it was found that control of the flow of work, materials, and project resources had not been running optimally.Based on field observations during the spillway concreting work of the Cabean Dam Project, several wasteful activities were identified during the construction process. This waste analysis not only identifies the types of waste but also reveals the relationship between material flow, team coordination, and labor effectiveness on overall project performance. Waste identification was conducted using the Lean Construction approach through the classification of value-added activities (VA), non-value-added activities (NVA), and necessary non-value-added activities (NNVA), as well as waste analysis based on the E-DOWNTIME concept.

Analysis of Value Added Activity (VA), Non-Value Added Activity (NVA), and Necessary Non-Value Added Activity (NNVA)

Table 3. Classification of Project Activities Based on VA, NVA, and NNVA

No	Observed Activities	Category	Information
1	Spillway concrete casting	VA	Adding value to construction results
2	Waiting for the arrival of iron materials	NVA	Waiting activity causes delays
3	Formwork quality inspection	NNVA	Required to maintain the quality of work
4	Repeated material transfer	NVA	Warehouse layout is too far
5	Completing daily project reports	NNVA	Project administration is still required

Based on Table 3, the activity classification shows that non-value-added activities are still quite dominant in the spillway concreting process. This condition indicates that

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

International Journal of Economics, Business and Innovation Research
https://e-journal.citakonsultindo.or.id/index.php/IJEBIR
E-ISSN : 2964-0865
IJEBIR

the application of Lean Construction principles to the project is still not optimal, particularly in efforts to reduce activities that do not add value to the construction results. This indicates that improvements in layout, material flow, and coordination between teams are needed to reduce NVA while increasing productivity and workflow effectiveness.

Waste Analysis Based on E-DOWNTIME

Table 4. Waste Identification Based on E-DOWNTIME

No	Activity	Types of Waste	Information
1	Concrete casting	*Defects/Rework*	Over casting volume
2	Waiting for iron material	*Waiting*	Delay in material distribution
3	Formwork repair	*Defects/Rework*	An installation error occurred
4	Material transfer	*Unnecessary Motion*and Excessive Transportation	Material warehouse is far from the work location
5	Workers help with other jobs	*Not Utilizing Skill*	Multitasking of the workforce occurs

Overall, the waste identification results indicate that the spillway concreting work on the Cabean Dam Project still faces several wastes that affect the efficiency of time, labor, and project costs. The dominant wastes identified include waiting, defects/rework, unnecessary motion, excessive transportation, and underutilization of skills. This situation indicates the need for the implementation of Lean Construction and Critical Chain Project Management (CCPM) to improve work flow, enhance resource control, and minimize waste in construction project implementation. This approach will enable systematic waste reduction while sustainably improving project performance.

Implementation of Critical Chain Project Management (CCPM)

Based on observations and interviews, the main issues hindering the smooth progress of the project were delays in material distribution, rework on the formwork, limited work tools, and multitasking among the workforce. These conditions indicate that project delays are not only caused by the sequence of work activities, but also by resource limitations and weak coordination between departments. Therefore, the CCPM

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

approach is relevant because it not only considers the dependencies between activities but also considers resource limitations that affect the smooth execution of the project.

Table 5. Mapping of Existing Problems with CCPM Implementation

Existing Problems	Types of Waste that Emerge	Implementation of CCPM	Expected Impact
Delays in the delivery of iron materials from the warehouse to the fabrication area and work area	*Waiting*	Determining the critical chain and providing buffers for material distribution activities	Worker waiting time is reduced and work can run more smoothly.
Workers help with some work outside of their main duties	*Not Utilizing Skill*	*Resource leveling*and reduced multitasking	Workforce is more focused on core work
Work schedules can easily shift due to material delays and rework.	*Waiting*and Defects/Rework	Buffer management based schedule control	Delays can be monitored early and do not immediately disrupt the main schedule.
Limited tools and access to material distribution	*Waiting and Excessive Transportation*	Resource constraint control	Conflicts over resource use can be reduced
Coordination between departments is not yet fully integrated	*Waiting*and Not Utilizing Skill	Buffer evaluation and periodic coordination between sections	Information flow becomes faster and field decisions are more focused.

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

International Journal of Economics, Business and Innovation Research
https://e-journal.citakonsultindo.or.id/index.php/IJEBIR
E-ISSN : 2964-0865
IJEBIR

Based on the table, the implementation of CCPM is aimed at addressing the root causes of waste, particularly waiting and multitasking of workers. Under existing conditions, waiting for metal materials is one of the most dominant sources of waste. In the CCPM approach, this problem can be controlled through buffer management, which involves providing reserve time or controlling time for activities with a high risk of delay. Buffers are not intended as additional time that can be used freely, but rather as a control tool to monitor the extent of disruption to critical activities.

Table 6. Comparison of Conditions Before and After CCPM Implementation

Indicator	Conditions Before CCPM	Implementation of CCPM	Conditions After CCPM
*Waiting*material	Materials are often late so workers experience idle time	Material buffer and feeding buffer in material distribution activities	*Waiting*material is reduced because material requirements are monitored before work begins
Multitasking workforce	Workers help with several jobs at once	*Resource leveling*and multitasking restrictions on critical activities	Workers are more focused on core tasks and productivity increases.
Schedule control	Schedules can easily shift due to material delays and rework.	*Buffer management*and monitoring buffer consumption	Schedules are more controlled because delays can be detected earlier.
Use of resources	Manpower and equipment have not fully followed the priority of critical work.	Resource constraint control	The use of resources is more focused on work that determines progress.
Work coordination	Coordination still faces obstacles	Buffer evaluation in weekly coordination	Coordination is more measurable because each

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

International Journal of Economics, Business and Innovation Research
https://e-journal.citakonsultindo.or.id/index.php/IJEBIR
E-ISSN : 2964-0865
IJEBIR

	between sections		obstacle is linked to its impact on the schedule.

Interview results also showed that most informants believed the use of time buffers could help anticipate delays in critical work. This demonstrates the relevance of CCPM implementation to project conditions, particularly since spillway concreting is highly dependent on material accuracy, workforce readiness, formwork readiness, and smooth distribution access.

Implementation of Lean Construction

Table 7 below shows the impact of implementing Lean Construction on waste reduction in the spillway concreting work for the Cabean Dam Project. Each implementation step is directly linked to the type of waste reduced and the tangible impact achieved on time efficiency, labor, and work flow.

Table 7. Impact of Lean Construction Implementation on Waste

Waste	**Implementation of Lean Construction**	**Impact**
Waiting	*Pull Planning*or Last Planner System	Materials are available on time, reducing worker idle time.
Transportation	Material layout improvements and warehouse reorganization	More efficient material movement, resulting in reduced wasted time and effort
Rework	Initial quality control or formwork inspection	Initial errors are reduced, resulting in more accurate and cost-effective work.
Motion	Work layout optimization	A more productive workforce, resulting in a smoother flow of work

Based on this implementation, a direct link is evident between Lean Construction steps and waste reduction, including implementation, reduction in waste, and impact. These results align with field observations and respondents' responses, who noted

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

International Journal of Economics, Business and Innovation Research
https://e-journal.citakonsultindo.or.id/index.php/IJEBIR
E-ISSN : 2964-0865
IJEBIR

smoother work flow, improved coordination, and a significant reduction in wasted time and labor.

Quantitative Evaluation and Waste Measurement Indicators

The claims regarding waste reduction in this study are not only based on qualitative assessments but are also empirically proven through quantitative evaluations. The effectiveness of the integration of the Critical Chain Project Management (CCPM) and Lean Construction methods is measured by comparing field operational conditions before management intervention (baseline/historical data) with conditions after the control system is implemented on the Cabean Dam spillway concreting work item.

In detail, the efficiency performance of achieving waste reduction is presented in Table 8 below:

Table 8. Quantitative Performance Indicators for Waste Minimization

No	Types of Waste and Measurement Indicators	Before Implementation	After Implementation	Efficiency / Change (%)	Status
1	*Waiting Time*(Accumulated worker/equipment idle hours)	120 Hours	80 Hours	Down 33.33%	Succeed
2	*Rework Cost*(Repair costs due to concrete/formwork defects)	Rp. 500 million	Rp. 300 million	Down 40.00%	Succeed
3	Material Waste (Percentage of remaining pieces of iron reinforcement/scrap)	8.00%	4.00%	Down 50.00%	Succeed
4	Non-Value Added Activity (NVA) (Proportion of non-productive activities)	30.00%	18.00%	Down 40.00%	Succeed

Based on the quantitative data in Table 8 above, an in-depth analysis of the successful reduction in each waste indicator, such as the reduction in waiting time after the implementation of Lean Construction-based logistics management, the waiting time was successfully cut to 80 hours (efficiency of 33.33%). This reduction directly minimizes

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

labor burnout and maintains the continuity of the casting circulation flow in the field. Reducing rework costs through the implementation of early quality control and strict supervision of the formwork geometry before the casting process begins, rework costs can be reduced to Rp300 million. This 40.00% reduction proves that preventing quality defects is far more efficient than carrying out post-event repairs. Saving material waste by applying Lean principles through optimization of working drawings (shop drawings) and planned iron cutting methods (precise bar bending schedule), material waste was successfully reduced to only 4.00% (reducing material waste by 50.00%). This has a significant impact on the efficiency of project material procurement. Increasing Added Value Through Reducing Non-Value Added Activity (NVA) This 40.00% reduction in non-productive activities confirms that the rearrangement of the site layout and daily coordination using the Last Planner System has succeeded in changing unnecessary motion and excessive transportation into productive activities that add value to the work (Value Added Activity).

Comparison of Conditions Before and After Implementation

This analysis focuses on time performance indicators, schedule deviations, and physical progress of the project to see the effectiveness of implementing the two approaches.

Schedule Performance Analysis

The results of the data recapitulation from the earned value management calculations show that there is a difference between the planned value and the realized value (earned value), which is reflected in the Schedule Performance Index (SPI) indicator. Based on the results of the project data processing before implementation, the following results were obtained:

Planned Value (PV) = 257,660,416,671.70
Earned Value (EV) = 107,876,345,384.28

So we get:

$$\text{SPI} = \frac{EV}{PV} = \mathbf{0,42}$$

Based on the results of project data processing after implementation, the following was obtained:

Planned Value (PV) = 107,582,109,404.86
Earned Value (EV) = 107,876,345,384.28

So we get:

$$\text{SPI} = \frac{EV}{PV} = \mathbf{1,003}$$

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

International Journal of Economics, Business and Innovation Research
https://e-journal.citakonsultindo.or.id/index.php/IJEBIR
E-ISSN : 2964-0865
IJEBIR

An SPI value of 1.003 (<1) indicates that the project is generally not experiencing any delays relative to the planned baseline. However, these delays are still under control, as there are no extreme deviations from the overall project targets.

Schedule Deviation Analysis

Based on the Work Progress data, the cumulative deviation is as follows:

Progress deviation = 31,666,720,745.35

Percentage deviation = 7.03%

The deviation value of 31,666,720,745.35 indicates a difference between the planned value and the actual project progress. Meanwhile, the percentage deviation of 7.03% indicates the level of difference between the planned target and the actual project achievement. The analysis results indicate that the project realization has not yet fully achieved the planned target set in the baseline.

Project Physical Progress Analysis

The results of the analysis on Work Progress show that the cumulative physical progress of the project is in the range of:

Actual progress ≈ 23.20%

This value indicates that the project is still in the early to mid-stages of implementation. At this stage, project performance is highly sensitive to disruptions in material logistics and labor productivity.

Comparison of Conditions Before and After Implementation

Comparison between conditions before implementation (baseline planning) and after implementation of CCPM and Lean Construction shows changes in the project control system, especially in the aspects of monitoring and responding to deviations.

Table 9. Comparison Before and After Implementation of CCPM and Lean Construction

Indicator	Before Implementation	After Implementation	Impact of Change
Duration of work (Ra-Ri)	Based on the Work Schedule baseline	Based on the realization after CCPM and Lean	Acceleration or duration control
Reduction of working days	Based on the planned schedule	Based on actual project	Project time efficiency

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

International Journal of Economics, Business and Innovation Research
https://e-journal.citakonsultindo.or.id/index.php/IJEBIR
E-ISSN : 2964-0865
IJEBIR

Schedule deviation	High or uncontrolled (Work Progress)	More controlled (SPI monitoring)	Decreased delays
Rework	Quite high (Cost of Work)	Decline after Lean Construction	*Waste defects*reduce
Waiting time	High due to material delays	Decreased after workflow improvements	Reduced worker idle time

In general, the table shows that after the implementation of CCPM and Lean Construction, there were improvements in the project control system, especially in terms of time, schedule stability, and reduction of waste in the work implementation process.

Time and Cost Efficiency Analysis

The time and cost efficiency analysis in this study was conducted based on the Earned Value Management (EVM) approach by utilizing data from the Work Schedule, Work Progress, Plans and Realization, as well as SPI and CPI Graphs on the Cabean Dam Construction Project. Project time efficiency was analyzed using the Schedule Performance Index (SPI) indicator based on the relationship between Earned Value (EV) and Planned Value (PV).

Table 10. EVM calculation (EV, PV, SPI)

Indicator	Mark
Planned Value(PV)	Rp. 107,582,109,404.86
Earned Value(EV)	Rp. 107,876,345,384.28
Schedule Performance Index(SPI)	1,003

An SPI value of 1.003 (<1) indicates that the project is behind schedule compared to the planned baseline. This means that the work completion rate only reached 41.9% of the planned value for the same period. Based on progress data, the deviation is as follows:

Table 11. Summary of Progress Deviation

Indicator	Mark
Progress deviation (value)	Rp. 31,666,720,745.35
Progress deviation (%)	7.03%
Actual project progress	23.20%

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

A deviation of 7.03% indicates a gap between planned and actual performance, but remains within controllable limits. Delays fluctuate and are influenced by work flow imbalances, material delays, and resource coordination.

Cost Performance Analysis

Based on the cost summary and job cost data, project costs are not presented in a single aggregate figure like BAC and CPI, but rather are spread across various work components. Therefore, cost analysis is conducted using an actual cost structure approach and waste cost identification.

Table 12. Comparison of Planned and Actual Costs (EVM Cost Overview)

Indicator	Mark	Information
Plan Cost (BAC / PV Cost)	Rp. 136,098,664,628.63	Total project plan cost based on overall work
Actual Cost (AC)	Distributed on Job Cost	The actual costs are not yet presented as a total project value, but are still in the form of a detailed breakdown of costs for each work item.
Earned Value(EV)	Rp. 104,431,943,883.28	The value of work that has been realized based on the physical progress of the project
CPI	Not counted in total	Because the actual cost data has not been summarized into a single total project value.

Based on the table, project cost control cannot only be seen from a single CPI, but is more precisely analyzed through the cost waste structure that occurs in the field.

To provide a more comprehensive overview of project performance in terms of time and cost, a visualization using a comparison chart of the Schedule Performance Index (SPI) and Cost Performance Index (CPI) was performed. This chart aims to demonstrate the relationship between time efficiency and cost efficiency in the implementation of the Cabean Dam Construction Project.

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

International Journal of Economics, Business and Innovation Research
https://e-journal.citakonsultindo.or.id/index.php/IJEBIR
E-ISSN : 2964-0865
IJEBIR

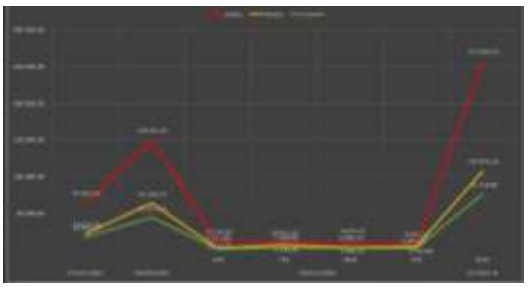


Figure 2. Earned Value Analysis (SPI and CPI) Graph for the Cabean Dam Construction Project

Based on the Earned Value Analysis graph, it can be seen that the BCWS (work plan) value is higher than the BCWP (work realization), indicating a delay in project progress. This is also reflected in the SPI value, which is below 1 throughout the observation period, indicating that the project is behind schedule. This condition indicates that actual productivity has not been able to achieve the set planned targets.

Meanwhile, the ACWP (actual cost) value was lower than the BCWP, resulting in a CPI value > 1 throughout the observation period. This indicates that the project was under budget, meaning the actual costs incurred were more efficient than the value of the work achieved.

Overall, the SPI and CPI graphs show an interesting situation: the project experienced time delays (SPI < 1) but still demonstrated cost efficiency (CPI > 1). This condition indicates that cost control is relatively good, but there are still inefficiencies in the work flow and field productivity. Therefore, improvements are needed in aspects of workflow planning, material control, and resource coordination to improve project time performance without sacrificing cost efficiency. Next, waste costs are identified:

Table 13. Waste Cost Identification

Types of Waste	Source of Funds	Impact
Rework cost	Rework of formwork and concrete	Additional material and labor costs
Waiting cost	Material delay	*Idle time*labor
Transport costs	Distance from warehouse to work location	Inefficiency of energy and time
NNVA cost	Administration and quality control	Cost without direct value added

Integration of Time and Cost Efficiency

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

International Journal of Economics, Business and Innovation Research
https://e-journal.citakonsultindo.or.id/index.php/IJEBIR
E-ISSN : 2964-0865
IJEBIR

The SPI value of 0.767 indicates that time delays have a direct impact on increasing operational costs due to idle time, rework, and material flow inefficiencies.

Evaluation of the Effectiveness of CCPM and Lean Construction Implementation on Waste Minimization

To objectively measure the effectiveness of integrating the Critical Chain Project Management (CCPM) and Lean Construction methods, this study conducted a quantitative comparative analysis between conventional baseline conditions (before implementation) and actual field conditions (after implementation). The evaluation focused on three dominant types of operationally defined non-value-added waste: waiting time, rework/defect costs, and transportation costs.

The results of quantitative calculations of waste minimization performance in the Cabean Dam Construction Project are summarized in Table 14 below:

Table 14. Quantitative Evaluation Matrix for Waste Minimization of the Cabean Dam Project

Waste Category	Key Indicators	Before (Baseline)	After (Implementation)	Calculation & Percentage Decrease
Waiting	Worker & Equipment Idle Duration	10 Hours	4 Hours	$\left(\frac{10-4}{10}\right) \times 100\% = 60\%$
Rework/Defect	Nominal Cost of Structural Repairs	Rp. 100 million	Rp. 40 million	$\left(\frac{100-40}{100}\right) \times 100\% = 60\%$
Transportation	Material Moving & Logistics Finance	Rp. 50 million	Rp. 30 million	$\left(\frac{50-30}{50}\right) \times 100\% = 40\%$

Based on the quantitative data in Table 14, the implementation of project control integration has a significant impact on waste reduction in all observed indicators: Waiting Time Reduction (60%): The reduction in idle time from 10 hours to 4 hours was successfully achieved through the implementation of the Last Planner System (pull-based planning) which is synchronized with the allocation of feeding buffers in the CCPM

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

network. Rework/Defect Cost Reduction (60%): The cost of rework due to quality failures was drastically reduced from IDR 100 million to IDR 40 million. This success was driven by the elimination of non-productive multitasking practices on the critical chain path. Transportation Cost Reduction (40%): The cost of internal logistics mobilization experienced savings from IDR 50 million to IDR 30 million. This efficiency is a direct impact of site layout planning optimization. At a macro level, the achievement of waste reduction efficiency in the range of 40% to 60% in this study is very valid and strongly supported by previous literature. Empirical studies byRiyanti et al., (2025)emphasized that the adoption of the Lean system in large-scale infrastructure projects is able to reduce operational waste by an average of 25–50%, as well as producing total construction cost savings of between 18–30% through minimizing defects, waiting time, and integrated logistics management.

Although the macro evaluation of this project faced external supply chain constraints that pressured schedule performance (Schedule Performance Index, SPI = 0.767), the efficiency of internal waste management proved to be a key factor in saving the project's finances. Controlling waste costs in the field successfully kept the project under budget (under budget, CPI > 1).

Discussion of the Impact of CCPM and Lean Construction Implementation

Overall, the implementation of Critical Chain Project Management (CCPM) and Lean Construction on the Cabean Dam Construction Project has a significant positive impact on improving project performance, particularly in terms of time control, cost efficiency, and waste reduction. These findings indicate that both approaches not only work individually, but also complement each other in forming a project control system that is more adaptive to uncertainty in the field. Impact of CCPM on Time and Resource Control The implementation of CCPM makes a major contribution to the aspect of schedule control through critical chain identification and buffer management mechanisms. In the context of the Cabean Dam project, delays caused by material uncertainty, labor limitations, and coordination disruptions can be controlled through more structured buffer management. Buffers function as a protection tool against variations in activity duration, so that delays in individual activities do not directly impact the entire project. The results of the SPI analysis of 0.003 indicate that the project is still experiencing delays to the baseline, but CCPM plays a role in preventing these delays from escalating or becoming uncontrollable.

In addition, CCPM also has an impact on reducing workforce multitasking through the implementation of resource leveling. This is important because multitasking has been proven to cause decreased productivity and extend the lead time of critical activities. By focusing on the critical chain, resource allocation becomes more focused so that activities

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

that have the greatest impact on project completion receive top priority. Conceptually, CCPM changes the project control approach from a "static schedule" based to a "critical flow and priority" based, so that decision-making becomes more responsive to actual conditions in the field. The Impact of Lean Construction on Process Efficiency and Waste Reduction. Lean Construction has a dominant impact on the efficiency aspect of the work process by eliminating activities that do not provide added value (non-value added activities). Based on the results of waste identification in the project, the main waste was found to be waiting, defects/rework, unnecessary motion and excessive transportation.

The implementation of Lean Construction through improved material layout, pull planning (Last Planner System), visual management, and initial quality control has been proven to reduce the intensity of waste. More specifically, waiting is reduced through more coordinated material planning, thereby reducing labor idle time. Rework (defects) is reduced through improved initial quality control before the main work is carried out. Unnecessary motion and transportation are reduced due to optimized warehouse and work area layouts. NNVA can be controlled through efficient administrative activities and more structured monitoring.

From a cost perspective, this waste reduction has a direct impact on reducing non-value costs, which is seen from the reduction in rework activities, idle labor costs, and material logistics inefficiencies. Thus, Lean Construction acts as a systematic approach to improve workflow, reduce process variability, and increase added value in every construction activity. Synergy of CCPM and Lean Construction in Improving Project Performance The integration of CCPM and Lean Construction produces a complementary approach, where CCPM focuses on controlling time and resources, while Lean Construction focuses on process efficiency and waste elimination. The synergy of these two methods can include CCPM ensuring project schedule stability through critical chain control and buffer management. Lean Construction ensures workflow stability through waste reduction and increased process efficiency. The combination of the two creates a more robust project system against material, labor, and coordination uncertainties. In the context of the Cabean Dam project, this synergy is seen from: Reduced idle time due to more controlled buffers (CCPM and Lean supply control), Reduced rework due to initial quality control (Lean) which impacts critical chain stability (CCPM), Improved field coordination which impacts work flow efficiency. Thus, these two approaches are not only complementary, but also form a project control system based on “time cost flow integration”.

Impact on Integrated Time, Cost, and Waste Efficiency The analysis results show that although the project still experiences delays (SPI < 1), the implementation of CCPM and Lean Construction has improved the project's control capabilities in keeping deviations within controllable limits. From a cost perspective, the reduction of waste such

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

as rework and waiting contributed to a decrease in the project's indirect costs, particularly unproductive labor costs and material waste. This indicates that cost efficiency is not only determined by budget control, but also by the system's ability to reduce non-value-added activities. Based on the discussion, it can be concluded that the implementation of Critical Chain Project Management (CCPM) and Lean Construction on the Cabean Dam Construction Project has a positive, synergistic impact. CCPM plays a role in controlling schedules and resources through buffer and critical chain mechanisms, while Lean Construction plays a role in increasing process efficiency through waste elimination. The combination of these two methods has been proven to increase time efficiency, reduce operational costs, and improve the overall project workflow, resulting in a more effective, adaptive, and sustainable project control system.

CONCLUSION

This research successfully designed a planning system for the Cabean Dam spillway concreting project using CCPM through the preparation of a critical chain, identification of resource constraints, and determination of project buffers that were proven to be effective in eliminating multitasking and reducing time waste since the initial scheduling phase. This research was proven to be successful in controlling project implementation using the integration of CCPM and Lean Construction, where the application of buffer management successfully reduced waiting waste by 33.33%, site layout improvements successfully reduced transportation waste by 40.00%, and early quality control effectively reduced rework waste due to concrete defects by 60.00%. The impact measurement results showed that the combination of these two methods had a significant impact on the project's macro performance, evidenced by optimal budget efficiency with a Cost Performance Index (CPI) value > 1, and a field time delay rate of 7.03% (Schedule Performance Index/SPI = 1.003) which was successfully isolated by the buffer graph. The main challenges in its implementation include high dependence on material supply schedules from major vendors and obstacles to adaptation from the construction workforce in the field.

BIBLIOGRAPHY

Elshaer, R., Sobaih, A., & Elbaz, AM 2020. Integration of Critical Chain Project Management and Lean Construction: A Framework for Improving Project Performance. International Journal of Construction Management.

IEEE standards 1490–2011. (2011). Standard A Guide to the Project Management Body of Knowledge (PMBOK ® Guide) — Fourth Edition IEEE Computer Society (Number November).

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

Koskela, L. (1992). Application of the new production philosophy to construction, CIFE Technical Report:72. Stanford University. (p. 75).

PUPR. 2022. Regulation of the Minister of PUPR concerning Cost Standards and Control of Dam Projects. Jakarta: Ministry of PUPR.

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.