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Cost Efficiency Analysis of Riverbank Protection Work Acceleration Using the Critical Path Method at the Masangan River, Pasuruan Regency

Ahzam Zarkasy Septian Danu*, Andi Patriadi, Esti Wulandari

Universitas 17 Agustus 1945 Surabaya, Indonesia

Email: 1472400080@surel.untag-sby.ac.id*, andipatriadi@untag-sby.ac.id, wulandariesti@untag-sby.ac.id

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Abstract

Riverbank protection projects are susceptible to delays caused by fluctuating river discharge, tidal conditions, adverse weather, and restricted working hours. Such delays can increase project costs and reduce the effectiveness of disaster mitigation measures. This study evaluated the cost efficiency of accelerating the Masangan Riverbank Protection Project in Pasuruan Regency using the Critical Path Method (CPM). A quantitative approach was applied using secondary data, including the work breakdown structure, baseline schedule, activity durations, work volumes, progress reports, S-curve, and project cost documents. CPM calculations were used to identify critical activities based on earliest start and finish times, latest start and finish times, and zero float values. Acceleration was implemented by adding workers to critical activities while maintaining eight working hours per day and six working days per week. Workforce additions reduced the durations of K-175 concrete work, rubble masonry, and weep-hole installation from 42 to 30 days, although direct labor costs increased. The respective cost slopes were IDR 668,824, IDR 1,637,280, and IDR 818,640 per day. K-175 concrete work was identified as the most economical acceleration alternative, whereas rubble masonry represented the highest additional cost. The integration of CPM and cost-slope analysis supported selective schedule acceleration by prioritizing critical activities that achieved the greatest time reduction with the lowest additional cost.

INTRODUCTION

Construction projects are characterized by high levels of complexity, making them susceptible to schedule delays and cost overruns. Effective project management is therefore essential to ensure that construction activities are completed within the planned time, budget, and quality requirements (Saputra et al., 2021). Among the key aspects of construction project management, time control plays a crucial role in minimizing deviations between planned and actual project performance through systematic planning,

scheduling, monitoring, and corrective actions (Pradita et al., 2023). Inadequate project control may result in delays that not only extend project duration but also increase overall project costs and reduce operational efficiency (Jamal et al., 2024).

Project delays remain one of the most common challenges in the construction industry. Such delays may arise from labor shortages, poor coordination, material supply problems, adverse weather conditions, or other unforeseen external factors (Dwi Akbar et al., 2024). Delayed completion negatively affects both contractors and project owners by increasing construction costs, disrupting resource allocation, and potentially resulting in noncompliance with contractual obligations (Ayatullah et al., 2023). Consequently, effective scheduling techniques are required to identify critical activities and develop appropriate acceleration strategies without compromising project quality (Mutia Astari & Subagyo, 2021).

Riverbank protection projects are particularly vulnerable to scheduling uncertainties because their implementation is strongly influenced by hydrological and environmental conditions. These structures play an important role in preventing riverbank erosion, mitigating slope failures, and protecting surrounding infrastructure and communities. In East Java, the Masangan River in Pasuruan Regency serves as an important water resource and drainage channel . However, continuous riverbank erosion caused by fluctuating river discharge, seasonal flooding, and morphological changes has increased the need for riverbank reinforcement works to maintain channel stability and reduce disaster risks (Andi et al., 2022).

During the implementation of the Masangan Riverbank Protection Project, several technical and environmental constraints significantly affected construction progress. Unpredictable weather conditions, high tidal water levels, fluctuating river discharge, and limited effective working hours due to tidal cycles frequently disrupted construction activities. These conditions caused the project to fall behind the planned schedule, highlighting the need for an effective acceleration strategy capable of reducing delays while maintaining construction quality and controlling additional costs.

One of the most widely applied scheduling techniques for construction project optimization is the Critical Path Method (CPM). CPM identifies the sequence of critical activities that directly determines the overall project duration and provides a systematic basis for project scheduling and control (Wilson Simanungkalit et al., 2022). By determining the critical path through forward-pass and backward-pass calculations, project managers can identify activities requiring priority attention and evaluate opportunities for schedule optimization (Sa'adah et al., 2021).

To further reduce project duration, CPM can be integrated with schedule acceleration techniques, such as fast-tracking, which shortens project completion time by executing compatible activities in parallel rather than sequentially (Priyanto et al., 2019). Although this approach can substantially reduce project duration and improve operational efficiency, it requires careful coordination and quality control to minimize the risks of rework and additional costs (Zuhriyah & Oetomo, 2022). Therefore, evaluating both the

time and cost implications of project acceleration is essential for determining the feasibility of acceleration strategies (Kadek et al., 2023).

Based on these considerations, this study aimed to analyze the cost efficiency of accelerating the Masangan Riverbank Protection Project in Pasuruan Regency using the Critical Path Method (CPM). The study evaluated the project schedule to identify critical activities and assessed the cost implications associated with schedule acceleration. The findings are expected to provide practical recommendations for improving time performance while maintaining cost efficiency in riverbank protection projects and other hydraulic infrastructure developments with similar construction characteristics.

METHOD

This study employed a quantitative research approach to evaluate the cost efficiency of accelerating the Masangan Riverbank Protection Project in Pasuruan Regency using the Critical Path Method (CPM). The study focused on identifying critical project activities, analyzing the existing schedule, and evaluating the impact of schedule acceleration on overall project costs. The analysis was conducted by comparing the normal project schedule with the accelerated schedule to determine the most cost-efficient alternative while maintaining the planned project scope.

The study used secondary data obtained from project documentation and relevant literature. The project documents included the work breakdown structure (WBS), baseline schedule, activity durations, work volumes, S-curve, progress reports, and cost data. These documents provided the information required to analyze the project schedule and assess the cost implications of acceleration. Supporting literature related to construction project management, scheduling techniques, and the Critical Path Method was also reviewed to establish the theoretical foundation of the study.

The research process began with the identification of project activities, including their logical relationships and durations. The project schedule was then analyzed using the Critical Path Method (CPM) to determine the sequence of activities that governed the overall project duration. The analysis involved calculating the earliest and latest start and finish times for each activity, including Earliest Start (ES), Earliest Finish (EF), Latest Start (LS), and Latest Finish (LF). Activities with zero float were identified as critical activities because delays in these activities directly affected the overall project completion time (Armanda Putri & Gunasti, 2021).

After the critical path was identified, project acceleration was performed by modifying the schedule of critical activities. The acceleration strategy involved adjusting the sequence of selected activities to allow parallel execution where technically feasible, thereby reducing the overall project duration. The revised schedule was subsequently analyzed to determine the new completion time and confirm changes in the critical path after acceleration (Mahapatni, 2019).

Finally, a cost-efficiency analysis was conducted by comparing project costs before and after schedule acceleration. The evaluation considered the financial impact of reducing project duration to determine the most economical acceleration alternative. The

results were used to assess whether the application of the Critical Path Method improved project time performance while maintaining cost efficiency in the Masangan Riverbank Protection Project in Pasuruan Regency. This approach provided a systematic basis for evaluating schedule optimization and its cost implications in riverbank protection construction projects.

RESULTS AND DISCUSSION

Project Profile

The Masangan River rubble masonry and gabion construction project in Pasuruan Regency is an emergency disaster mitigation project intended to reduce the risk of river overflow during the rainy season (Pradita et al., 2023). Without immediate countermeasures, the increasing river discharge may accelerate riverbank erosion, leading to progressive bank failure and landslides. The project information is summarized as follows (Matahelumual et al., 2022).

Table 1. Project Information

Description	Information
Project Name	Emergency Disaster Mitigation Project
Project Location	Masangan Village, Bangil District, Pasuruan Regency, Indonesia
Project Type	Self-managed Project
Funding Source	DIPA of OP SDA Brantas
Project Commencement	9 February 2026
Project Completion	20 June 2026
Contract Duration	19 Weeks (114 Days)
Project Owner	OP SDA II BBWS Brantas
Consultant/Designer	OP SDA II BBWS Brantas
Supervising Engineer	OP SDA II BBWS Brantas
Contractor	OP SDA II BBWS Brantas
Type of Work	Rubble Masonry and Gabion Construction
Length of Retaining Structure	150 m
Description	Information

Source: Project Data

Bill of Quantities

The Bill of Quantities (BOQ) summarizes all construction activities required to complete the riverbank protection project. The work items include preparation works, dewatering, earthworks, concrete works, structural works, gabion installation, and piling works. The detailed quantities are presented in Table 2.

Table 2. Bill of Quantities

No.	Work Item	Unit	Qty
1	**PREPARATION WORKS**		
1.1	Surveying and setting out (Bouwplank installation)	m	150,00

No.	Work Item	Unit	Qty
1.2	Site clearing and stripping	m^2	150,00
1.3	Occupational Health and Safety Management System (OHSMS/SMK3)	LS	1,00
1.4	Mobilization and demobilization	LS	2,00
2	**DEWATERING WORKS**		
2.1	Bamboo sheet retaining structure	m^2	229,50
2.2	Cofferdam retaining frame	m	421,00
2.3	Water pump operation	hari	5,00
3	**EARTHWORKS**		
3.1	Common excavation	m^3	379,50
3.2	Compacted granular backfill	m^3	345,83
3.3	Soil compaction	m^3	345,83
4	**CONCRETE WORKS**		
4.1	Plain reinforcing steel for columns, beams, tie beams, and ground beams	kg	3115,00
4.2	Concrete grade K-175	m^3	64,69
4.3	Foundation and ground beam formwork	m^2	75,00
4.4	Column formwork	m^2	40,63
5	**STRUCTURAL WORKS**		
5.1	Rubble masonry (1 cement : 4 sand mortar)	m^3	470,25
5.2	Weep hole installation	m^1	140,30
5.3	Rubber joint filter (t = 1 cm)	m^2	79,06
5.4	Plastering	m^2	75,00
5.5	Joint finishing (pointing)	m^2	525,00
6	**GABION WORKS**		
6.1	Gabion installation	m^3	192,50
6.2	Bamboo piles	m	350,00
6.3	Medium-grade geotextile installation	m^2	210,00
7	**PILE DRIVING WORKS**		
7.1	Supply of precast concrete piles (20 × 20 × 300 cm)	bh	70,00
7.2	Pile penetration	m^1	140,00

Source: Project Data

Workforce and Equipment

The workforce required for each construction activity was determined according to the type and complexity of the work. Manual labor was primarily employed for masonry, gabion installation, reinforcement, and finishing works, whereas mechanized operations were utilized for earthworks and pile driving. The workforce allocation and construction equipment used in the project are presented in Table 3.

Table 3. Workforce and Equipment

No.	Work Item	Number of Workers (man-day)	Construction Method	Equipment
1	**PREPARATION WORKS**			

No.	Work Item	Number of Workers (man-day)	Construction Method	Equipment
1.1	Surveying and setting out (Bouwplank installation)	2	Manual	–
1.2	Site clearing and stripping	3	Manual	–
1.3	Occupational Health and Safety Management System (OHSMS/SMK3)	–	–	–
1.4	Mobilization and demobilization	–	–	–
2	**DEWATERING WORKS**			
2.1	Bamboo sheet retaining structure	3	Manual	–
2.2	Cofferdam retaining frame	4	Manual	–
2.3	Water pump operation	1	–	–
3	**EARTHWORKS**			
3.1	Common excavation	2	Mechanical	1 PC120 Excavator
3.2	Compacted granular backfill	2	Mechanical	1 PC120 Excavator
3.3	Soil compaction	1	Mechanical	1 PC120 Excavator
4	**CONCRETE WORKS**			
4.1	Plain reinforcing steel for columns, beams, tie beams, and ground beams	4	Manual	–
4.2	Concrete grade K-175	4	Manual	1 m³ Concrete Mixer
4.3	Foundation and ground beam formwork	2	Manual	–
4.4	Column formwork	2	Manual	–
5	**STRUCTURAL WORKS**			
5.1	Rubble masonry (1 cement : 4 sand mortar)	6	Manual	–

No.	Work Item	Number of Workers (man-day)	Construction Method	Equipment
5.2	Weep hole installation	3	Manual	–
5.3	Rubber joint filter (t = 1 cm)	2	Manual	–
5.4	Plastering	4	Manual	–
5.5	Joint finishing (pointing)	2	Manual	–
6	**GABION WORKS**			
6.1	Gabion installation	4	Manual	–
6.2	Bamboo piles	2	Manual	–
6.3	Medium-grade geotextile installation	2	Manual	–
7	**PILE DRIVING WORKS**			
7.1	Supply of precast concrete piles (20 × 20 × 300 cm)	–	–	–
7.2	Pile penetration	2	Mechanical	1 PC120 Excavator

Source: Project Data

Labor Coefficients

Labor coefficients represent the number of man-days (OH) required to complete one unit of work. These coefficients were used as the basis for estimating activity durations and labor requirements in the Critical Path Method (CPM) analysis. The labor coefficients for each work item are presented in Table 4.

Table 4. Labor Coefficients

No.	Work Item	Labor Coefficient (OH)
1	**PREPARATION WORKS**	
1.1	Surveying and setting out (Bouwplank installation)	0,014
1.2	Site clearing and stripping	0,100
1.3	Occupational Health and Safety Management System (OHSMS/SMK3)	1,000
1.4	Mobilization and demobilization	2,000
2	**DEWATERING WORKS**	
2.1	Bamboo sheet retaining structure	0,150
2.2	Cofferdam retaining frame	0,150
2.3	Water pump operation	5,000
3	**EARTHWORKS**	
3.1	Common excavation	0,135
3.2	Compacted granular backfill	0,065

No.	Work Item	Labor Coefficient (OH)
3.3	Soil compaction	
4	**CONCRETE WORKS**	
4.1	Plain reinforcing steel for columns, beams, tie beams, and ground beams	0,003
4.2	Concrete grade K-175	1,250
4.3	Foundation and ground beam formwork	0,300
4.4	Column formwork	0,660
5	**STRUCTURAL WORKS**	
5.1	Rubble masonry (1 cement : 4 sand mortar)	2,230
5.2	Weep hole installation	2,230
5.3	Rubber joint filter (t = 1 cm)	79,063
5.4	Plastering	0,450
5.5	Joint finishing (pointing)	0,400
6	**GABION WORKS**	
6.1	Gabion installation	0,480
6.2	Bamboo piles	0,120
6.3	Medium-grade geotextile installation	0,016
7	**PILE DRIVING WORKS**	
7.1	Supply of precast concrete piles (20 × 20 × 300 cm)	0,100
7.2	Pile penetration	0,027

Source: Project Data

Project Cost Estimate

The Project Cost Estimate (PCE) represents the financial planning document prepared to estimate the total cost required for the implementation of the Masangan Riverbank Protection Project. The cost estimate includes all construction activities, beginning with preparation works, dewatering, earthworks, concrete works, structural masonry, gabion installation, and pile driving (Ginting & Sembiring, 2020; Hidayat & Nugraha, 2021; Kurniawan & Setiawan, 2022). Each work item was calculated based on the measured work quantities and unit prices for materials, labor, and equipment in accordance with the project planning documents. The cost estimate also incorporates indirect costs and applicable taxes to provide a comprehensive project budget (Prasetyo & Widodo, 2021; Rahman & Sari, 2023; Setiawan & Putri, 2022; Wibowo & Santoso, 2024). An accurate cost estimate is essential for effective financial management, enabling efficient resource allocation, minimizing the risk of cost overruns, and ensuring that the project can be completed within the planned budget while maintaining the required quality standards. The detailed project cost estimate for the Masangan River rubble masonry and gabion construction project is presented in Table 5.

Table 5. Project Cost Estimate

No.	Work Item	Cost (Rp)
1	**PREPARATION WORKS**	
1.1	Surveying and setting out (Bouwplank installation)	Rp. 2.857.221,00

No.	Work Item	Cost (Rp)
1.2	Site clearing and stripping	Rp. 2.184.000,00
1.3	Occupational Health and Safety Management System (OHSMS/SMK3)	Rp. 3.897.765,00
1.4	Mobilization and demobilization	Rp. 4.440.000,00
2	**DEWATERING WORKS**	
2.1	Bamboo sheet retaining structure	Rp. 11.101.685,83
2.2	Cofferdam retaining frame	Rp. 30.698.014,25
2.3	Water pump operation	
3	**EARTHWORKS**	Rp. 10.847.962,85
3.1	Common excavation	Rp. 3.272.964,70
3.2	Compacted granular backfill	
3.3	Soil compaction	
4	**CONCRETE WORKS**	Rp. 43.219.113,70
4.1	Plain reinforcing steel for columns, beams, tie beams, and ground beams	Rp. 56.897.422,94
4.2	Concrete grade K-175	Rp. 5.275.889,50
4.3	Foundation and ground beam formwork	Rp. 4.526.736,69
4.4	Column formwork	
5	**STRUCTURAL WORKS**	Rp. 668.230.317,50
5.1	Rubble masonry (1 cement : 4 sand mortar)	Rp. 5.908.574,98
5.2	Weep hole installation	Rp. 18.681.300,00
5.3	Rubber joint filter (t = 1 cm)	Rp. 4.967.823,39
5.4	Plastering	Rp. 26.080.206,64
5.5	Joint finishing (pointing)	
6	**GABION WORKS**	Rp. 225.470.437,50
6.1	Gabion installation	Rp. 11.017.098,75
6.2	Bamboo piles	Rp. 16.238.570,88
6.3	Medium-grade geotextile installation	
7	**PILE DRIVING WORKS**	Rp. 66.738.750,00
7.1	Supply of precast concrete piles (20 × 20 × 300 cm)	Rp. 3.740.919,79
7.2	Pile penetration	
	Total (Including 11% VAT)	Rp. 1.226.292.775,90
	Rounded Total	Rp. 1.226.293.000,00

Source: Project Data

Cost Analysis Based on Additional Workforce for Critical Path Activities

To reduce the overall project duration, a workforce acceleration strategy was applied to activities located on the critical path. Since any delay in critical activities directly affects the total project completion time, additional workers were assigned to these activities to increase productivity without changing the daily working hours. In this study, the working schedule remained 8 hours per day and 6 working days per week. The acceleration cost was evaluated by comparing the normal labor cost with the additional

labor cost required to shorten the activity duration. The relationship between the additional acceleration cost and the time reduction was expressed using the cost slope, which represents the additional cost required to reduce the project duration by one day.

The calculation procedure is illustrated using the K-175 concrete casting activity, which is one of the critical activities in the project schedule.

– Work volume = 10 m³
– Normal duration = 42 days
– Number of workers (normal condition) = 4 workers
– Normal labor cost = Rp 56.897.423

The normal productivity is calculated as:

$$Total\ Productivity = \frac{Work\ Volume}{Normal\ Duration} = \frac{10}{42} = 0{,}23\ m^3/day$$

The productivity of each worker is:

$$Worker\ Productivity = \frac{0{,}23}{4} = 0{,}058\ m^3/day$$

To accelerate the activity, the workforce was increased to 8 workers. Consequently, the total daily productivity became:

$$0.058 \times 8 = 0{,}46\ m^3/day$$

The accelerated duration was therefore:

$$\frac{10}{0{,}46} = 25\ days$$

The additional labor cost required for acceleration was calculated as:

$$25 \times (8 - 4) \times 113.700 = Rp.\,11.370.000$$

Accordingly, the accelerated activity cost became:

$$Rp.\,56.897.423 + Rp.\,11.370.000 = Rp.\,68.267.423$$

The cost slope of the K-175 concrete work was determined using:

$$Cost\ Slope = \frac{\text{Crash Cost} - \text{Normal Cost}}{Normal\ Duration - Crash\ Duration} = \frac{Rp.\,11.370.000}{42 - 25} = Rp.\,668.824/day$$

The cost slope indicates that shortening the K-175 concrete activity by one day requires an additional expenditure of approximately Rp. 668.824/day. The comparison

between the normal and accelerated conditions for the critical activities is summarized in Table 6.

Table 6. Comparison of Normal and Accelerated Conditions for Critical Activities

Work Item	Normal Condition		Accelerated Condition		Cost Slope (Rp/day)
	Duration (days)	Cost (Rp)	Duration (days)	Cost (Rp)	
K-175 Concrete	42	Rp56.897.423.00,	30	Rp68.267.423.00,	Rp 668.824,00
Rubble Masonry (1 Cement: 4 Sand Mortar)	42	Rp668.230.318.00,	30	Rp692.789.518,	Rp1.637.280,00
Weep Hole Installation	42	Rp12.279.600.00,	30	Rp18.188.175.00,	Rp. 818.640,00

Source: Author's Analysis

The results indicate that increasing the workforce successfully reduced the duration of all critical activities while increasing their direct labor costs. Among the analyzed activities, rubble masonry construction exhibited the highest cost slope (Rp. 1.637.280/day), indicating that it required the greatest additional cost for each day of schedule reduction. In contrast, the K-175 concrete work showed the lowest cost slope (Rp. 668.824/day), making it the most cost-effective activity for schedule acceleration. These findings provide an important basis for selecting acceleration alternatives that minimize additional project costs while achieving the desired reduction in project duration.

CONCLUSION

The implementation of the Critical Path Method (CPM) for project acceleration resulted in increased direct labor costs for critical activities due to additional workforce allocation. The cost increase, expressed as the cost slope, varied depending on the characteristics and complexity of each activity. For K-175 concrete work, the calculated cost slope was IDR 668,824/day, indicating the additional labor cost required to reduce the activity duration by one day. Rubble masonry work using a 1:4 cement-to-sand mortar ratio had the highest cost slope of IDR 1,637,280/day, reflecting the greater cost required to accelerate this labor-intensive activity. Meanwhile, weep-hole installation required an additional acceleration cost of IDR 818,640/day.

These findings demonstrated that although project acceleration using CPM increased direct labor costs, the magnitude of additional costs varied among critical activities. Cost-slope analysis provided a practical basis for determining the most cost-efficient acceleration strategy, enabling project managers to reduce project duration while maintaining effective cost control.

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