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Construction Schedule Management for Densely Populated Areas Using CPM-Crashing

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A B S T R A C T

Construction work in densely populated areas faces various challenges in its implementation. The impacts caused include buildings and residences in the vicinity often damaged due to the development of socio-economic activities in the environment. The safety of residents can also be threatened due to the use of heavy equipment and other environmental impacts. These things require the project to be implemented as soon as possible. This research aims to analyze the application of the crashing method in canal construction projects in densely populated areas. This research uses a quantitative approach to analyze the effectiveness of the Crashing method in implementing construction projects. Quantitative data regarding project time, costs, and activities. Each of the three acceleration alternatives is scheduled to be completed in 30, 45, and 60 days sooner. The best alternative is then chosen after obtaining the acceleration costs. As a result of this research, dependable actions can be planned to be carried out to speed up the project. Project acceleration has three times the alternative of thirty, forty-five, and sixty days. The findings show that the 60-day acceleration is worthwhile, with an additional cost of IDR. 46,709,624 was considered when calculating the slope costs. This is seen by the percentage of additional expenses, which grew by only 2.2% from the initial costs but accelerated to 33.3% of the planned timeline. The research results reveal the effectiveness of CPM-crashing techniques for projects in densely populated areas and can be used to develop measures for reducing potential dangers.

1. Introduction

As a developing country, Indonesia still attempts to eliminate slums and provide decent, sanitary housing [1]. The number of Indonesians living in cities has now reached 112 million. Slums house over a quarter of the metropolitan population, or approximately 25 million

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people [2]. According to the Central Statistics Agency (BPS), the percentage of slum households in Indonesia is around 13.86% in 2019 and will continue to rise based on the previous year's pattern [3]. Land use for residential purposes is expected to expand in the future.

The government prioritizes infrastructure projects through the National Strategic Project (PSN) to boost economic activity and reduce regional inequality. Land use in Pekalongan City has been quite dynamic in the last ten years. Settlements are the land use class that has seen the greatest increase in area, totaling 313.17 hectares [4]. According to data from the Central Java Province Public Housing and Settlement Area Service (Disperakim), 498.77 hectares of residential land in Pekalongan were classified as slum land in 2022 [5]. The 5th Mission 3rd Priority Program of the Regent-Deputy contains initiatives and programs for managing slum areas in the Pekalongan Regency [6]. Various initiatives have been taken to address them to help the attainment of the national targets outlined in the 2015-2019 RPJMN and the 100-0-100 target, particularly the reduction of the slum areas in Pekalongan Regency.

One such project is improving the drainage system in Pekalongan, a high-density neighborhood. Land cover functions and a poorly designed drainage system will worsen environmental impacts in densely populated areas. The lack of drainage is substantial enough to be of concern, with a rate of roughly 55%. The RT 17 RW 06 Simbang Kulon Village, Buaran District, is where the drainage procurement will occur. Buaran District is an area with a dense population. The density of houses in this neighborhood is high since it is a popular destination for batik artisans. Getting to the area is challenging because of the limited roads and disorganized homes. This causes additional pressure on infrastructure, especially inadequate drainage systems. With a high population, the risk of waterlogging and flooding increases, especially during high rainfall. Thus, improving infrastructure, including drainage systems, is very important to overcome environmental problems in areas with dense populations, such as Buaran District.

In its implementation, the project's work in densely populated areas causes issues and brings additional challenges [7]. Adverse effects on Buildings and dwellings nearby are frequently damaged by development [8], which could potentially affect the neighborhood's socio-economic activity[9]. The safety of the inhabitants may also be in jeopardy due to the usage of heavy machinery and other environmental impact. These things are demanding, and the project was pressed to start as quickly as possible. Inadequate planning inevitably emerged because floods and tidal floods are of significant concern in the North Pekalongan District.

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According to recent studies, the crashing method is efficient at assisting projects to meet their objectives as quickly and inexpensively as possible. The Critical Path Method (CPM) is one strategy developed to address the issue of project acceleration [10]. A task on the critical path cannot be postponed since doing so could negatively affect the project's overall success [11]. The crashing Critical Path Method (CPM-Crashing) is the best project-specific acceleration strategy. Numerous research studies have demonstrated how useful the CPM-crashing strategy is for assisting in the prediction of the proper acceleration model [12][13][14]. A network analysis called CPM tries to reduce project costs overall. A critical path is a sequence (set) of activity components with the longest total time and the quickest project completion time. The CPM technique is known to have these qualities [15]. Using planning tools will create a realistic image of the time and money needed for each activity and the number of available resources [16]. Accelerating the completion date of ongoing construction projects is difficult because of continuity difficulties [17][18]. Accelerating the incorrect activity will result in high money consumption without impacting the project's length or spending more [19]. Recent research indicates that the crashing method works well to help projects reach their goals as fast and affordably as feasible [10]. One tactic created to deal with the problem of project acceleration is the Critical Path Method (CPM). The crashing Critical Path Method is the most effective project-specific acceleration technique [15].

Although the crashing approach has been effectively applied, modeling acceleration in densely populated areas has not been a research focus. This study aimed to analyze the implementation of crashing method on channel construction projects in densely populated areas. Thus, it is expected that an effective will be found with a focus on improving time efficiency and cost management.

2. Research Method

This research uses a quantitative approach to analyze the effectiveness of the Crashing method in implementing construction projects. Quantitative data on project time, costs, and activities will be analyzed with mathematical tools. The main techniques are Project Crashing, cost, and schedule trade-off analysis. Each of the three accelerated alternatives is scheduled to be completed in 30, 45, and 60 days faster. The optimum option is chosen using cost slope computation. The three proposed alternatives are used to simulate the calculation of additional costs required for acceleration. The simulation results of the additional cash will be utilized to determine which project acceleration is most feasible.

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2.1 Data

This project has a contract value of 22.962.645.241,37 Rupiah and a planned duration of 12 months. The primary goal of this initiative is to improve the quality of the site's slum settlements. The project's surrounding population is 7773 persons, with a population growth rate of 0.02 per year [20]. Secondary data in this study include occupational data in the cost budget plan (RAB), S-Curve, and the unit price analysis (AHSP). The Pekalongan Regency wage reference is used by AHSP [21]. The cost budget plan (RAB) is used as a reference point, the S-Curve is used to gauge implementation progress, and the unit price analysis (AHSP) is utilized to estimate labor expenses. Local workers and the surrounding area provide empowered human resources. Human resources necessitate at least 20-40 workers and two foremen. Meanwhile, the project is being implemented using traditional methods as well as basic tools such as excavators, bulldozers, and dump trucks.

2.2 Critical Path Method

This study uses CPM calculations automatically using the Microsoft project application. Microsoft Project 2019 is used to calculate the CPM critical path [10]. The core work that requires the most analysis is the one with the highest percentage. The results of time acceleration can be used as a benchmark and a guide for projects of a similar sort [22]. Twenty-two tasks (See **Table 1**) with a high volume of work were gathered using RAB data gathering.

Table 1. Core Task Drainage Project.

Code	Task Name	Duration (days)
1	Soil Excavation	27
2	Landfill	5
3	Box Culvert Installation 50x50x1[illegible] cm (K350)	16
4	Installation of Reinforced Concrete Box Culvert (Box Culvert Custom 2 JC size.50x50x120 cm, K350) (with cover)	7
5	Installation of Reinforced Concrete Box Culvert (Box Culvert Custom 3 JC size.50x50x120 cm, K350) (with cover)	8
6	Installation of U-shaped Channel Type DS 1a (with cover) (size.30x40x120 cm, K350)	27
7	Custom Type [illegible] U-shaped Channel Mount 90° (with cover) (size.30x40x120 cm, K350)	9
8	Concrete Casting structure [illegible] 20 Mpa	7
9	Concrete Casting str[illegible]e= 10 Mpa	12
10	Installation of Plain Reinforcing Steel-BjTP 280	30
11	Landfill 1 m³ with Urug Sand	4
12	Landfill 1 m³ Solid Sirtu	6
13	Candi[illegible]rap installation (100x100x50 cm, F'c 15 Mpa)	8
14	Welded wire webbing work (Welded Wire Mesh)	7
15	Concrete Casting fc' = 15 Mpa	24
16	Installation of 1 M' PVC pipe type AW Ø 4"	15
17	Concrete Casting structure, fc'30 MPa	11
18	Installation 1m² Floor Hardener	14
19	1 m² field cleaning and leveling	7
20	Motive Concrete Work	14
21	Masonry Demolition	6
22	Concrete Demolition	5

Source: Project's Documentary (2022).

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The code will be used in the task notation based on the information above. The data has already been translated into the Microsoft Project 2019 to create the critical path. Every activity's expected completion time is determined using practitioner estimations or historical data. The longest link in the network, known as the critical path, is very important since delays impact the total time needed to complete the project. One can postpone tasks without causing the project's completion to be delayed by using loose time, also known as tolerance time.

2.3 Crashing Analysis

Crashing analysis by calculating the total acceleration time, total acceleration cost, and total acceleration cost per unit of time (cost slope). Only those activities traversed by the critical path are used to calculate the three metrics. The activity with the lowest cost slope value will be crashed, and network planning will then be changed according to the most recent duration of the crashing process. Until the work reaches saturation point, crashing will be performed repeatedly.

New Duration (Dn B) = Dn L + $Dn\ L/Di$ (LET-EET) (1)

Dn L as Task duration (days). Di is the Total time on the critical path. LET is the Latest Event Time on the last task, and EET represents the Earliest Event Time on the last task. Without acceleration, the normal duration is Dn L. LET calculates the longest start time (LS) and latest finish time (LF) for each activity in the network starting from the last node. EET is the forward calculation (forward) where we start the calculation from node 1, assuming the start time equals zero.

Regular costs are the direct expenditures incurred to carry out actions having a regular duration. Acceleration costs are the direct costs associated with performing activities more quickly due to the shorter duration of the control stage. The length of the work can be reduced through the calculation of a new duration [23]. With the following equation, the Total Acceleration Time may be calculated from these two components: Acceleration costs can be calculated as follows:

Total Acceleration Cost = Acceleration Cost + Normal Cost (2)

Normal Time is the initial amount of time required to finish the task. The quickest optimization time to complete tasks is acceleration time. Following is a formula for calculating acceleration time:

Total Acceleration Time = Normal Time-Acceleration Time (3)

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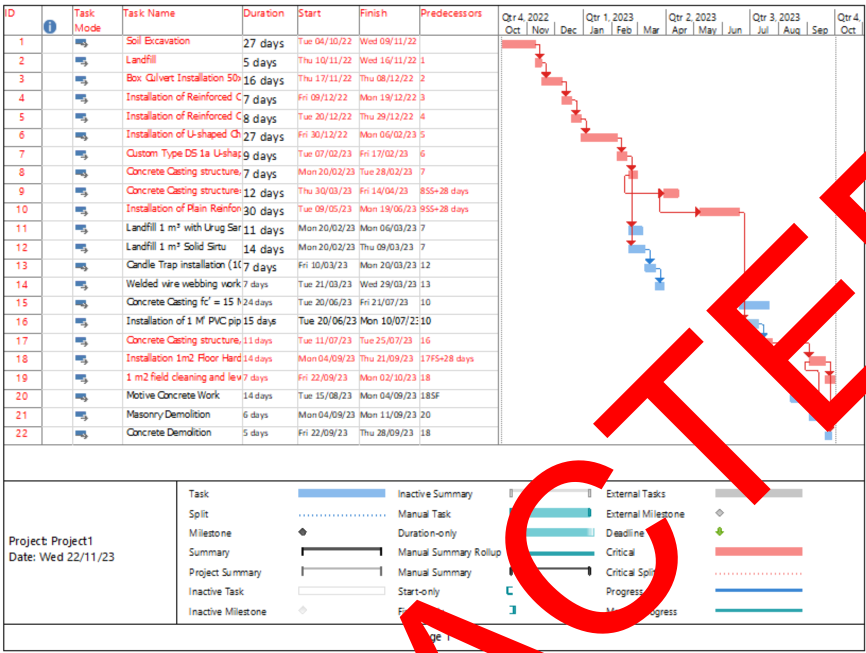
3. Results and Discussions

All work is first defined, and then Microsoft Project is used to insert antecedents and duration data. This application's computation will display the project's crucial path. To facilitate visualization, the critical path has been colored red. **Figure 1** and **Table 2** show the outcomes of a critical path analysis performed with Microsoft Project 2019 to identify the task.



Source: Data Analysis (2023)

Figure 1. Critical Path of Microsoft Project 2019.

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Based on **Figure 1**, it was discovered that 13 of the 22 tasks were critical tasks, meaning that only this work was processed in the crashing calculation. Population density has an impact on critical path activities as well. The location of the work in a densely populated area means that several jobs that require ample space and access, such as excavation work, waste management (landfill), installation, and concrete casting, are on a critical trajectory. Space limitations interfere with access, increase security risks, and make logistics difficult. Thus, only 180 of the 233 days were examined to determine the crashing time and expenses. This step was taken because the work was considered critical and required attention in calculating the speed increase.

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Table 2. Critical Tasks.

Code	Task Name	Duration (days)
1	Soil Excavation	27
2	Landfill	5
3	Box Culvert Installation 50x50x120 cm (K350)	16
4	Installation of Reinforced Concrete Box Culvert (Box Culvert Custom 2 JC size.50x50x120 cm, K350) (with cover)	7
5	Installation of Reinforced Concrete Box Culvert (Box Culvert Custom 3 JC size.50x50x120 cm, K350) (with cover)	8
6	Installation of U-shaped Channel Type DS 1a (with cover) (size.30x40x120 cm, K350)	27
7	Custom Type DS 1a U-shaped Channel Mount 90° (with cover) (size.30x40x120 cm, K350)	9
8	Concrete Casting structure, fc' 20 Mpa	7
9	Concrete Casting structure= 10 Mpa	12
10	Installation of Plain Reinforcing Steel-BjTP 280	30
17	Concrete Casting structure, fc'30 MPa	11
18	Installation 1m^2 Floor Hardener	14
19	1 m^2 field cleaning and leveling	[illegible]

Source: Data Analysis (2023).

According to earlier studies, Only 40–50% of tasks are on the crucial path. Similar to the findings of this study, 59% of the tasks in this study are on the critical path, as usual reducing the overall task by half [12][24][25]. The primary determinants of whether a task becomes a critical path are its predecessor and the length of the duration. According to previous research, the critical path is created from the longest path and may affect the amount of time it takes to complete the entire project [26][10][illegible][25]. This is consistent with the study results shown in **Figure 1**, where the longest path of linked activity forms the critical path.

3.1 Optimization Duration

Each work is calculated using Equation 1 to find the time optimization (new duration). The results are provided in **Table 3** as new durations for acceleration of 30 days, 45 days, and 60 days. The crashing time analysis is calculated using Equation 3.

Table 3. New Duration Tasks.

Code	Normal Duration	Crashing duration (days)		
		30	45	60
1	27	23	20	18
2	5	4	4	3
3	16	13	12	11
4	7	6	5	5
5	8	7	6	5
6	27	23	20	18
7	9	8	7	6
8	7	6	5	5
9	12	10	9	8
10	30	25	23	20
17	11	9	8	7
18	14	12	11	9
19	7	6	5	5

Source: Data Analysis (2023).

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Table 3 shows the new duration of each task for acceleration, which is 152, 135, and 120. Three alternative calculations are required to optimize costs and time [27]. Previous studies found that the anticipated time acceleration varied but was often around 60 days [27][28]. Other factors like the weather, time off, and force majeure are thought not to be considered in this project. Nonetheless, it is perfect for calculating acceleration and analyzing other influential elements [29]. The shorter time will result in higher overtime hours, but it will also result in lower indirect costs for project management and operations. This analysis also demonstrates that each acceleration option reduces overall task length while increasing overtime hours, implying that productivity will also decline slightly.

3.2 Acceleration Cost

The cost of acceleration is calculated using the worker coefficient data from the AHSP. Time, work coefficient, productivity, overtime hours, worker needs, and overtime expenses are all considered during optimization. The crashing time analysis is calculated using Equation 2. **Table 4** shows the acceleration cost.

Table 4. Crashing Cost.

Code	Additional cost for Acceleration		
	30 days	45 days	60 days
1	IDR 4.565.059	IDR 5.463.471	IDR 6.361.884
2	IDR 59.829	IDR 7[illegible].603	IDR 83.377
3	IDR 4.054.768	IDR 4.852.755	IDR 5.650.741
4	IDR 873.34[illegible]	IDR 1.045.224	IDR 1.217.100
5	IDR 14.8[illegible]	IDR 17.759	IDR 20.679
6	IDR 5.[illegible]0.433	IDR 6.547.025	IDR 7.623.616
7	IDR 62.651	IDR 74.981	IDR 87.311
8	IDR 1.54[illegible].111	IDR 1.849.192	IDR 2.153.273
9	IDR 1.615.[illegible]	IDR 1.933.644	IDR 2.251.612
10	IDR 8.639.594	IDR 10.339.883	IDR 12.040.173
17	IDR 2.881.241	IDR 3.448.275	IDR 4.015.309
18	IDR 1.7[illegible]9.503	IDR 2.045.937	IDR 2.382.370
19	IDR [illegible].025.094	IDR 2.423.636	IDR 2.822.179
Total	IDR 33.517.144	IDR 40.113.384	IDR 46.709.624

Source: Data Analysis (2023).

Table 4 displays the increased costs that need to be accelerated. These results demonstrate that the additional acceleration costs are equivalent to the duration reduction. There is an additional cost of IDR. 33,517,144; IDR. 40,113,384; and IDR. 46,709,624 for each option. Using these numbers, the accelerated 30 to 45 days and 60 days differ by 6,596,240 Rupiah.

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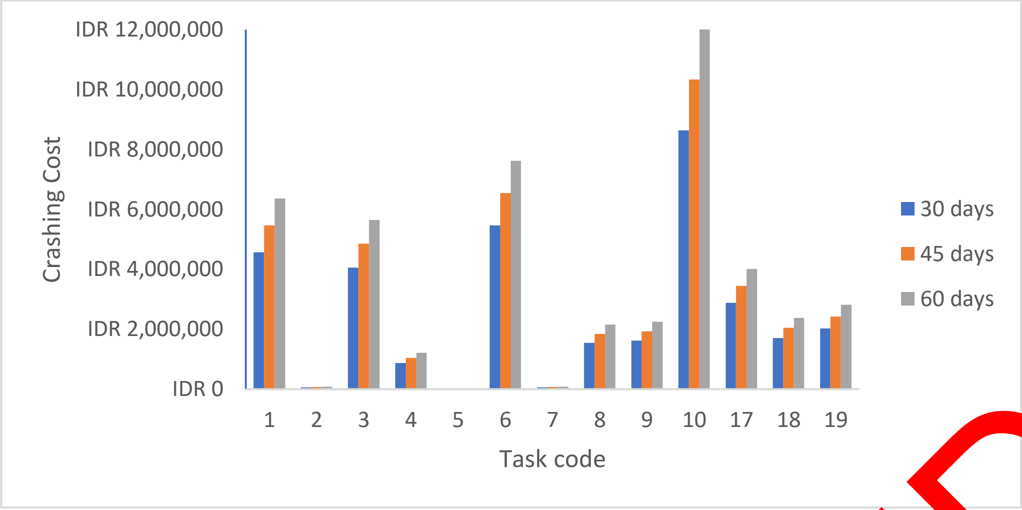

Figure 2. Comparison of Crashing Cost.

Figure 2 then shows a comparison of cost calculations. Following the three-project constraint, namely the trade-off of costs and time, any duration reduction entails a disproportionately high cost. The fastest project completion results from choosing the best alternative. Therefore, the reduced 60 working days will be quite worth it compared to the cost. The cost slope concept can be used to calculate the most cost-effective time to accomplish a project. Once an estimate of the duration has been achieved, the most advantageous time can be decided.

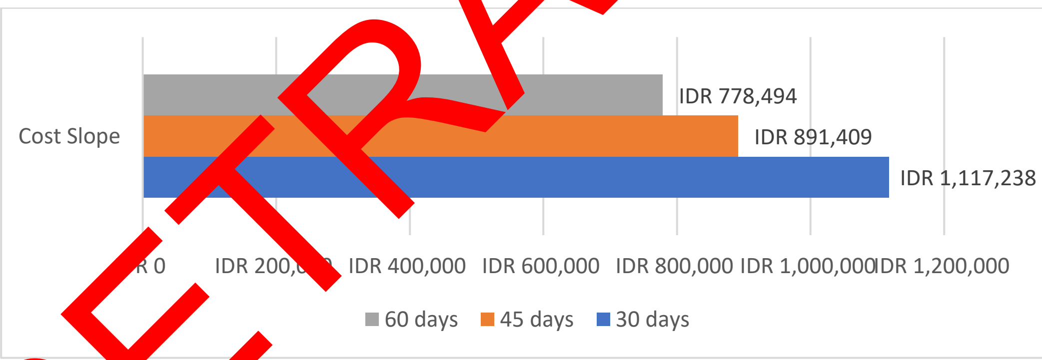

Figure 3. Difference of Cost Slope.

30-day acceleration costs IDR. 1,117,238; the 45-day acceleration cost slope IDR. 891,409; and the 60-day acceleration costs IDR. 778,494 according to the cost slope calculation. **Figure 3** depicts the difference in cost slope values. The contractor is frequently perplexed about how much delay to compensate for by crashing so that some profit can still be realized. To overcome this issue, the cost slope is reformed in a limited optimization formulation to maximize profit for the contractor [30]. Because the direct cost-time diagram is not linear, the activity cost slope cannot be constant at different times. The slope value with the lowest slope thus determines the most reasonable additional cost. The slope cost is computed by dividing the

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price difference by the acceleration time [31]. The project will benefit from speeding up time [32][33]. The final decision to choose 60 days is the most appropriate if technical and external considerations aren't considered. The project acceleration for 60 days is highly recommended. According to prior research, the selection of acceleration time is based on optimizing the trade-off of time and cost, and a proportional alternative from the cheapest cost with the fastest time is picked [34][35][36]. Consequently, to receive advantages equal to 60 days, the project must cover an additional IDR cost. 778,497 each day. Of course, this is directly related to the dangers that may develop if the project is carried out in an area with a high population density. According to the cost slope calculation, days of expedited time will save eight weeks and an additional IDR. 46.709.624. The initial implementation cost was IDR 21,720,949,136 after that increased by approximately 2.2% of the project cost. Meanwhile, the project implementation time has been cut by up to 33.33% from the original timeline.

3.3 Accelerating Project Implementation

Crash's implementation includes providing critical tasks with more resources. Allocating resources from non-essential tasks to critical tasks is another option. Acceleration will result in at least 2 to 3 hours of overtime per day during the 60 days of work, with the expected additional expenditures stated in **Table 4**. Some of the workers assigned to non-critical work will be diverted to fill the resources that may also be constrained in the project.

Acceleration implementation in this location can concentrate on the prefabricated construction process because the structure is ready to be built. Ex situ concrete production might shorten a lengthy process such as installing plain reinforcing steel. Although prefabrication technologies are often nearly twice as expensive as traditional techniques, the anticipated costs for this project have not been determined. Another step in the application process is to avoid waiting for one task to be completed before beginning another. For example, soil excavation work might be accompanied by a landfill or installation that consumes a lot of time, in this case, concrete structures such as Box Culvert Installation.

Meanwhile, more advanced technology is required to install elements that take considerable time to ensure the implementation process can be accelerated. For example, in this case, the Installation of a U-shaped Channel can be aided by using a crane that has been proven to lift more than an excavator. These findings suggest that prefabrication, improved technology, and adaptable work that can be completed concurrently are among the most significant breakthroughs for simplifying and accelerating projects in densely populated areas. Shifting the work schedule to the nighttime is one way to help work faster.

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4. Conclusion

The analysis's findings indicate that the 60-day acceleration has a slope cost of IDR. 778,494 is the most practical option to consider. This is seen by the percentage of additional expenses, which grew by only 2.2% from the initial costs but accelerated to 33.3% of the planned timeline. Allocating resources from non-essential tasks to critical tasks is an option. Acceleration will result in at least 2 to 3 hours of overtime per day during the 60 days of work. The research results reveal the effectiveness of CPM-crashing techniques for projects in densely populated areas and can be used to develop measures for reducing potential dangers.

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