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Schedule Acceleration Planning in Construction Project (Case Study: Japek II Selatan Tollroad)

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ABSTRACT

This study focuses on the remaining work at stations (STA) 53+950 to 54+550 in Jakarta – Cikampek II Selatan Toll Road Package III project to find the critical path, completion durations, and project costs before and after acceleration. The CPM Technique was used to compile network planning diagrams, determine the critical path and project duration. Crashing Project was applied to crash schedule through the total project duration and cost whose changes due to the implementation of the crashing method. The critical path was found in mobilization, tree felling, clearing, dig and haul, borrow material, subgrade preparation, base course (A grade), subbase course (B grade), drainage layer, lean concrete (t=10 cm), concrete pavement, concrete barrier type B, and signage. In the CPM, the duration of project completion is 214 days. The total project budget under normal circumstances is Rp22.073.412.654. After accelerating with the Crashing Project by proposed overtime was obtained the reduced total cost of Rp32.004.882 from the total normal cost of Rp22.073.412.654 to Rp22.041.407.771 with an optimum duration of 183 days.

Keywords:
CPM; Planning; Overtime; Crashing; Scheduling

1. INTRODUCTION

Planning various project activities is a very important process stage as the basis to complete the projects in an optimal time. The process of providing infrastructure is still relatively slow, due to obstacles in various stages of the project from preparation to implementation. In general, weak coordination among stakeholders often causes delays in decision-making. At the planning stage, there were problems due to the weak quality of project preparation and limited funding allocation[1]. Implementation of work on a project not only requires reliable resources but also requires a good management system. At the planning stage, it is necessary to estimate the project implementation time. Various variations

in the completion time of a project result in the estimated completion time cannot be ascertained. Therefore, the accuracy of the estimated completion time of the project is determined by the level of accuracy of the duration of each activity in the project[2].
The construction of Jakarta – Cikampek II Selatan Toll Road Package III is a project of PT. Jasamarga Japek Selatan as a Toll Road Business Entity (BUJT) involving various parties such as PT. Waskita Karya Karya Tbk (contractor), PT. Cipta Strada (technical consultant), and government agencies related to state assets. The construction of the toll road began in May 2019 and is planned to be completed by the end of 2020. However, the realization of the construction process caused construction delays. Several factors on the ground that hamper the activity project, resulting in an addendum or contract extension as much as twice and is expected to be completed in January 2022. Inhibitory factors such as bad weather, design changes because they were not matched with existing conditions, materials did not arrive on time, less effective utilization of working hours due to lack of supervision in the field, and uncompleted daily work volume is due to several factors. These factors include determining the duration of each activity that is less accurate and has not improved scheduling in the worst situation. As a result, many jobs suffer setbacks so that they were not completed by a predetermined date and lead to delays in project completion. Initially, the Jakarta – Cikampek II Selatan Toll Road Package III project was planned to be able to operate during the Eid holiday in 2020 and was completed in November 2020 with a total completion time for STA 53+950 to 54+550 was 290 days, but it is still ongoing with a lot of work remaining and getting stuck in the previous planning. Therefore, scheduling is necessary for the remaining work at STA 53+950 to 54+550 using the Critical Path Method to determine which activities are in the critical path and Crashing Project to crash the schedule to get the optimum result including the time and cost.
There are three main components of a construction project including aspects of time, quality, and cost which are factors in the success of the project. Within the planned timeframe, project implementers are required to be able to systematically manage project work to achieve success according to the initial plan. However, the contractor, as the project implementer in the field, in this study was unable to complete the project on time. Therefore, an addendum or contract extension was carried out twice. In this study, the researchers focused on a case study on the remaining work at STA 53+950 to 54+550 on the Jakarta – Cikampek II Selatan Toll Road Package III project to find the critical path, duration, and completion cost before and after scheduling acceleration using the proposed overtime to crash the schedule.
Some of the methods employed in this study include the CPM method to develop a model of network diagram and find the critical path. This study objective is getting an optimum project scheduling using CPM and Crashing Project (Time-Cost Trade-Off) with the lowest cost and the shortest completion duration. Technically, the complete duration of the project will be shorter than the normal conditions when the crashing method is being applied. One of the crashing methods used in this study is the Time-Cost Trade-Off (TCTO), which analyzed the exchange of time and cost. Crashing the Schedule was carried out using the Crashing Project method to calculate all aspects of duration and costs that change due to acceleration. Therefore, scheduling the remaining work can be done by determining the critical path of the project activities and accelerating the schedule by proposed overtime to get the optimum schedule of the project will help PT. Jasamarga Japek Selatan as a Toll Road Business Entity (BUJT) and PT. Waskita Karya Karya Tbk as a contractor to crash the schedule after being approved by a technical consultant. The benefit from this study is getting an optimum project scheduling using CPM and Crashing Project that can be a reference for supervisors in evaluating the project and improving the efficiency of the company in four stations which is STA 53+950 to 54+550. This study was conducted after the cut-off on 13th November 2020 and the monitoring process was carried out starting from March to 4th June 2021 only at STA 53+950 to 54+550.

1.1 Construction Project

A construction project can be defined as a series of temporary activities, carried out once and are limited by time, costs, and daily resources. In a series of activities, there are various stages of the process that can process project resources into an activity result in the form of buildings. The process that occurs in the series of activities certainly involves many related construction parties, both directly and indirectly[3].

1.2 Project Execution Time

The benchmark for a project’s success can be seen through the completion time with minimal costs that need to be estimated and maximizing the quality value of the work. Management in a project that is carried out systematically is used to ensure the duration of the project work time is following the initial agreement[4]. Each activity is determined by a scheduling model based on the Work Breakdown Structure (WBS), all scheduled activities need to be uniquely identified and described, starting with a verb, including at least one unique specific object, and adjective clarification if necessary[5]. In planning, a project must be able to obtain maximum profits and work properly to enable the duration of the project and the cost incurred optimally.

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1.3 Network Model

Network planning can be concluded as a project planning and control that describes the dependency relationship between each project work in a network diagram. The network diagram can show which jobs will be carried out simultaneously (parallel) or sequentially (serial). Network planning can assist in the process of planning and scheduling projects. Some of the benefits of Network Planning[6] including:

1. Planning a project has a high level of complexity.
2. Scheduling by sorting each job efficiently.
3. Organizing the division of labor against the budget and available manpower.
4. Evaluating scheduling to overcome obstacles that cause delays.
5. Determining the Trade-Off between the time and cost of project activities.
6. Knowing the probability value to complete a particular project.

1.4 Project Time Management

Project Time Management is an activity that covers all the processes and procedures needed for a project to run on time. Time is one of the resources for work that must be managed effectively and efficiently in every project activity. Effectiveness can be seen from the use of predetermined time to achieve goals and efficiency that related to reduce the specified time. Project Time Management can simply be described as the process engagement to ensure the project completion time. Project Time Management includes a variety of processes needed to manage timely project completion[5] including:

1. Plan Schedule Management. The process of establishing policies, procedures, and documentation to carry out planning, developing, managing, executing, and controlling the project schedule.
2. Define Activities. The process of identifying and documenting a specific event that must be implemented to achieve the deliverables of a project planning.
3. Sequence Activities. The process of identifying and documenting the order of work based on dependency relationships between project activities.
4. Estimate Activity Duration. The process of estimating the number of working periods required to complete a project activity.
5. Develop Schedule. The process for developing a schedule begins with analyzing the sequence of activities, duration, resources needed, and schedule constraints to create a schedule for project execution, monitoring, and controlling.
6. Control Schedule. The process of monitoring project status to update project schedules and manage changes to the schedule baseline.

1.5 Critical Path Method (CPM)

A method that uses arrow diagrams in a critical path is known as the Critical Path Method. As a result, the route can calculate the time of a specific action. The Critical Path Method is also known as Earliest Event Time (EET) and Last Event Time (LET) which is the earliest event or the fastest time of activity while lET is the most recent or late event of work activity. This method can assist in identifying critical paths that are not allowed to have obstacles or delays in carrying out project work that might result in delays in completion[7]. Critical Path Method can be defined as a method that uses arrow diagrams in a critical path so that the path can estimate the duration of a particular activity. A critical path is a series of activities that are on the longest route of a network diagram and have minimal slack and float values. Slack and float are the amount of time delay activity (allowance time) without delaying or interfering with the completion of the entire project[8].

Critical Path Method (CPM) is a project management model that makes cost the object of analysis. The CPM method can analyze the network diagram that has been built to optimize the total project cost by accelerating or reducing the total project completion time. On the principle of the network, network planning is the dependence between each part of the work that can be visualized or described in a network diagram[9]. Through the critical path, several benefits can be obtained as follows:

1. Delays in work on the critical path can hinder the completion of all project work.
2. If the work on the critical path can be accelerated, the duration of project completion will be shorter.
3. The process of controlling or supervising is carried out through the completion of the right critical path and the exchange of time or tradeoffs with efficient costs and a crash program is held to shorten project time with the additional alternative of overtime costs.

By understanding the purpose of breaking the project scope into several work components in detail, the critical path will be structured and a series of activities will be broken down into several components to increase the accuracy of project

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completion time estimation. CPM is also a method used to determine the critical path contained in a series of project activities using an arrow diagram. Thus, it is also called a critical path diagram[10].

1.6 Crashing Project

Every project has potential risks because no project is complete without risk. Risks can affect project viability, but potential risks can be identified before the project starts. In various situations, when a risk occurs, it can cause delays in project completion, and steps that companies need to take to deal with these risks are to speed up work, such as providing overtime. However, the decision has the possibility that the total cost of the project may increase from normal conditions[11]. The fact that often occurs in the world of project management is that a decision will always arise in exchanging costs and time in each project management, for example, project completion is ahead of schedule when proposing an alternative with additional working hours (overtime) or the number of workers[12]. Crashing Project has several provisions, including:

a. Time Component

There are two components, namely:

1. Normal time is the time required to complete an activity under normal circumstances.
2. Crash Time is the shortest time in an accelerated state that is most likely to complete the activity.

The formula below relates normal time and crash time.

$$\text{Total crash time} = \text{normal time} - \text{crash time} \tag{1}$$

b. Cost Component

There are three components, namely:

1. Normal Cost, direct costs incurred to complete activities under normal conditions.
2. Crash Cost, direct costs incurred to complete activities in accelerated or crashed conditions.
3. Crash Cost per Unit Time (Slope), an additional direct cost per day in completing activities in accelerated or crashed conditions. The following formula can be used to determine this[13]:

$$\text{Crash Cost per Unit (cost slope)} = \frac{\text{Cc - Cn}}{\text{Tc - Tn}} \tag{2}$$

Crashing using additional working hours might affect the level of project efficiency. The addition of working hours can be an alternative way to speed up project scheduling. Productivity for alternatives can be calculated using formulas 3 to 5[14].

$$\text{Daily Productivity} = \frac{\text{Volume}}{\text{NormalDuration}} \tag{3}$$

$$\text{Productivity/hour} = \frac{\text{Daily Productivity}}{\text{Normal Duration}} \tag{4}$$

$$\text{Productivity Crash} = \text{Daily Productivity} + (\text{Total Overtime} \times \text{Productivity per hour} \times \%) \tag{5}$$

Based on the daily productivity value after the crash, the duration of the project completion can be seen after the acceleration process of each activity on the critical path[15]. The value of the crash cost can be calculated using formulas 7 and 8[14].

$$\text{Crash Duration} = \frac{\text{Volume}}{\text{Productivity per crash}} \tag{6}$$

$$\text{Total Overtime Wage Cost} = \text{Number of workers} \times (3 \text{ hours} \times \text{crashing}) \times \text{daily overtime cost} \tag{7}$$

$$\text{Crash Cost} = \text{Normal Direct Cost} + \text{Total Overtime Wage Cost} \tag{8}$$

The provisions of time and overtime pay for workers are regulated in Article 1 of PP No. 35/2021 and Labor Law No. 13/2003. The regulations explain that the payment provisions for companies that employ workers exceed working time, including:

1. 1.5 times the hourly wage for the first overtime.
2. Increase by twice the hourly wage of each subsequent overtime.
3. If the employee has non-fixed allowance, then the overtime multiplier wage is 75%, while the overtime multiplier wage if the employee has a fixed allowance is 100%.

1.7 Research Comparisons from Different Viewpoints

Scheduling is a process of planning and controlling the allocation of resources in doing job activities that must be completed at a certain time. Several previous studies are used as references in this study consisting of:

1. Designing project schedule using crashing method to compress the fiber to the home project schedule[8]
   One of the STTF project building locales is the Indra Prahasta II lodging area. The project delays because of the Covid-19 calamity in Indonesia. Deferrals in project execution can bring about potential possibilities in picking another organization that offers comparable types of assistance. The undertaking timetable can be sped up utilizing the smashing strategy and TCTO (Time Cost Trade-Off) investigation to take care of this issue. This current exploration's speed increase will be completed with options for adding 3 to 1 hours and an option in contrast to expanding laborers' number. The project has a normal length of 55 working days with an absolute expense of Rp604.124.460. The outcomes acquired from information handling, on the option of adding 1 hour of additional time work, the absolute span becomes 54 working days with a total cost of Rp605.734.138. The result for 2 hours of additional time work, the undertaking's absolute span can be diminished to 54 days with a total cost of Rp 606.803.619. Also, for the expansion of 3 hours additional time, the all-out term can be abbreviated to 54 days with a total cost of Rp606.803.619. Concerning expanding the number of laborers, project length can be abbreviated to 54 working days with a total project cost of Rp 604.556.748.
2. Developing Schedule With Linear Programming (Case Study: STTF II Project Komplek Sukamukti Banjaran)[11]
   Shift to The Front II Komplek Sukamukti Banjaran Project is one of the ventures executed by one of the organizations occupied with media communications. In its execution, each venture including Shift to The Front II Komplek Sukamukti Banjaran has a period limit indicated in the agreement. Deferral in a venture can be expected by speeding up the length of finishing by utilizing the smashing technique with the use of straight programming. Direct programming will help cycle in the estimation of slamming since, in such a case that straight writing computer programs weren't utilized, emphasis will be rehashed. The target capacity of this booking is to limit the expense. This examination means to discover a compromise between the expenses and the base time expected to finish this project. The speed increase of the term of this investigation was done utilizing the expansion of 4 to 1 hours of additional time work. The ordinary time for this task is 35 days with a help charge of Rp52.335.690. From the consequences of the smashing investigation, the elective picked is to add 1 hour of extra time to 34 days with a total cost of Rp52.375.492. This speed increase will influence the whole venture because there are 33 unique areas chipped away at Shift to The Front II and assuming this load of areas can be sped up, the term of fulfillment of the whole project will be successful.
3. Analysis of Acceleration Time Of Project Solving Using Fast-Track And Crash Program Method[14]
   The motivation behind this examination was to decide the speed increase time and cost-saving venture Phase II Hotel Dewarna Bojonegoro. Considering the report on the acknowledgment until week 13 or 86 working days came to 34.58% while the level of introductory arrangement of 53.522%, bringing about a deviation among arranged and figured it out. Therefore, work has been deferred time initially wanted to be finished inside 233 days to 261 days. Speeding up the project completion time to keep away from delays in the evaluation of this technique and the fast-track and crash program and then compared the results. The result of the examination utilizing and the fast-track and crash program as far as time can be stressed again as the first arrangement that the task is finished inside 233 days. As far as the cost with quick track strategy requires a charge of Rp26.376.440.619, while the technique for the crashing program requires an expense of Rp26.504.146.817. Both techniques can reduce costs due to project delays, at first adding up to Rp27.059.140.712. In terms of the cost of a fast-track method is cheaper but has a greater risk because if one of the jobs that are on the critical path is delayed will affect other jobs.

2. METHOD

Variables in this study consist of inputs, processes, outputs, and other variables related to this research. The structure of the conceptual model in this research requires input derived from project documents, direct, and indirect costs. The output generated from this conceptual model is a project schedule with optimum time and cost that has been accelerated. Figure 1 shows the conceptual model which explained the variables which affect the project schedule.

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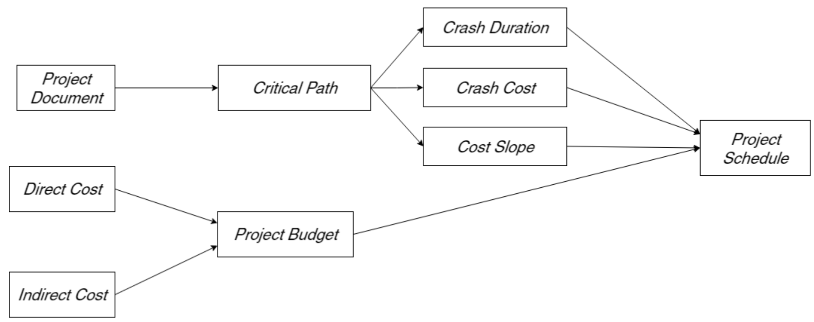

Figure 1 – Conceptual Model

Data were collected from PT. Jasamarga, Japek Selatan as the contractor and PT. Waskita Karya Tbk as the contractor in the Jakarta – Cikampek II Selatan Toll Road Package III Development project. There are two variables needed in the data collection process, namely cost variables including a list of basic unit prices for workers' wages, the cost budget plans, and time variables including the volume of work and the S curve. Project document in this project including the details of project activity, estimated duration, and volume of work. In addition, the data to be used in this research is a direct and indirect cost or can be referred to as the budget of the needs of each project activity in a work item. The direct costs such as materials, production costs, labor wages, and equipment costs in the project. The indirect costs such as overhead, profit, and value-added tax (VAT) in each component of the work in the project.

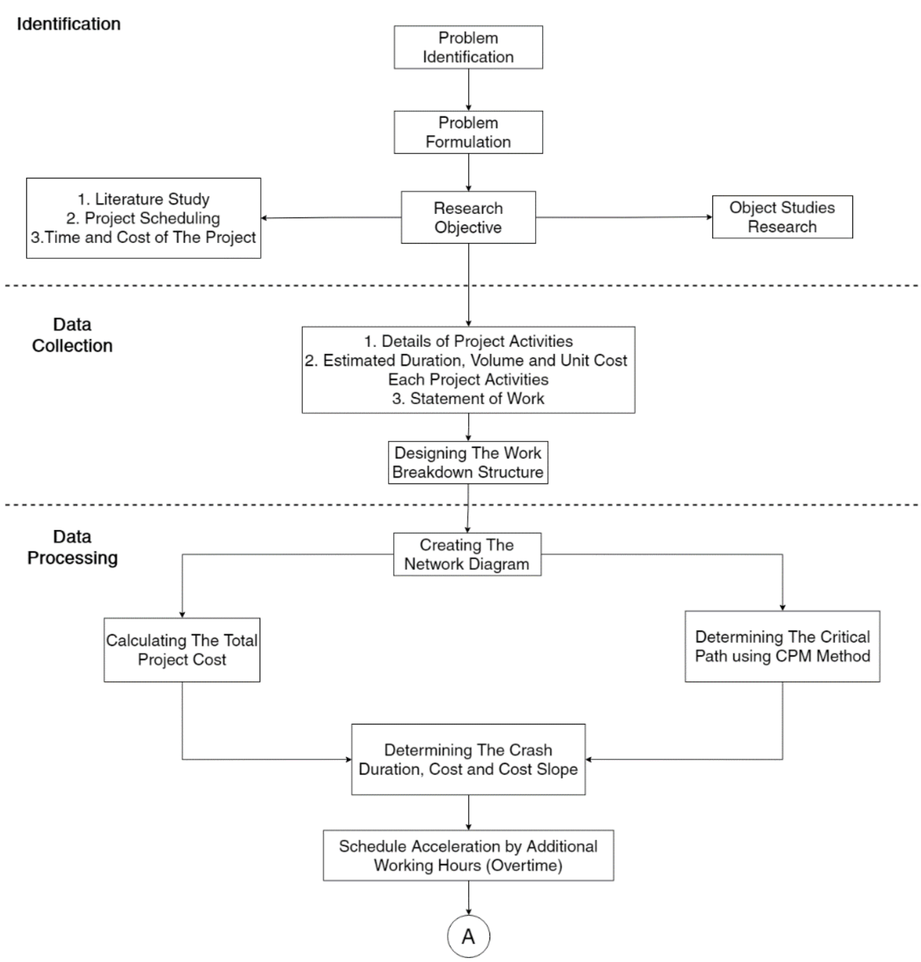

Figure 2 – Research Design Step 1

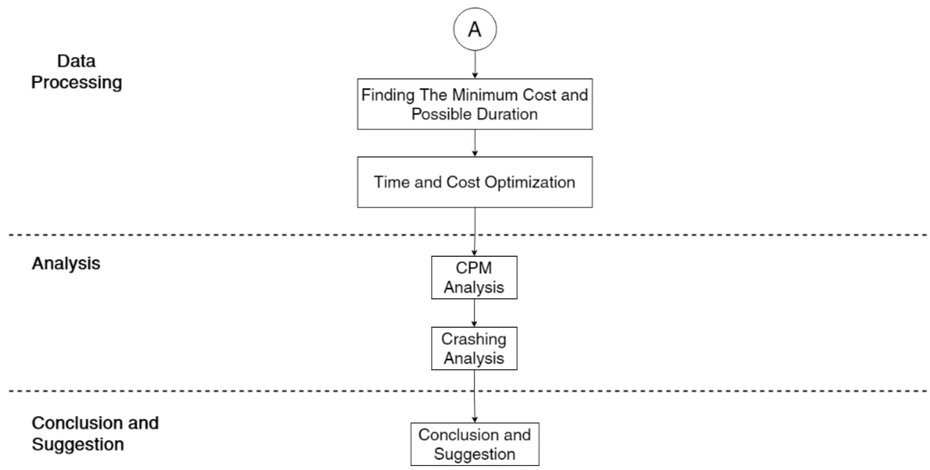

Figure 3 – Research Design Step 2

Based on Figure 2 shows the initial stage in this research is identifying various problems that occur in the implementation of the project. Formulate what problems to focus on in the research, determine what objectives and objects to discuss within this research. The next stage is collecting the various data needed for the project scheduling process. After various project data have been collected, each activity is divided into several sub-elements of work that are arranged through a work breakdown structure to be able to determine the details of labor needs in a project. The next step in this study was to develop a network diagram and determining the critical path of a series of project activities using the CPM method. After determining the critical path, the project schedule needs to be crashed. The project schedule was crashed using Crashing Project. One of the methods to crash the project schedule is using Time-Cost Trade-Off (TCTO) by proposing additional overtime. Crashing is only performed on project activities that are on the critical path. Crashing analysis can determine the crash duration, crash cost, cost slope, and total project cost after crashing. The accelerated activity is the activity that has the lowest cost slope value, after which the network was rearranged with the crashing duration. Crashing is done repeatedly until the schedule gets the optimum cost and completion duration. The last stage is the data analysis of both methods used in this study that is equipped with conclusions and suggestions to explain the result of the acceleration schedule.

3. RESULT AND DISCUSSION

3.1 Activity List, Estimated Duration and Work Volume

A document that lists all activities covered in the project is called an activity list. In the activity list, there is information about previous activities or predecessors. Other documents needed to complete the activity list information are estimated duration and volume. Estimated Duration serves to do the planning or estimate of the duration needed to complete a project based on each activity organized in the project. An important part of a project is also in the work volume document. How much work must be fulfilled in an activity can be seen in the work volume document. Activity list and estimated duration can be used as inputs or inputs in the creation of a network diagram of the project to be implemented. Work volume data is used as input to perform the crashing process as a calculation of crash cost and duration. Table 1 shows the activity list, estimated duration, and volume of work in this project.

Table 1 – Activity List, Estimated Duration and Work Volume

Code	Work Component	Volume	Units	Duration	Predecessor	Unit Cost	Total Cost
	Prepare						
A	Mobilization	0,030	Ls	1	-	Rp3.701.642.835	Rp111.049.285
B	Tree Felling	90,31	Bh	15	A	Rp838.179	Rp75.693.138
C	Clearing	15.629,13	m2	7	B	Rp4.775	Rp74.629.096
	Drainage						
D	Box Culvert 2m x 2m (STA 53+950)	191,15	m3	71	C	Rp1.430.209	Rp273.377.299
	Box Culvert 2m x 2m (STA 54+465)	191,15	m3		C	Rp1.430.209	Rp273.384.450
E	Water Detour and Excavation Structure	1.019,78	m3	19	C	Rp35.945	Rp36.656.161
F	Blinding Stone	3.351,78	m3	3	E	Rp338.042	Rp1.133.042.415
G	LC	164,63	m3	8	F	Rp87.200	Rp14.355.736

Code	Work Component	Volume	Units	Duration	Predecessor	Unit Cost	Total Cost
	Land Work						
H	Dig and Haul	12.668,25	m3	72	C	Rp33.592	Rp425.551.854
I	Borrow Material	6.696,88	m3	14	H	Rp104.701	Rp701.170.033
	Subgrade						
J	Subgrade Preparation	12.487,70	m2	14	I	Rp3.037	Rp37.925.145
	Subbase						
K	Base Course (A grade)	1.199,57	m3	28	J	Rp404.875	Rp485.674.554
L	Subbase Course (B grade)	486,00	m3	36	K	Rp390.146	Rp189.610.956
	Pavement						
M	Drainage Layer	3.490,43	m3	28	L	Rp404.875	Rp1.413.189.196
N	Lean Concrete (t = 10 cm)	1.596,81	m3	44	M	Rp976.977	Rp1.560.049.900
O	Concrete Pavement	4.739,32	m3	53	N	Rp1.421.440	Rp6.736.659.021
P	Asphalt Work	1.329,86	ton	79	O	Rp1.145.916	Rp1.523.907.824
	Other Work						
Q	Solid Sodding	29.043,27	m2	15	P	Rp14.948	Rp434.138.750
R	Guardrail Type A	1.056,81	m	26	P	Rp809.706	Rp855.702.699
S	End of Guardrail	5,85	Bh	6	R	Rp435.995	Rp2.549.117
T	Signage	13,30	Bh	28	R	Rp2.720.360	Rp36.192.333
U	Road Marking Type A	783,22	m2	12	G	Rp205.541	Rp160.983.822
V	Concrete Barrier, Type B (Single Faced)	1.124,23	m	109	O	Rp1.291.969	Rp1.452.474.615
W	Guidepost Type A	12,19	Bh	9	Q	Rp132.792	Rp1.618.292
X	Guidepost Type B	70,55	Bh	9	R	Rp121.456	Rp8.568.316
Y	RUMIJA Fence 2nd Type	1.385,29	m	52	Q	Rp161.941	Rp224.335.788
	Total Project Budget (direct cost)						Rp18.242.489.797

3.2 Project Budget

A project budget is a calculation of the direct cost that has been designed before carrying out the project. It is intended as a reference or cost limit in carrying out project activities. Table 1 shows the budget details of each activity in the Jakarta - Cikampek II Selatan Toll Road Package III (STA 53+950 to 54+550). The total project budget of this project is Rp18.242.489.797 (direct cost). Indirect costs include overhead, profit, and value-added tax (VAT). Each indirect fee has a percentage of 7%, 3%, and 10%. The value of indirect cost is Rp3.830.922.857, so the total project budget of the project is Rp22.073.412.654.

3.3 CPM Method Analysis Results

Dependency relationships between activities describe how the sequence of project activities runs from beginning to end. In a series of project activities, it is necessary to find a critical path. Determining the critical path can be analyzed using the CPM method. The existence of a critical path as presented in Figure 4 to reduce project costs if it is continued with scheduling acceleration. Table 2 explains what activities are critical.

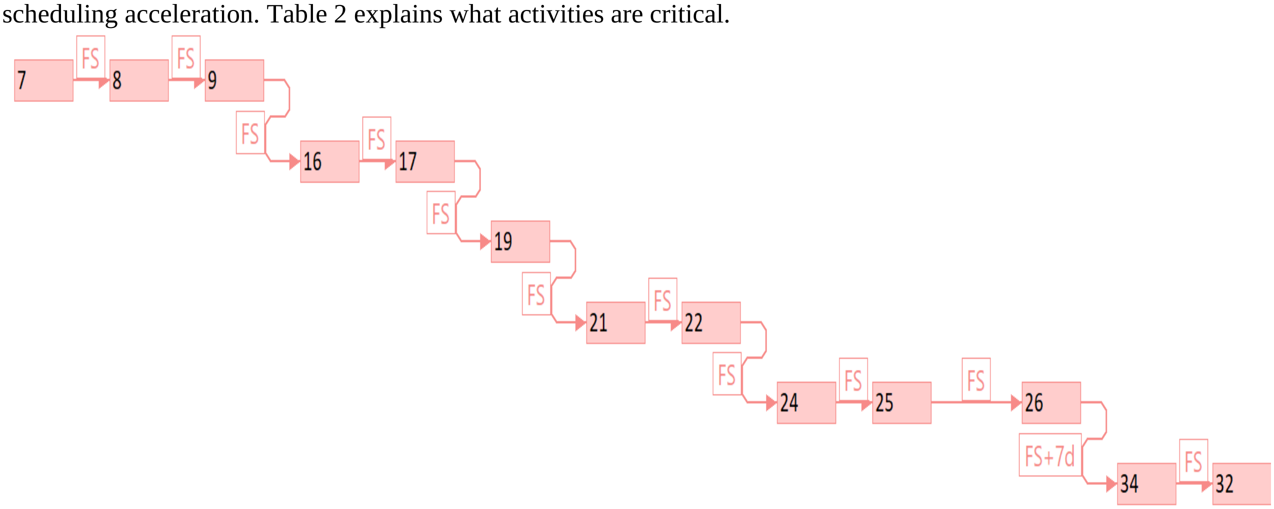

Figure 4 - Critical Path

Table 2 - List of Activities on the Critical Path

ID	Code	Work Component	Activity Time	Early Start	Early Finish	Late Start	Late Finish	Free Slack	Total Slack	Description
STA 53+950 – 54+100										
7	A	Mobilization	1	0	1	0	1	0 days	0 days	Critical
8	B	Tree Felling	15	1	16	1	16	0 days	0 days	Critical
9	C	Clearing	7	16	23	16	23	0 days	0 days	Critical
16	H	Dig and Haul	72	23	95	23	95	0 days	0 days	Critical
17	I	Borrow Material	15	95	110	95	110	0 days	0 days	Critical
19	J	Subgrade Preparation	7	110	117	110	117	0 days	0 days	Critical
21	K	Base Course (A grade)	7	117	124	117	124	0 days	0 days	Critical
22	L	Subbase Course (B grade)	10	124	134	124	134	0 days	0 days	Critical
24	M	Drainage Layer	7	134	141	134	141	0 days	0 days	Critical
25	N	Lean Concrete (t = 10 cm)	10	141	151	141	151	0 days	0 days	Critical
26	O	Concrete Pavement	15	151	166	151	166	0 days	0 days	Critical
34	V	Concrete Barrier, Type B (Single Faced)	34	166	200	166	200	0 days	0 days	Critical
32	T	Signage	7	207	214	207	214	0 days	0 days	Critical

Activities can be categorized as critical if:

$$\text{Late Start (LS)} - \text{Early Start (ES)} = \text{Late Finish (LF)} - \text{Early Finish (EF)}$$
$$\text{Total Slack} = 0$$

Based on the results of data processing presented in Table 2, the sequence of critical activities is A – B – C – H – I – J – K – L – M – N – O – V – T because it has a total slack value of 0. The sequence of activities in the critical path is adjusted to the dependencies between project activities.

3.4 Crashing Project Analysis Results

In the design of scheduling acceleration, it is necessary to investigate what series of activities are included in the critical path as presented in Table 2. The next step was to calculate Crash Duration, Crash Cost, Cost Slope, and Total Cost as an evaluation of scheduling in the project with the proposed three hours of overtime.

3.4.1 Crash Duration, Crash Cost, and Cost Slope

The first step that is required to be taken in designing an accelerated schedule is to determine the total crash time or crash duration of a series of project activities that are on a critical path on the network that has been found using the CPM method. Crash duration can be found by calculating the volume of work, daily productivity, productivity per hour, and productivity after crashing. Normal working hours in one day are 8 hours, and overtime hours for 3 hours, so the total working hours in one day is 11 hours.
Example of calculating crash duration on a tree felling with the following formula (1, 3, 4, 5, 6)[14]:

1. Working Volume

Volume = 90,31 Bh

2. Daily Productivity

$$\frac{\text{Volume}}{\text{Normal Duration}} = \frac{90{,}31}{15} = 6{,}0204 \text{ Bh/day}$$

3. Productivity per hour

$$\frac{\text{daily Productivity}}{\text{Normal Working Hours}} = \frac{6{,}0204}{8} = 0{,}7526/\text{hour}$$

4. Productivity after Crash

Normal working hours = 8 hours

Overtime hours = 3 hours

Productivity after Crashing = $\text{Daily Productivity} + (3 \times \text{Productivity per hour} \times \text{coef. effectiveness})$

$$= 6{,}0204 + (3 \times 0{,}7526 \times 0{,}75) = 7{,}7137 \text{ Bh/day}$$

5. Crash Duration

$$\frac{\text{Volume}}{\text{Productivity after Crashing}} = \frac{90{,}31}{7{,}7137} = 12 \text{ days}$$

A tree felling activity has a working volume of 90,31 in units of Bh. Calculation of the crash duration of each activity must find the value of productivity after the crash. The first step is dividing the volume and normal duration to get the daily productivity of 6,0204 Bh/day. The second is dividing the daily productivity and normal working hours by 0,7526/hour. The third is finding the productivity after crashing. Once we find it, the crash duration can be calculated by dividing the work volume and productivity after crashing. As we see from the result above, the crash duration of tree felling become 12 days from 15 days of work under normal circumstance. After the crash duration is determined, any direct costs related to project activity in the critical path will be calculated in the crash cost calculation. The direct costs associated with this study were the cost of renting equipment and employee wages (foreman, laborer, worker, driver, heavy equipment operator, and operator's assistant.

Example of calculating the crash cost on a tree felling with the following formula (7 and 8)[14]:

Type of worker

$$= \text{Number of Workers} \times (\text{Overtime hours} \times \text{Total crash}) \times [(1{,}5 \times 1 \text{ hour normal wage}) + (2 \times 2 \times 1 \text{ hour normal wage})]$$

Overtime expense:

1. Foreman

$$= 1 \times (3 \times 3) \times [(1{,}5 \times Rp7.281) + (2 \times 2 \times Rp7.281)] = Rp360.424$$

2. Laborer

$$= 6 \times (3 \times 3) \times [(1{,}5 \times Rp5.964) + (2 \times 2 \times Rp5.964)] = Rp1.771.180$$

3. Worker

$$= 8 \times (3 \times 3) \times [(1{,}5 \times Rp4.657) + (2 \times 2 \times Rp4.657)] = Rp1.844.295$$

4. Driver

$$= 4 \times (3 \times 3) \times [(1{,}5 \times Rp6.600) + (2 \times 2 \times Rp6.600)] = Rp1.306.800$$

5. Heavy Equipment Operator

$$= 0 \times (3 \times 3) \times [(1{,}5 \times Rp4.054) + (2 \times 2 \times Rp4.054)] = Rp0$$

6. Operator's Assistant

$$= 0 \times (3 \times 3) \times [(1{,}5 \times Rp3.583) + (2 \times 2 \times Rp3.583)] = Rp0$$

$$\text{Crash Cost} = \text{Normal Cost} + \text{Overtime Fee}$$

$$= Rp75.693.138 + Rp5.282.699$$

$$= Rp80.975.837$$

The crash cost means a direct cost if the company implementing the crashing method by proposed overtime that will affect the duration and total cost of each activity. In the tree felling activity, there is an increase in total cost from Rp75.693.138 to Rp80.975.837. The next step is determining the Cost Slope to find out how much additional direct costs per day. Cost slope analysis is used to find out which activities result in the smallest cost increases. Cost slope calculation is done by dividing the subtraction results between crash and normal cost with normal and crash duration.

An example of calculating the cost slope on a tree felling job using formula 2[13]:

Cost Slope $= \frac{\text{Rp80.975.837} - \text{Rp75.693.138}}{15-12} = \text{Rp1.760.900/day}$

Table 3 - Crash Duration, Crash Cost, and Cost Slope

Code	Work Component	Duration		Total Crash	Normal Cost	Crash Cost	Cost Slope
		Normal	Crash				
A	Mobilization	1	1	0	Rp111.049.285	Rp111.049.285	Rp0
B	Tree Felling	15	12	3	Rp75.693.138	Rp80.975.837	Rp1.760.900
C	Clearing	7	5	2	Rp74.629.096	Rp77.910.862	Rp1.640.883
H	Dig and Haul	72	70	2	Rp425.551.854	Rp428.896.498	Rp1.672.322
I	Borrow Material	15	13	2	Rp701.170.033	Rp704.968.168	Rp1.899.068
J	Subgrade Preparation	7	5	2	Rp18.962.572	Rp22.473.225	Rp1.755.326
K	Base Course (A grade)	7	5	2	Rp121.418.639	Rp124.806.390	Rp1.693.875
L	Subbase Course (B grade)	10	8	2	Rp47.402.739	Rp50.790.490	Rp1.693.875
M	Drainage Layer	7	5	2	Rp353.297.299	Rp356.685.050	Rp1.693.875
N	Lean Concrete (t = 10 cm)	10	8	2	Rp390.012.475	Rp393.498.689	Rp1.743.107
O	Concrete Pavement	15	12	3	Rp1.684.164.755	Rp1.689.205.058	Rp1.680.101
T	Signage	7	5	2	Rp9.048.083	Rp12.517.895	Rp1.734.906
V	Concrete Barrier, Type B (Single Faced)	34	27	7	Rp363.118.654	Rp374.380.456	Rp1.608.829

Table 3 shows the acceleration time of each activity, mobilization constant in 1 day, tree felling becomes 12 days, clearing 5 days, dig and haul 70 days, borrow material 13 days, subgrade preparation 5 days, base course (A grade) 5 days, subbase course (B grade) 8 days, drainage layer 5 days, lean concrete (t = 10 cm) 8 days, concrete pavement 12 days, signage 5 days, and concrete barrier type B become 27 days. Table 3 also shows the costs incurred with the proposed addition of working hours (overtime) during the duration of acceleration have significant costs. This happens because there is a difference in duration that affects the direct cost in an activity, so that normal costs will be summed up with the cost of crashing to get a new value, namely crash cost. However, mobilization work is constantly the same because the mobilization activity is completed on the same day so there is no crash cost value or equal to normal cost. Crash cost for tree felling of Rp80.975.837, clearing of Rp77.910.862, dig and haul of Rp428.896.498, borrow material of Rp704.968.168, subgrade preparation of Rp22.473.225, base course (A grade) of Rp124.806.390, subbase course (B grade) of Rp50.790.490, drainage layer of Rp356.685.050, lean concrete (t = 10 cm) of Rp393.498.689, concrete pavement of Rp1.689.205.058, signage of Rp12.517.895, and concrete barrier type B of Rp374.380.456.

3.4.2 Project Cost Recapitulation Before and After Crashing

After the cost slope of each project activity in the critical path is known, it is necessary to describe the direct costs, indirect costs, and total crashing costs with the proposed overtime. Therefore, it is necessary to calculate or recapitulate project costs after scheduling acceleration. The purpose of the crashing project is to optimize the duration of the activities at the lowest cost. Direct costs include equipment rental costs and employee wages, while indirect costs include overhead, profit, and value-added tax (VAT). Each indirect fee has a percentage of 7%, 3%, and 10%. Total Cost calculation is done with two stages, namely the normal stage (before crashing) and the compression stage (after crashing).

Example of calculating the total project cost on a tree felling after crashing:

1. Normal Stage

Normal Duration = 214 days
Direct Cost = Rp18.242.489.797
Overhead Cost and Profit = (7% + 3%) × Direct Cost
VAT = 10% × (Direct Cost + Overhead Cost and Profit)
Indirect Cost = Overhead Cost and Profit + VAT
Indirect Cost = Rp1.824.248.980 + Rp2.006.673.878 = Rp3.830.922.857
Total Project Cost = Direct Cost + Indirect Cost = Rp22.073.412.654

2. Compression Stage

Cost Slope/day = Rp1.760.900
Normal Duration = 15 days
Crash Duration = 12 days
Total Crash = 3 days

Total Project Duration = 211 days
Additional Cost = Rp1.760.900/days × 3 days = Rp5.282.699
Direct Cost = Normal Stage Direct Cost + Additional Cost
Direct Cost = Rp18.242.489.797 + Rp5.282.699
= Rp18.247.772.495

Indirect Cost $= \frac{\text{Normal Phase Indirect Cost}}{\text{Normal Duration}} \times \text{Total Project Duration}$

$= \frac{\text{Rp3.830.922.857}}{214} \times 211 = \text{Rp3.777.218.331}$

Total Project Cost After Crashing (Total Cost)
= Direct Cost + Indirect Cost
= Rp18.247.772.495 + Rp3.777.218.331
= Rp22.024.990.827

Table 4 - Recapitulation of Costs on the Proposed Overtime

No	Work Component	Additional Cost	Direct Cost	Indirect Cost	Total Cost
1	Tree Felling	Rp5.282.699	Rp18.247.772.495	Rp3.777.218.331	Rp22.024.990.827
2	Clearing	Rp3.281.767	Rp18.245.771.563	Rp3.795.119.840	Rp22.040.891.403
3	Dig and Haul	Rp3.344.644	Rp18.245.834.441	Rp3.795.119.840	Rp22.040.954.281
4	Borrow Material	Rp3.798.135	Rp18.246.287.932	Rp3.795.119.840	Rp22.041.407.771
5	Subgrade Preparation	Rp3.510.652	Rp18.246.000.449	Rp3.795.119.840	Rp22.041.120.289
6	Base Course (A grade)	Rp3.387.751	Rp18.245.877.547	Rp3.795.119.840	Rp22.040.997.387
7	Subbase Course (B grade)	Rp3.387.751	Rp18.245.877.547	Rp3.795.119.840	Rp22.040.997.387
8	Drainage Layer	Rp3.387.751	Rp18.245.877.547	Rp3.795.119.840	Rp22.040.997.387
9	Lean Concrete (t = 10 cm)	Rp3.486.214	Rp18.245.976.011	Rp3.795.119.840	Rp22.041.095.850
10	Concrete Pavement	Rp5.040.302	Rp18.247.530.099	Rp3.777.218.331	Rp22.024.748.430
11	Signage	Rp3.469.812	Rp18.245.959.609	Rp3.795.119.840	Rp22.041.079.448
12	Concrete Barrier, Type B (Single Faced)	Rp11.261.802	Rp18.253.751.599	Rp3.705.612,297	Rp21.959.363.895

Based on the results of data processing, it is known that normal stage (before crashing) calculations have a project completion duration of 214 days. Direct costs and indirect costs at normal stages are Rp18.242.489.797 and Rp3.830.922.857, so the total cost of the project amounted to Rp22.073.412.654. At the compression stage having a project completion duration of 183 days with the proposed addition of working hours (overtime) for 3 hours starting at 20.00 to 23.00 indicates a decrease in the total cost of the project of Rp22.041.407.771. The reduction total cost of Rp32.004.882, where the total cost of the project after crashing is less than the total cost under normal circumstances (before crashing). Except for the total cost of mobilization activities is still the same as normal conditions.
The total cost of each work component has the lowest to the highest value. However, the value of these costs is calculated to be cheaper than the total cost of the project under normal circumstances which is Rp22.073.412.654. The lowest total cost is in Concrete Barrier Type B (Single Faced) of Rp21.959.363.895 and the highest total cost is in Borrow Material of Rp22.041.407.771.

Table 5 - Compression Stages of Each work component on the Critical Path

Code	Work Component	Compression Stage	Duration		Total Duration	Direct Cost	Indirect Cost	Total Cost
			Normal	Crash				
Normal Circumstance					214	Rp18.242.489.797	Rp3.830.922.857	Rp22.073.412.654
V	Concrete Barrier, Type B (Single Faced)	Stage 1	34	27	207	Rp18.253.751.599	Rp3.705.612.297	Rp21.959.363.895
C	Clearing	Stage 2	7	5	205	Rp18.245.771.563	Rp3.795.119.840	Rp22.040.891.403
H	Dig and Haul	Stage 3	72	70	203	Rp18.245.834.441	Rp3.795.119.840	Rp22.040.954.281

Code	Work Component	Compression Stage	Duration		Total Duration	Direct Cost	Indirect Cost	Total Cost
			Normal	Crash				
O	Concrete Pavement	Stage 4	15	12	200	Rp18.247.530.099	Rp3.777.218.331	Rp22.024.748.430
M	Drainage Layer	Stage 5	7	5	198	Rp18.245.877.547	Rp3.795.119.840	Rp22.040.997.387
L	Subbase Course (B grade)	Stage 6	10	8	196	Rp18.245.877.547	Rp3.795.119.840	Rp22.040.997.387
K	Base Course (A grade)	Stage 7	7	5	194	Rp18.245.877.547	Rp3.795.119.840	Rp22.040.997.387
T	Signage	Stage 8	7	5	192	Rp18.245.959.609	Rp3.795.119.840	Rp22.041.079.448
N	Lean Concrete (t = 10 cm)	Stage 9	10	8	190	Rp18.245.976.011	Rp3.795.119.840	Rp22.041.095.850
J	Subgrade Preparation	Stage 10	7	5	188	Rp18.246.000.449	Rp3.795.119.840	Rp22.041.120.289
B	Tree Felling	Stage 11	15	12	185	Rp18.247.772.495	Rp3.777.218.331	Rp22.024.990.827
I	Borrow Material	Stage 12	15	13	183	Rp18.246.287.932	Rp3.795.119.840	Rp22.041.407.771

Acceleration priority on work components that are on the critical path can be done by referring to the cost slope. The order of work packages or work components can be determined based on the lowest cost slope value for each iteration[13]. The priority order of accelerated activity is V – C – H – O – M – L – K – T – N – J – B – I. These activities are the installation of type B concrete barriers, clearing, dig and haul, concrete pavement, drainage layers, subbase course (B grade), base course (A grade), toll road signage, lean concrete (t = 10 cm), subgrade preparation, tree felling, and borrow materials. Acceleration using crashing project by proposed overtime was obtained a total project cost of Rp22.041.407.771 and 183 days to crash all components of project work.

4. CONCLUSION

4.1 Conclusion

Based on the study that has been carried out on the Jakarta – Cikampek II Selatan Toll Road Package III (STA 53+950 to 54+550) project, the following conclusions can be drawn:

1. Based on the results of the analysis using the Critical Path Method (CPM), a critical path was found consisting of mobilization activities, tree felling, clearing, dig and haul, borrow material, subgrade preparation, base course (A grade), subbase course (B grade), drainage layer, lean concrete (t = 10 cm), concrete pavement, type B concrete barrier installation, and signage. The sequence of activities in the critical path is A – B – C – H – I – J – K – L – M – N – O – V – T adjusted for the dependency relationship between project activities.
2. The duration of project completion using the CPM method is 214 days. The total cost of the project under normal conditions is Rp22.073.412.654.
   This project has a normal duration for completion of 214 days with a total cost is Rp22.073.412.654. The proposed overtime required 12 times of crashing to achieve the optimum duration of project completion for 183 days with a total cost is Rp22.041.407.771. After implementing the Crashing Project method by adding working hours (overtime), the reduction between the total cost after crashing and the normal stage is Rp32.004.882. The Crashing Project method is also 31 days shorter for the duration of project completion.
   The priority order of accelerated activity is V – C – H – O – M – L – K – T – N – J – B – I. These activities are the installation of type B concrete barriers, clearing, dig and haul, concrete pavement, drainage layers, subbase course (B grade), base course (A grade), toll road signage, lean concrete (t = 10 cm), subgrade preparation, tree felling, and borrow materials.

4.2 Suggestion

Based on the results of the study in the Jakarta – Cikampek II Selatan Toll Road Package III (STA 53+950 to 54+550), it is expected that the following suggestions to be taken into consideration:

1. The activity that is on the critical path needs to be considered and given adequate supervision in order not to result in delays in the implementation of project activities that lead to delays.
2. Future study is expected to use another proposal and method to accelerate the project schedule.
3. Periodically re-check the duration of the project every time there are data changes to obtain the correct analysis results with the optimum duration of project completion time.

Disclaimer

The authors whose names are written certify that they have no conflict of interest.

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