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Network Planning Analysis on Road Construction Projects by CV. X Using Evaluation Review Technique (PERT) – Critical Path Method (CPM) and Crashing Method

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Abstract: Indonesia is currently actively developing infrastructure to improve the economy and welfare of its people. One of the infrastructure developments undertaken by the government is road pavement. CV.X is the company that won the asphalt project tender with a contract value of IDR 4.046.873.346 and must complete it within 114 days. During the process of working on the project, there were indications of possible delays in project completion. So this study aims to perform optimal planning, scheduling, and control in CV. X in carrying out road construction project. This study used the PERT – CPM method to determine the optimal completion time using critical pathways and the concept of probability. The result of the PERT – CPM method is an activity in critical flow with an optimal duration of 115 days, where the duration exceeds the contract period so it needs to be crashing. The crashing method is an attempt to speed up the duration of the project and streamline the costs incurred. In this study, 2 scenarios were obtained to help reduce the duration and cost savings that can be used by project implementers. The first scenario is to reduce the duration based on the optimal duration from 115 days to 108 days with a saving of IDR 690,354 or 0,02%. The value of the savings is classified as very small because crashing can only be done with additional labor and limited working hours. If the crashing method is not done, then the second scenario is to pay a penalty of IDR 40,468,733.

Keywords: Optimal cost, network planning, PERT-CPM method, crashing method

1. Introduction

Indonesia is currently actively carrying out development in the field of infrastructure. According to the Global Competitiveness Report 2018, Indonesia's infrastructure still lags at 71st than other countries such as Singapore, Thailand, and Malaysia [1]. Therefore, the Indonesian government is accelerating the development and equalization of infrastructure as the driver of the country's economy and expanding employment [2]. By 2024, the Indonesian government targeting the construction of 3,000 km of highways, building 36 new airports, 43 air bridge routes, and more. This is done so that Indonesia becomes a developing country in the industrial, maritime, tourism, development of disadvantaged areas, and others, to realize a prosperous Indonesia [3].

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One of the infrastructure development carried out by Indonesian government is the road. Roads are part of the transportation infrastructure system that supports human needs to provide quality and quantity of human resources. Road construction projects can also provide economic mobility to form employment, social health, and education opportunities for the community. This is done to combat social inequality in certain regions as well as combat poverty. Road infrastructure development can also stimulate urban space expansion, rural settlements' growth, increased connections, and accessibility between areas [4]–[6].

The construction industry has an important role in supporting growth and development in the field of development. The part of the construction industry is closely related to the implementation of development in all fields. Given the importance of this role, construction services must develop a role in development [7]. Construction projects are closely related to complex projects' time, cost, and resources, so many procedures must be planned. This results in delays, budget swelling, and uncoordinated work if not properly prepared. More than 76.3% of construction projects faced problems as a result of not complying with initial estimates. Therefore, procrastination is considered one of the most common problems that harm the project and the implementing party. With daily delays, overall costs, labor, utilities, and resources will increase rapidly, resulting in planning, scheduling, and control [2], [8]. Planning, scheduling, and control are important in doing a project, so it needs to be carried out with optimal time and cost. These three aspects are known as Network Planning. Network Planning is project management done by connecting several activities in the form of workflows to be completed sequentially. Network planning aims to complete a project with the planned duration, minimum cost, and at the desired level of quality [9].

One of the methods used to design Network Planning is the Critical Path Method (CPM). The CPM is a project management tool used to help plan, schedule, and control a project by identifying critical activities and determining the minimum duration required to complete a project [10]. Identification is made by dividing the project into several work activities and then visualized with flow charts and then calculated for the project's duration. The duration obtained after calculating with the CPM is the initial duration of the activity start (*ES*), the initial duration of the activity completion (*EF*), the end duration of the activity started (*LS*), the end duration of the completed activity (*LF*), and the grace period (slack) [11]. The CPM is known to have a characteristic critical activity described with the longest path (critical path). Usually, the project's duration should not be longer than the critical path. Any delays in critical paths will affect the duration of project completion [7], [10], [12].

A construction project is usually said to be successful if completed on time, and the budget is in line with estimates, and stakeholders are satisfied. However, many uncertainty factors, so each activity's duration can't be determined definitively [2], [7]. The uncertainty is the estimated value of project activity using three assumptions: optimistic time, the most likely time, and pessimistic time, combined into the expected duration and standard deviation [13], [14]. Program Evaluation and Review Technique (PERT) can overcome uncertain project completion time by using the concept of probability and optimizing the time and cost required to complete the project [15], [16]. Calculation on PERT using average value *(*mean) and variance to get project completion estimate [17].

In addition to planning, scheduling, and controlling, it is also important to conduct a cost analysis. Cost analysis is performed to determine the lowest cost by reducing critical activity. Project costs are divided into direct costs, indirect costs, and penalty fees [18]. Direct costs are costs directly related to project activities. Indirect costs are overheads that are not directly related but affect the implementation of the project. A project certainly sets a contract, so there are sanctions if it does not meet the target or is called a penalty fee [19]. Delays in completing the project can be anticipated by accelerating the project's duration, which should take into account cost and quality. One method to drain the duration of project completion is crashing. The crashing method calculates direct cost and indirect cost in duration reduction, which is then selected as the lowest total cost [20]. The estimated duration of work in the activity is carried out considering several alternatives, including the addition of working hours (overtime), the addition of labor, the addition of shifts that will incur additional costs optimally [21].

CV. X is a construction project services company in the development, implementation, and development located in Lamongan. One of the projects was carried out by CV. X is a road construction project with a contract period of 114 days and a cost of IDR 4,046,873,346. Some issues that CV. X needs to be aware of is when carrying out construction of this road is a swelling of the cost and duration of implementing the project that exceeds the contract, so it must pay a fine. Various factors of the project delays can occur due to limited labor, defective equipment, or adverse weather conditions that may interfere with the initial planning. The problem that is often encountered in the implementation of construction projects is the discrepancy between the schedule plan and the construction schedule's realization schedule so that during the project. Planning and scheduling are activities that affect projects, but control is also important [7], [22]. To control the difference between the schedule plan and the realization of development, CV. X needs to use network planning with the PERT – CPM method. Also, to analyze the acceleration of the project's duration so that it is known how long the project can be completed by increasing the cost due to its acceleration, we can use the crashing method. The crashing method has several alternatives in its implementation, namely the addition of labor, the addition of working hours (overtime), the addition of shift work. Because this project has limited implementation time that can only be done at night, the crashing method used using alternative labor additions. The implementation of the project carried out at night is so as not to interfere with mobility during peak hours.

2. Literature Review

Kusumadarma et al. [11] planning feeder wiring projects at STO Nanjung using CPM. This project is delayed because the project does not use methods that match the type of project. The results of Kusumadarma et al. showed that the FO cable project could be done within 46 days with 16 critical activities.

Lee et al. [15] stated that the PERT method could be used to calculate uncertainty, but this study combines pert and fuzzy methods to require linear programming to make the most of resources and costs. Abbasi et al. [16] carried out the PERT method to develop mathematical programs in minimizing pessimistic time. This study shows that reducing suspicious time can lead to a decrease in project completion duration and its variance to increase the likelihood of project completion.

Lermen et al. [18] used the PERT – CPM method to optimize cost and duration accelerated in the production of horizontal laminators (machines used to cut plastic forum blocks of industrial mattresses). This study's result is that the project can be completed within 333.3 hours, which was initially completed within 520 hours and the cost resulting from this method decreased by 12.56% from the initial cost of the contract. Baits et al. [23] conducted research focusing on scheduling the construction of public restrooms in Cianjur square. Initially, the contractor used the Bar Chart in the preparation of the schedule. However, in a unique scale project, Bar Chart is a method whose application is limited, using a combination of pert and CPM methods. The result of this study was scheduling using CPM obtained a minimum duration of 135 days with 20 critical activities, then analyzed further with PERT received that the probability for the duration of completion of 139.78 days is 68%, 95% for completion for 144.56 days, and 99.7% for completion of 149.34 days.

Ahmed [24] researched by creating a functional diagram design by ensuring the critical path, then use crashing to find the optimal duration and cost needed, so that duration reduction of 6.67% from the normal duration and a cost reduction of 7.10% from the normal cost is obtained. Ririh et al. [20] researched calculating the fastest duration in building an apartment conducted by Waskita Karya. This project turns out to have the potential to experience delays from the contract's duration, which is 42 months, with a cost of IDR 614,627,071,968. This study using the crashing method to optimized the duration reduced to 39 months with a total cost of IDR 618,665,777,827. The study also said that the crashing method is better than the fast-tracking method because it results in problem-solving without causing overlapped schedules.

3. Methodology

3.1 Research Data

This study uses primary and secondary data. Primary data is in the form of interviews with parties involved in the project's implementation so that information is obtained in the form of sequences and relationships between project activities. Meanwhile, secondary data is in the form of a data archive on the company's project implementation in three estimated time and cost budgeting for the shipping project in Gresik in 2018.

3.2 Data Analysis

3.2.1 Determine The Estimated Uncertainty Using The PERT Method.

PERT is a method that combines uncertainty in the duration of an activity in its analysis to identify activities that could cause delays with the concept of probability. The estimates used in the PERT method are optimistic time (*ta*), real-time (*tm*), and pessimistic time (*tb*) [25]. The three estimates are used to determine the expected time (*te*) and variance (σ^2) to calculate project time risk.

$$te = \frac{ta + 4tm + tb}{6} \tag{1}$$

$$\sigma^2 = \left[\frac{tb - ta}{6}\right]^2 \tag{2}$$

3.2.2 Build A Network Planning Using The CPM Method

CPM is a method of creating a network that uses deterministic estimation and has a critical path. The critical path is an important aspect of the stage to project planning. Earliest Start (ES), Earliest Finish (EF), Latest Start (LS), and Latest Finish (LF) are parameters needed to determine the critical path, which further defines the slack time (Slack) of these parameters [26].

$$ES = \text{Max}\left(EF_0\right) \tag{3}$$

$$EF = ES + \text{Duration} \tag{4}$$

$$LF = \text{Min}\left(LS_{i+1}\right) \tag{5}$$

$$LS = LF - \text{Duration} \tag{6}$$

$$\text{Slack} = LS - ES \,/\, /\text{Slack} = LF - EF \tag{7}$$

3.2.3 Determine The Probability of The Project Using The PERT – CPM Method

PERT – CPM techniques are based on network planning and modeling to help companies monitor and control a project. This method is a technique that combines the PERT method in estimating uncertain completion times and the CPM method in optimizing project scheduling [18], [27]. In this technique, calculating the probability of completing the project with the expected duration is required, so z is needed.

$$z = \frac{T(d) - Te}{S} \tag{8}$$

where z = area value of the area; $T(d)$ = targeted time; Te = Expected time on Critical Path; and S = standard deviation of activities on critical paths.

3.2.4 Determine The Acceleration of Working Duration and Cost Efficiency Using The Crashing Method

Crashing is a method that can be obtained a trade-off between duration and cost so that better scheduling and more controlled projects are obtained [28]. This crashing method will choose the lowest cost slope that will shorten the critical path to form a new path. This stage will be repeated (iterated) until the desired project duration or crashing cost is sufficient [16]. In mathematical form, the relationship between duration and cost of normal activities as well as duration and cost of activities after a crash can be denoted as follows [14], [29]:

$$DP = \frac{AV}{ND} \tag{9}$$

$$DP_1 = DP \times \frac{\text{Labor}_0 + \text{Labor}_1}{\text{Labor}_0} \tag{10}$$

$$CD = \frac{AV}{DP_1} \tag{11}$$

$$TAC = (\text{Labor}_0 + \text{Labor}_1) \times \text{Salary} \tag{12}$$

$$CC = NC + (TAC \times CD) \tag{13}$$

$$CS = \frac{CC - NC}{ND - CD} \tag{14}$$

where *DP* = Daily Productivity; *AV* = Activity Volume; *ND* = Normal Duration of Activity; DP_1 = Daily Productivity After Crashing; $Labor_0$ = Normal Workers per Activity; $Labor_1$ = Additional Workers per Activity; *CD* = Crash Duration; *TAC* = Total Additional Cost; Salary = Salary per Day; *CC* = Crash Cost; *NC* = Normal Cost; and *CD* = *CS* = Cost Slope.

4. Results and Discussion

4.1 Determining Uncertainty Estimation Using the Program Evaluation Review Technique (PERT)

PERT is a method that uses three-time estimates (*ta, tm,* and *tb* values) by giving range and variance as the duration of uncertainty if a project encounters various constraints. The values *ta*, *tm*, and *tb* are obtained from the project executor as an estimate of the time required to carry out each activity, so that in the PERT method will be obtained *te* values and variances using Eq. (1) and Eq. (2) the results of which are presented in Table 1. It was identified that the expected time (*te*) is influenced by three-time estimates to become a single time. At the same time, the variance value (σ^2) is influenced by optimistic time (*ta*) and pessimistic time (*tb*), which if the value is getting more significant, then the deviation of duration is also greater.

Table 1 - Probability of project completion duration

No.	Activity Description	Duration (day)				
		ta	*tm*	*tb*	*te*	σ^2
A.	Re-Measurement and Survey	1	2	3	2	0.111
B.	Pillar Installation	1	2	2	2	0.02778
C.	Making Director Keet Container	1	2	4	2	0.25
D.	Installation of Nameplate Project	1	2	2	2	0.02778
E.	Traffic Security	1	2	3	2	0.111
F.	Land Clearing	2	3	5	3	0.25
G.	Soil Test	1	2	4	2	0.25
H.	Procurement of Material	1	2	4	2	0.25
I.	Procurement of Heavy Equipment	2	3	5	3	0.25
J.	Excavation	9	10	12	10	0.25
K.	Sand lining	7	8	10	8	0.25
L.	Micropile Installation	9	10	12	10	0.25
M.	Work Floor Casting	12	14	15	14	0.25
N.	U-Ditch Installation	8	10	11	10	0.25
O.	Granular Pavement Excavation	8	10	12	10	0.4444
P.	heap Land	7	10	11	10	0.4444
Q.	Class B Aggregate Base	10	14	15	14	0.69444
R.	Class A Aggregate Base	10	14	15	14	0.69444
S.	The adhesive layer	7	10	12	10	0.69444
T.	Laston asphalt wear coated AC-WC	7	10	12	10	0.69444
U.	Laston Layer Between Levelers AC-BC	7	10	12	10	0.69444

V.	Road Shoulder Condition Retrieval	9	10	12	10	0.25
W.	Thermoplastic Road Markings	1	2	3	2	0.11111
X.	Finishing	2	3	5	3	0.25

4.2 Developing Network Planning Using Critical Path Method (CPM)

Once te and variance values are obtained, they are used as a duration of time in building a network of work on the CPM. The basis for determining the duration of each project activity is to obtain a *te*. The preparation of network planning in the CPM begins with creating a network planning model and then determining the critical path. Network planning models are made based on the order in which project activities are completed.

In determining critical paths, there is a forward pass process including *ES* (Eq. (3)) and *EF* (Eq. (4)) as well as backward passes including *LF* (Eq. (5)) and *LS* (Eq. (6)). Both processes are then used to obtain slack values calculated using Eq. (7). Suppose an activity has a value of slack = 0. In that case, the activity is on a critical path, so it significantly influences other activities in case of delays in that path. However, if the slack value is ≠ 0, then the activity is not traversed by critical paths. The result can be shown in Table 2.

Table 2 - Critical Path Determination Using CPM

No	Activity Description	Duration (day)	*ES*	*EF*	*LS*	*LF*	*Slack*
A.	Re-Measurement and Survey	2	0	2	0	2	0
B.	Pillar Installation	2	2	4	2	4	0
C.	Making Director Keet Container	2	2	4	4	6	2
D.	Installation of Nameplate Project	2	2	4	4	6	2
E.	Traffic Security	2	4	6	4	6	0
F.	Land Clearing	3	6	9	6	9	0
G.	Soil Test	2	9	11	9	11	0
H.	Procurement of Material	2	11	13	12	14	1
I.	Procurement of Heavy Equipment	3	11	14	11	14	0
J.	Excavation	10	14	24	14	24	0
K.	Sand Lining	8	24	32	60	68	36
L.	Micropile Installation	10	32	42	68	78	36
M.	Work Floor Casting	14	42	56	78	92	36
N.	U-Ditch Installation	10	56	66	92	102	36
O.	Granular Pavement Excavation	10	24	34	24	34	0
P.	Heap Land	10	34	44	34	44	0
Q.	Class B Aggregate Base	14	44	58	44	58	0
R.	Class A Aggregate Base	14	58	72	58	72	0
S.	The adhesive layer	10	72	82	72	82	0
T.	Laston asphalt wear coated AC-WC	10	82	92	82	92	0
U.	Laston Layer Between Levelers AC-BC	10	92	102	92	102	0
V.	Road Shoulder Condition Retrieval	10	102	112	102	112	0
W.	Thermoplastic Road Markings	2	102	104	110	112	8
X.	Finishing	3	112	115	112	115	0

Based on Table 2, it was obtained the activities that are on the critical path are A, B, E, F, G, I, J, O, P, Q, R, S, T, U, V, and X. And the activities that are not on the critical path are C, D, H, K, L, M, N, and W. Furthermore, these activities are described in the network model as in Fig.1.

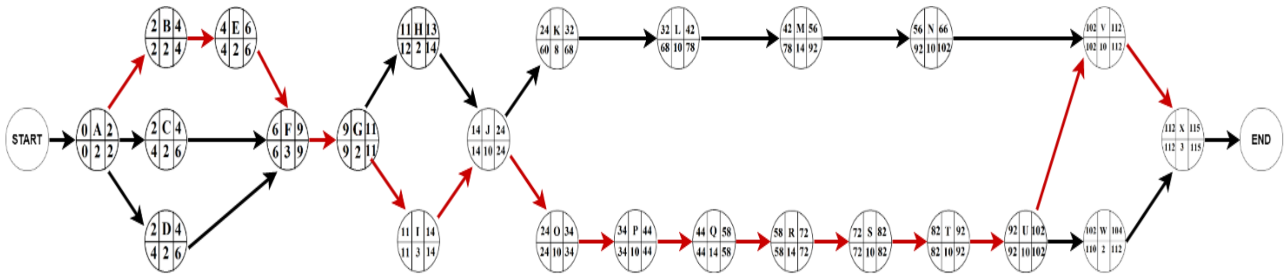

Fig. 1 - Network planning using CPM

Fig. 1 shows network planning between activities connected with arrows. The red arrow indicates the activity, which is a critical path. If the activity is delayed, then the project will experience work delays. If an activity that is not traversed by a critical path experiences a work delay, it will not affect the project completion duration as long as it does not exceed the specified slack time. This critical path is also helpful in determining probability so that the calculation will focus more on the activity that most affects the risk of work delays.

4.3 Determining Project Probability Using the PERT-CPM Method

Project probability is necessary to consider the possibilities in creating a work schedule. A project certainly has constraint factors in each implementation, so the probability is required to determine the possibility of the project being completed more slowly, according to the specified schedule, or faster. In this case, a value of *Te* and variance (*S*) are required in the PERT – CPM calculation process. However, te values and variances use values in activities that are on the critical path only.

The *Te* value obtained from the total expected time on the critical path alone is 115 days, while the variance value (*S*) is derived from the square root of the total variance (σ^2), which is on the critical path of 2,472. This variance value (*S*) will be used to measure risk deviations associated with the project. Both values are used to determine the *z* value that serves to determine the probability of the project completion duration as expected. This study assumes 114 days as the maximum duration of completion of work on the project's daily calendar, so the z value obtained is (Eq. (8)):

$$z = \frac{T(d) - Te}{S} = \frac{114 - 115}{2,472} = -0.4045 \tag{15}$$

Then, this z value can be seen in the *z* score table. In the *z* score table, the value -0.4045 has a probability value of 0.3429, so it can be described as the project probability distribution curve in Fig. 2. The probability value if percentage means that 34.29% of project probabilities can be completed in less than equal to 114 days (≤). The probability of completion of a project with a maximum working duration of 114 days is still below 50%. In the probability of a working duration, a value close to 0% means that the duration is impossible to complete, while a value close to 100% means that the duration is very likely to be resolved. In the *z* score table, a probability that closes to 100% is 3.49%, so the most likely duration is resolved as:

$$z = \frac{T(d) - Te}{S} \Rightarrow 3.49 = \frac{x - 115}{2.472} \Rightarrow x \approx 124 \tag{16}$$

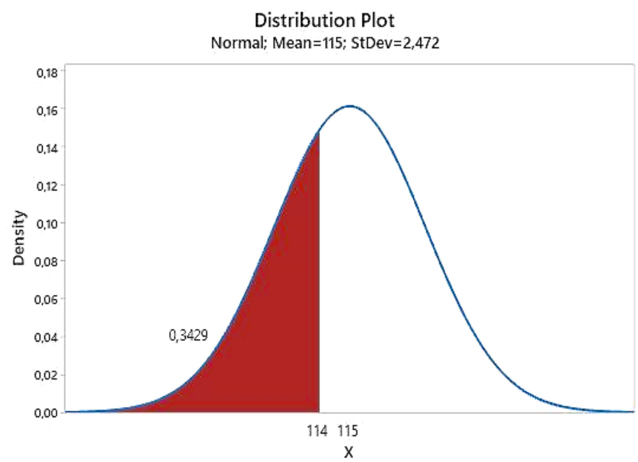

Fig. 2 - Project probability distribution curve For 114 days

Based on Fig. 3, it was found that the duration of completion of the project that has the highest probability of completion (almost close to 100%) is 124 days. The 115th duration, which is the average duration generated through CPM, represents the minimum time required for project completion. In reality, various uncertainties often appear to be constraints so that the project completion time is difficult to equal the CPM, as shown in the following S curve, which states the probability of project work progress.

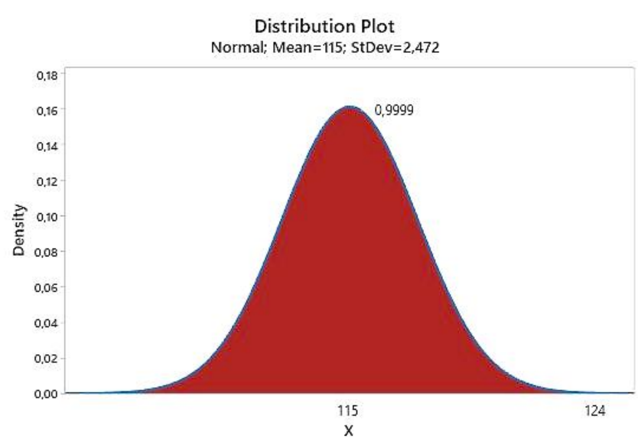

Fig. 3 - Project probability distribution curve with duration 124 days

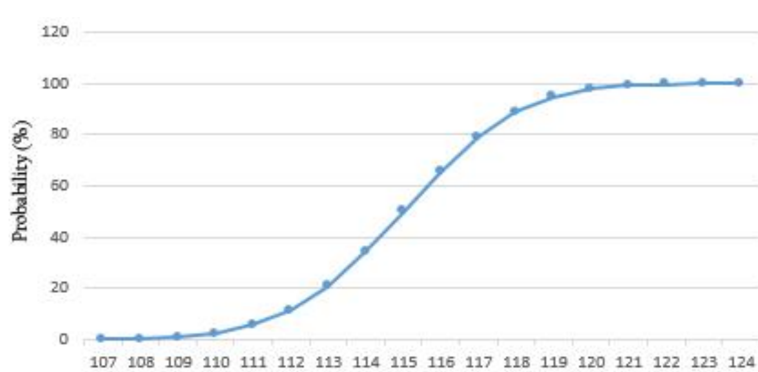

Fig. 4 - Probability recapitulation of project duration

Based on Fig. 4, it was obtained that if the project activity is given the fastest duration and has a low probability percentage value, then the project is unlikely to be completed on time because the risk charged becomes greater, just like the 107th duration in contrast to the 124th duration that has a high probability percentage value so that with that oldest duration, CV. X can maximize its work against risks stemming from various factors of uncertainty. So with the target time according to the contract, which is 114 days, of course CV. X was unable to complete his work which certainly implicated the occurrence of a penalty to be paid CV. X.

4.4 Determining the Acceleration of Work Duration and Cost Using Crashing Method

A company certainly has other options to solve problems in the implementation of the project. One of them is to accelerate or reduce the duration and cost using the crashing method. There are various kinds of alternatives that can be used in crashing methods, such as the addition of shift work, the addition of working hours, or the addition of labor. In this study, the alternative used was the addition of labor. This is due to CV. X has limitations in time that can only be done at night shift (working hours are limited from 8 p.m to 4 a.m.), so they can not use alternatives to adding working hours or adding shifts.

Table 3 - Recapitulation of crash duration, crash cost, and cost slope values

Activity code	***ND*** (Day)	***NC*** (IDR)	***CD*** (Day)	***CC*** (IDR)	***Cost Slope***
A.	2	1,000,000	1	1,160,000	160,000
B.	2	700,000	1	780,000	80,000
C.	2	7,000,000	1	7,160,000	160,000
D.	2	1,000,000	1	1,080,000	80,000
E.	2	800,000	1	880,000	80,000
F.	3	800,000	2	960,000	160,000
G.	2	1,000,000	1	1,160,000	160,000
H.	2	700,000	1	860,000	160,000
I.	3	800,000	2	1,120,000	320,000
J.	10	23,890,511	8	25,170,511	640,000
K.	8	9,157,635	6	10,117,635	480,000
L.	10	6,253,000	8	7,533,000	640,000
M.	14	5,952,750	11	6,832,750	293,333
N.	10	330,851,003	7	331,971,003	373,333
O.	10	686,014,829	7	687,134,829	373,333
P.	10	69,552,894	7	70,672,894	373,333
Q.	14	421,519,638	10	423,119,638	400,000
R.	14	189,804,371	10	191,404,371	400,000
S.	10	64,590,627	6	65,550,627	240,000
T.	10	1,363,429,574	8	1,364,709,574	640,000
U.	10	293,693,750	8	294,973,750	640,000
V.	10	98,446,803	7	99,566,803	373,333
W.	2	73,750 .757	1	73,910,757	160,000
X.	3	3,500,000	2	3,980,000	480,000

(*ND* = Normal duration; *NC* = Normal cost; *CD* = Crash duration; *CC* = crash cost)

Normal cost (*NC*) in this project has a total of IDR 3,654,208,142, while crash cost (*CC*) influenced by the cost slope value has a total of IDR 3,671,808,142. Because the critical activity is the activity that has the most significant impact on the duration of completion, the crashing method focuses on critical activities. In the process of crashing requires network planning with CPM approach in the previous calculation. This network planning has 16 critical activities that are 115 days long. Iteration is one of the processes performed in the crashing method. The iteration process is done by selecting the smallest cost slope value of the critical activity. Then the activity is reduced in duration so that a new network planning is arranged. The process is carried out in critical activities because it is the most influential activity in case of a work delay. If a critical activity is delayed, the project will not be completed promptly. The process is carried out continuously until there is no longer any critical activity reduced.

Based on Fig. 5, it was obtained that initially network planning has a duration of 115 days, then iteration is done to reduce the duration by one day in activity B. Activity B was chosen because it has the smallest cost slope value compared to other critical paths. This stage 1 crashing iteration process results in a duration of 114 business days. Furthermore, iterations continue to be under-moderated, and iterations will stop until no other critical activity can be reduced (reaching the optimal point). In this study, the end of the crashing iteration process resulted in 76 days of 19 iterations of crashes.

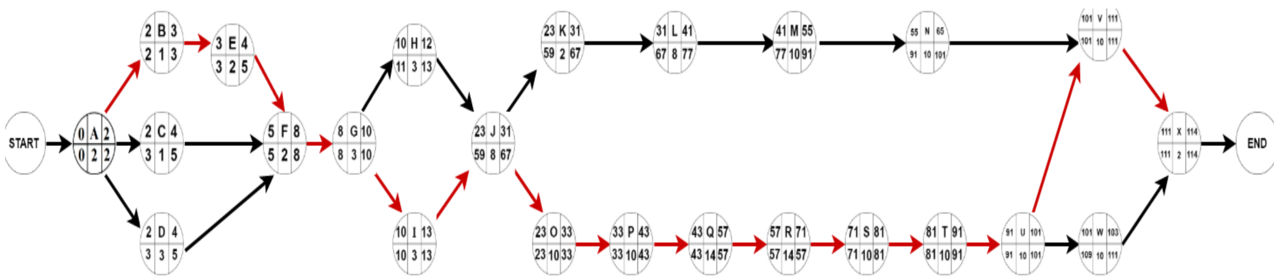

Fig. 5 - Iteration of crashing phase 1 on road construction project by CV. X

To determine whether the results of crashing duration are optimal, of course the duration must be reanalyzed to be associated with the cost of crashing. Therefore, time cost trade-off (TCTO) analysis is carried out which calculation refers to the value of cost slope and network planning crashing results so that direct costs, indirect costs, and total costs are generated for each acceleration duration. With these total costs, project organizers can choose the duration with the lowest total cost. The calculation is shown in Table 4.

Table 4 - Recapitulation of direct costs, indirect costs, and total costs based on acceleration duration

No.	Crash Duration (Day)	Direct Costs (IDR)	Indirect Costs (IDR)	Total Costs (IDR)
1.	114	3,654,288,142	24,552,256	3,678,840,398
2.	113	3,654,368,142	24,336,886	3,678,705,028
3.	112	3,654,448,142	24,121,515	3,678,569,657
4.	111	3,654,608,142	23,906,144	3,678,514,286
5.	110	3,654,768,142	23,690,774	3,678,458,916
6.	109	3,654,928,142	23,475,403	3,678,403,545
7.	108	3,655,088,142	23,260,032	3,678,348,174
8.	104	3,656,048,142	22,398,550	3,678,446,692
9.	103	3,656,368,142	22,183,179	3,678,551,321
10.	102	3,656,528,142	21,967,808	3,678,495,950
11.	99	3,657,648,142	21,321,696	3,678,969,838
12.	96	3,658,768,142	20,675,584	3,679,443,726
13.	93	3,659,888,142	20,029,472	3,679,917,614

14.	89	3,661,488,142	19,167,990	3,680,656,132
15.	85	3,663,088,142	18,306,507	3,681,394,649
16.	84	3,663,568,142	18,091,136	3,681,659,278
17.	81	3,665,648,142	17,229,654	3,682,877,796
18.	78	3,666,928,142	16,583,542	3,683,511,684
19.	76	3,668,688,142	16,368,171	3,685,056,313

Based on Table 4, it is obtained that the 108th duration is the optimal duration in accelerating work because it has the lowest total cost value compared to other durations to save the company's cost expenditure. The Company is not recommended to choose the duration of completion of the 76th work, because the total cost is maximum, as shown in graph below. As be referred to Fig. 6, the cost immediately after a crash on the 76th to the 114th duration decreases. This because the more significant duration of the crash, the greater the direct costs incurred, such as the cost of adding material load, equipment, labor, and others. However, unlike the 114th duration, it only takes one crash day from the expected duration of 115 days. Therefore, the cost immediately after the crash is also small. Based on Fig. 7, indirect costs (electricity, water, administration, etc.) after crashes obtained in the 76th to 114th duration will increase. This because the more significant the duration, the smaller the indirect costs incurred.

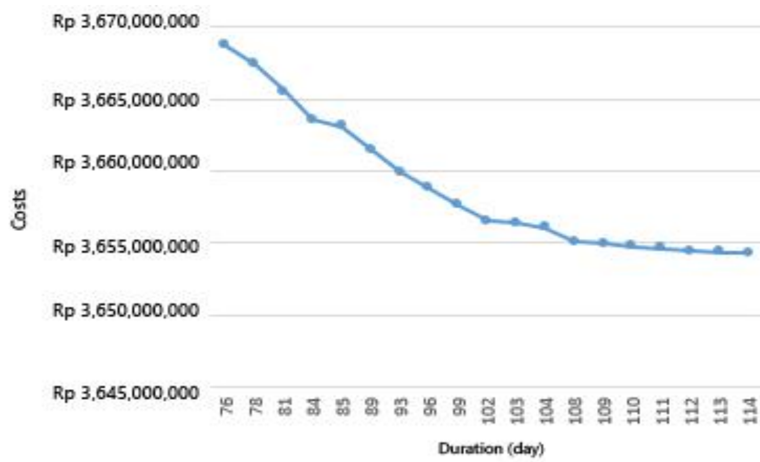

Fig. 6 - Direct cost due to the process of crashing the addition of labor

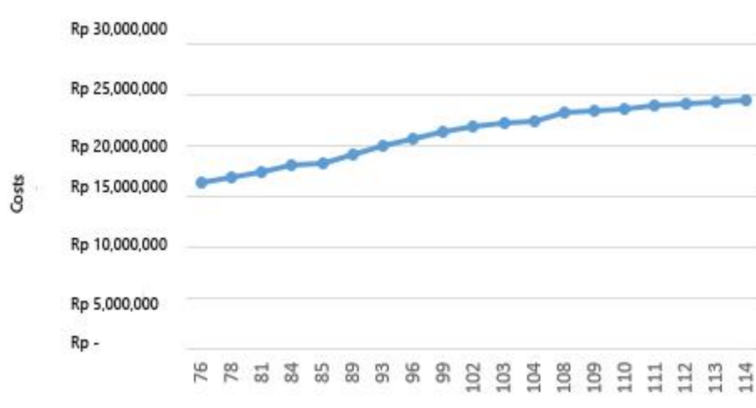

Fig. 7 - Indirect cost due to labor increase crashing process

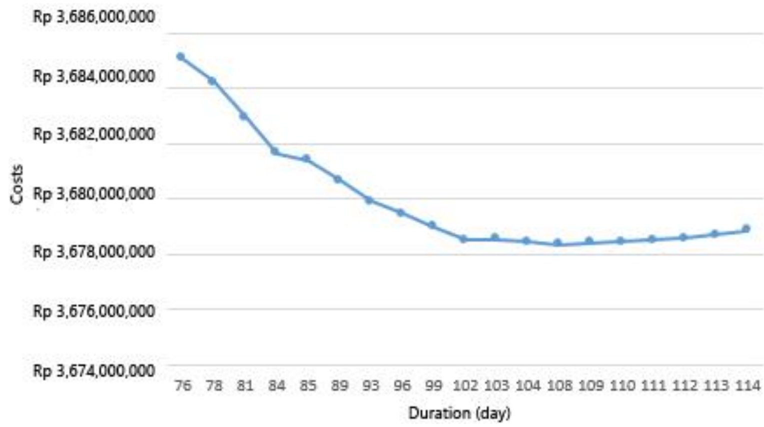

Fig. 8 - Total direct costs and indirect costs due to the process of crashing the addition of labor

Based on Fig. 8, it can be seen that there was a decrease and increase in total costs in the duration of the 76th to 114th. The total cost of the 76th duration is still the largest because achieving that duration also requires additional costs due to the crashing process. However, the chart continued to fall until the 109th duration which subsequently increased. From the chart, it can be said that the 108th duration is a duration with the lowest total cost. So if a company wants to reduce the duration (crash duration), the 108th duration is the optimal duration that can be chosen because it has a low total cost to reduce the costs incurred.

The first scenario that can be an alternative to project completion is to reduce the time from the 115th to the 108th duration. The 115th duration is the optimal duration obtained from the CPM process, while the 108th duration is the optimal duration performed for the acceleration of activity. Calculated companies can accelerate the duration of 6 days and save costs of IDR 690,354.

The second scenario is to pay the penalty. Suppose it is assumed that the project is completed in accordance with a probability value approaching 100% which is 124 days. In that case, the duration of delay that this project can experience is ten days from the specified contract duration of 114 days, with the following calculations:

$$\text{Penalty} = \left(\frac{1}{1000} \times \text{Late Duration}\right) \times \text{Contract Value} = \left(\frac{1}{1000} \times 10 \text{ Days}\right) \times \text{IDR}\, 4.046.873.346 = \text{IDR}\, 40.468.733 \qquad (17)$$

The penalty amount to be paid for the second scenario is IDR 40,468,733.

5. Conclusion

In this study, we plan, schedule, and control shipping projects using the PERT – CPM method, which resulted in an optimal duration of 115 days, where the duration exceeded the contract duration set at 114 days. To overcome these work delays, there are two scenarios that can be chosen. The first scenario is crashing by reducing the working duration from 115 days to 108 days with a cost saving of IDR 690,354 or 0.02%. The value of the savings is classified as very small because crashing can only be done with additional labor and limited working hours. The second scenario is to pay a penalty fee of IDR 40,468,733. The penalty fee is calculated based on the delay in the project's completion time multiplied by the fine. Companies are advised to choose the first scenario. This study uses an alternative crashing with the addition of the number of workers due to limited working hours. If faced with other similar case studies but no time limit, it may be possible to try other crashing alternatives such as the addition of shift work or the addition of working hours (overtime).

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