

# Study of Rescheduling of MV Alfa Trans Satu Ship Repair Using Critical Path Method (CPM) and Project Evaluation and Review Technique (PERT)

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**Abstract** - The ship repair project must work according to the schedule agreed in the work contract. However, in the process there are often delays between the initial plan and work in the field. The scheduling method is one of the influences on the success of repairs in order to produce efficient scheduling and cost planning. Based on these conditions, this study aims to obtain a new duration and the most optimal cost of crashing through an alternative, namely additional working hours (overtime hours) and additional workforce in the MV Alfa Trans Satu Ship repair project by applying the CPM and PERT methods. Based on the crash duration calculation using the CPM, the most effective and efficient alternative that can be used to accelerate the MV Alfa Trans Satu Ship repair project is by adding a workforce of 32 Person (an increase of 30% from the initial workforce). This acceleration alternative produces a duration below the normal duration, 21 days from the initial 25 days. The probability of success for this project using the PERT method can be completed within 21 days of 98.46%. The percentage increase in costs is only 4% of the normal for critical work, IDR 50,800,000.

**Keywords** - Crash Duration, CPM, PERT

## I. INTRODUCTION

The ship repair project must work according to the schedule agreed in the work contract. However, in the process there are often delays between the initial plan and work in the field. A project is declared successful if it can fulfill its objectives. The project can be completed on time by the planned costs and the quality that has been determined. Based on this, it is necessary to have project planning and scheduling so that project success can be achieved.

Time planning for a repair project work always refers to the estimate when the master schedule is made (schedule master); a problem can occur if there is a discrepancy between the plans made and the actual implementation at the project site.

Delay is the effect of a combination of dependencies due to the nature of the project which is sensitive to specific changes, so planning alone is not necessarily enough to ensure that the project work is completed on time according to plan. Management of resources in a construction seeks to be competitive and able to carry out project work on time (on schedule), on budget (on budget), and smoothly according to work specifications (on specification).

Based on the results of previous research entitled "Optimization of the SPOB Repair Schedule. Prosper Three 3537 DWT Using the Critical Path Method to

Anticipate Project Delays" the duration was reduced from 30 to 24 days. This reduction in duration is carried out with two alternatives, namely the addition of a workforce from 39 Person to 51 Person and 3 hours of work (overtime) per day [1]. Similar research on the Survey Vessel Geomarin-III 649 DWT found that the project duration was 20 days with 53 activities. After analysis using the Critical Path Method, 19 work activities were found that were on the critical path, and an additional workforce of 14 Person reduced the project duration to 16. After crashing, an overall cost reduction of 6%, namely IDR 153,790,000 from the initial cost of IDR 163,670,000 [2].

Another method used in ship repair scheduling is the Project Evaluation and Review Technique (PERT). This method has been used in previous ship repair research entitled "Implementation of the Project Evaluation and Review Technique (PERT) on Scheduling KMP Royal Nusantara Ship Repairs" in scheduling Royal Nusantara Ship repairs which can be accelerated to 22 days from the initial plan of 25 days with the alternative of adding working hours (overtime) and labor and obtaining a project success probability of 81.33% [3].

Research "Comparative Analysis of CPM, PDM, and PERT Methods in KN Ship Repair Scheduling Planning. RB 309 Ternate 01" obtained the calculation of the duration acceleration results with the CPM and PDM methods having the same results, namely on

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scheduling A for 48 days, scheduling B for 33 days, and scheduling C for 21 days. The success of the project using the PERT method can be completed in 48 days by 48.67%, scheduling B 34 days 5 hours 21 minutes with the possibility that the project can be completed in 48 days by 99.35% and scheduling C 22 days 5 hours 21 minutes with the possibility that the Ternate 01 project can be completed in 48 days by 99.99% [4]. The research entitled "Evaluation of the Matarbariunit-02 Fabrication Project Using the CPM and PERT Methods of PT. Dui Esa Unggul" obtained the optimal duration of the steel structure fabrication project Matarbari Project Unit-02 priority 3 (P133) PT. Dui Esa Unggul uses the CPM method, which is 42 days from the normal time, namely 51 days, and there is a probability of 71.57% [5].

Based on other research using the Time Cost Trade-Off (TCTO) method, it is accelerated by four days from the normal duration. Using the PERT method, the project success calculation within 20 days is 87.90% [6]. Based on research entitled "Evaluation of the Stroke Center Building Project (Flamboyant Pavilion) Using the Critical Path Method (CPM) and Crashing," the cost of wages with an alternative addition of labor is IDR 3,381,751,094.43. In comparison, the cost of wages with the alternative of additional working hours is IDR 3,381,632,949.92. From the results of this analysis, a more economical alternative to completing the project is adding overtime hours because it saves IDR 118,145.49 from adding labor [7].

Based on research entitled "Analysis of Km Tonasa Line VIII Repair Network Planning Using the CPM Method to Anticipate Delays in Completion of Repairs (Case Study at PT. Dok Perkapalan Surabaya)" delays in project completion are caused by several things, including power outages, material delays, lack of

manpower, additional work by the owner, and payment [8].

This study took data from the MV Alfa Trans Satu ship, which is a cargo ship. MV Alfa Trans Satu has a length of 60.2 meters and a width of 14.88 meters with a speed of 9.6 knots. The MV Alfa Trans Satu ship is planned to carry out repairs from August 24, 2022, to September 27, 2022, or 25 days, with a contract value of IDR 444,802,698.00. The realization of MV Alfa Trans Satu ship repairs was completed on October 4, 2022, a delay from the initial project schedule. This delay was due to the ineffective allocation of manpower.

The scheduling method is one of the influences on the success of repairs in order to produce efficient scheduling and cost planning. This study applies the Critical Path Method (CPM) method and calculates the probability using the Project Evaluation and Review Technique (PERT) in planning and scheduling the MV Alfa Trans Satu Ship repair project assisted with Microsoft Project Software. This study aims to obtain a new duration after rescheduling ship repairs and the most optimal costs to speed up the duration of the project by crashing through two alternative options, namely additional working hours (overtime hours) and additional workforce for the smooth running of a project and overcoming opportunities that could hinder the repair process.

## II. METHOD

### A. Research Data

This study analyzes the MV Alfa Trans Satu ship repair project. This ship is a cargo ship with IMO number 9274721, which has the ship's main dimensions, as shown in Table 1.

TABLE 1.

MAIN PARTICULAR SHIP		
Number	Dimension	Full-scale
1.	GT	1587 ton
2.	LOA	60.20 m
3.	Breadth	14.88 m
4.	Height	5.00 m
5.	Draft	3.90 m

This repair project experienced a delay from the initial planning, scheduled for August 24, 2022, to September 27, 2022, or 25 days. However, this repair project was realized on October 4, 2022.

This study applies the Critical Path Method (CPM) method and calculates the probability using the Project Evaluation and Review Technique (PERT) in planning and scheduling the MV Alfa Trans Satu Ship repair project to get a new duration after rescheduling the ship repair and the most optimal costs to speed up the duration of the project by crashing through alternatives namely additional working hours (overtime hours) and additional workforce.

### B. Critical Path Method

CPM is known for its critical path, a project management method with a series of activity components with the longest total time and the fastest project completion period [9].

### C. Program Evaluation and Review Technique

PERT is an approach method that assumes that the duration of an activity depends on many factors and variations, so it is better to give a range of estimates, namely by using a three-digit estimate [10]. PERT also introduces other parameters that "measure" that uncertainty quantitatively, such as "standard deviation" and Variance.

#### D. Completion Steps

This research begins with accelerating projects on a critical path using the Critical Path Method (CPM) method with alternative work hours (overtime hours) and additional labor to get a crash duration value of work on the critical path. Crash duration is useful for calculating crash costs for jobs on a critical path. After getting the results of project acceleration, it can determine the probability value or opportunity for the project to be completed using the Project Evaluation and Review Technique (PERT) method.

### III. RESULTS AND DISCUSSION

Following are the results of data processing from the data that has been obtained and the discussion of this study.

#### A. Arranging Activity Sequences

A systematic arrangement of inter-activity relationships between jobs from start to finish by

analyzing the main schedule and repair lists is carried out based on predecessors and successors so that work is included in the critical path. Predecessor is an activity that is carried out before the activity in question occurs. Meanwhile, the successor is carried out after the activity has occurred. The relationship between activities is expressed by the relationship between finish to start (FS) and start to start (SS).

Based on the arrangement of activity sequences assisted by Microsoft Project Software, several critical activities were obtained in the MV Alfa Trans Satu Ship repair project.

#### B. Determining the Critical Path on the Schedule

The critical path is a path with a collection of activities with the longest duration, which can be known if the activities have a total float or slack,  $TF = 0$  [11]. In the MV Alfa Trans Satu Ship repair project, there are 14 works on the critical path.

TABLE 2.  
CRITICAL PATH ACTIVITY AT NORMAL DURATION

ID	Job Name	Earliest Start	Earliest Finish	Latest Start	Latest Finish	Slack
A1	Docking	Wed 24/08/22	Wed 24/08/22	Wed 24/08/22	Wed 24/08/22	0
A2	Ship in Dry Dock	Wed 24/08/22	Thu 08/09/22	Wed 24/08/22	Thu 08/09/22	0
A3	Ship Docked at Pier	Fri 09/09/22	Tue 27/09/22	Fri 09/09/22	Tue 27/09/22	0
A4	Sea Trial & Compasseren	Mon 26/09/22	Mon 26/09/22	Mon 26/09/22	Mon 26/09/22	0
C1	Scrapping	Wed 24/08/22	Thu 25/08/22	Wed 24/08/22	Thu 25/08/22	0
C2	High-Pressure Fresh Water Wash (Water Jet)	Thu 25/08/22	Thu 01/09/22	Thu 25/08/22	Thu 01/09/22	0
C3	Sandblasting	Fri 26/08/22	Tue 30/08/22	Fri 26/08/22	Tue 30/08/22	0
D1	Below the Waterline	Tue 30/08/22	Tue 06/09/22	Tue 30/08/22	Tue 06/09/22	0
D2	Above the Waterline	Wed 14/09/22	Tue 20/09/22	Wed 14/09/22	Tue 20/09/22	0
E1	Bolder Tali Mooring Single Bolder	Fri 09/09/22	Mon 26/09/22	Fri 09/09/22	Mon 26/09/22	0
M4	SpeedLog	Wed 21/09/22	Thu 22/09/22	Wed 21/09/22	Thu 22/09/22	0
M5	Gyro Compass	Fri 23/09/22	Fri 23/09/22	Fri 23/09/22	Fri 23/09/22	0
N1	Certificate Classes	Tue 27/09/22	Tue 27/09/22	Tue 27/09/22	Tue 27/09/22	0
N2	Statutory Certificate	Tue 27/09/22	Tue 27/09/22	Tue 27/09/22	Tue 27/09/22	0

#### C. Calculation of Normal Daily Productivity

The productivity of a group of workers is the ability of the workforce to complete work (a unit of work volume) divided into units of time, hours, or days. Productivity determines the amount of labor and wages that need to be paid [11]. The value of normal daily

productivity is obtained from the calculation of the following formula:

$$\text{Normal Daily Productivity (PHN)} = \frac{\text{Job Volume}}{\text{Normal Duration}} \quad (1)$$

The following is the calculation of normal daily productivity on the repair of the MV Alfa Trans Satu Ship.

TABLE 3.  
CALCULATION OF NORMAL DAILY PRODUCTIVITY ON THE CRITICAL PATH

ID	Normal Duration (Days)	Job Volume	Unit	NDP
A1	1	1	ls	1
A2	12	12	ls	1
A3	13	13	ls	1
A4	1	1	lot	1
C1	2	110	m2	55
C2	6	1450	m2	241.67
C3	3	1350	m2	450
D1	6	10000	kg	1666.67
D2	5	7000	kg	1400
E1	12	16	pcs	1.33
M4	2	1	ls	0.5
M5	1	1	ls	1
N1	1	1	lot	1
N2	1	1	lot	1

D. Alternative Acceleration

Alternative acceleration is a way to speed up the time or duration of activities in completing the project to avoid delays in the implementation of project work and will affect the project costs to be paid. Shortening the duration of the project work can use alternatives to adding working hours (overtime hours) and adding manpower.

1) Alternative to Additional Working Hours (Overtime Hours)

One strategy is to shorten project work duration, namely by adding working hours (overtime hours) outside of normal working hours. Normal working time for the MV Alfa Trans Satu Ship repair project is

8 hours per day (08.00-17.00) with one hour break time (12.00-13.00). Additional working hours (overtime hours) are carried out for 1 hour (17.00-18.00), 2 hours (17.00-19.00), 3 hours (17.00-20.00), and 4 hours (17.00-21.00) after normal working hours are over. Productivity after additional working hours (overtime hours) has decreased from normal productivity. This is caused by various factors, such as worker fatigue, etc. The decrease in the productivity of additional working hours (overtime hours) in the hour is 0.1 or the difference in the productivity index is 0.1 per hour [12]. Indications of decreased productivity due to additional working hours (overtime) can be seen in Table 4.

TABLE 4.  
PRODUCTIVITY DECLINE COEFFICIENT

Overtime Hours	Decreased Productivity Index	Work Performance (%)
1	0.1	90
2	0.2	80
3	0.3	70
4	0.4	60

Productivity after additional working hours (overtime hours) can be calculated using the following formula:

$$PPJK = PHN + (PJN \times Koef.PP \times DJL) \quad (2)$$

Information:

PPJK : Productivity of Additional Working Hours  
PHN : Normal Daily Productivity

PJN : Normal Hourly Productivity  
Koef. PP : Productivity Reduction Coefficient  
DJL : Duration of Overtime Hours (Hours)

Productivity after additional working hours (overtime hours) in the MV Alfa Trans Satu Ship repair project, which is on a critical trajectory can be seen in Table 5 below.

TABLE 5.  
CALCULATION OF PRODUCTIVITY AFTER ADDITIONAL WORKING HOURS (OVERTIME HOURS) ON THE CRITICAL PATH

ID	PHN	PJN	1 Hour			2 Hours			3 Hours			4 Hours		
			Koef. PP	DJL (Hours)	PPJK	Koef. PP	DJL (Hours)	PPJK	Koef. PP	DJL (Hours)	PPJK	Koef. PP	DJL (Hours)	PPJK
A1	1.00	0.13	0.9	1	1.11	0.8	2	1.20	0.7	3	1.26	0.6	4	1.30
A2	1.00	0.13	0.9	1	1.11	0.8	2	1.20	0.7	3	1.26	0.6	4	1.30
A4	1.00	0.13	0.9	1	1.11	0.8	2	1.20	0.7	3	1.26	0.6	4	1.30
A5	1.00	0.13	0.9	1	1.11	0.8	2	1.20	0.7	3	1.26	0.6	4	1.30
C1	55.00	6.88	0.9	1	61.19	0.8	2	66.00	0.7	3	69.44	0.6	4	71.50
C2	241.67	30.21	0.9	1	268.85	0.8	2	290.00	0.7	3	305.10	0.6	4	314.17
C3	450.00	56.25	0.9	1	500.63	0.8	2	540.00	0.7	3	568.13	0.6	4	585.00
D1	1666.67	208.33	0.9	1	1854.17	0.8	2	2000.00	0.7	3	2104.17	0.6	4	2166.67
D2	1400.00	175.00	0.9	1	1557.50	0.8	2	1680.00	0.7	3	1767.50	0.6	4	1820.00
E1	1.33	0.17	0.9	1	1.48	0.8	2	1.60	0.7	3	1.68	0.6	4	1.73
M4	0.50	0.06	0.9	1	0.56	0.8	2	0.60	0.7	3	0.63	0.6	4	0.65
M5	1.00	0.13	0.9	1	1.11	0.8	2	1.20	0.7	3	1.26	0.6	4	1.30
N1	1.00	0.13	0.9	1	1.11	0.8	2	1.20	0.7	3	1.26	0.6	4	1.30
N2	1.00	0.13	0.9	1	1.11	0.8	2	1.20	0.7	3	1.26	0.6	4	1.30

2) Alternatives to Additional Labor

The addition of labor is also an alternative to shorten the duration of project work to produce an effective and efficient project.

This study assumes an additional workforce based on increased daily productivity due to additional working hours (overtime hours). Productivity increase after additional working hours can be calculated using the following formula:

$$PPPJK = \frac{(PPJK - PHN)}{PHN} \times 100\% \quad (3)$$

Information:

PPPJK : Increased Productivity Additional Working Hours

PPJK : Productivity of Additional Working Hours

PHN : Normal Daily Productivity

The formula can calculate the addition of accelerated labor:

$$TKP = PPPJK \times TKN \quad (4)$$

Information:

TKP : Acceleration Workforce (Person)

PPPJK : Increased Productivity Additional Working Hours

TKN : Normal Workforce (Person)

Increased productivity after the addition of manpower due to additional working hours (overtime hours) and accelerated labor in the MV Alfa Trans Satu Ship repair project, which is on a critical trajectory can be seen in Table 6 below.

TABLE 6.  
CALCULATION OF INCREASED PRODUCTIVITY FOR ADDITIONAL LABOR AND ACCELERATED LABOR

ID	TKN (Person)	PHN	11%			20%			26%			30%		
			PPJK	PPPJK	TKP	PPJK	PPPJK	TKP	PPJK	PPPJK	TKP	PPJK	PPPJK	TKP
A1	10	1.00	1.11	0.11	1	1.20	0.20	2	1.26	0.26	3	1.30	0.30	3
A2	4	1.00	1.11	0.11	0	1.20	0.20	1	1.26	0.26	1	1.30	0.30	1
A3	8	1.00	1.11	0.11	1	1.20	0.20	2	1.26	0.26	2	1.30	0.30	2
A4	16	1.00	1.11	0.11	2	1.20	0.20	3	1.26	0.26	4	1.30	0.30	5
C1	5	55.00	61.19	0.11	1	66.00	0.20	1	69.44	0.26	1	71.50	0.30	2
C2	5	241.67	268.85	0.11	1	290.00	0.20	1	305.10	0.26	1	314.17	0.30	2
C3	7	450.00	500.63	0.11	1	540.00	0.20	1	568.13	0.26	2	585.00	0.30	2
D1	16	1666.67	1854.17	0.11	2	2000.00	0.20	3	2104.17	0.26	4	2166.67	0.30	5
D2	18	1400.00	1557.50	0.11	2	1680.00	0.20	4	1767.50	0.26	5	1820.00	0.30	5
E1	4	1.33	1.48	0.11	0	1.60	0.20	1	1.68	0.26	1	1.73	0.30	1
M4	3	0.50	0.56	0.11	0	0.60	0.20	1	0.63	0.26	1	0.65	0.30	1
M5	3	1.00	1.11	0.11	0	1.20	0.20	1	1.26	0.26	1	1.30	0.30	1
N1	3	1.00	1.11	0.11	0	1.20	0.20	1	1.26	0.26	1	1.30	0.30	1
N2	3	1.00	1.11	0.11	0	1.20	0.20	1	1.26	0.26	1	1.30	0.30	1

Information:

TKN : Normal Workforce (Person)

PHN : Normal Daily Productivity

PPJK : Productivity of Additional Working Hours

PPPJK : Increased Productivity Additional Working Hours

TKP : Acceleration Workforce (Person)

in productivity of working hours of 30% of the initial workforce of 32 Person.

The formula for calculating productivity after adding labor:

$$PPTK = PHN + \frac{(PHN \times TKP)}{TKN} \quad (5)$$

Information:

PPTK : Productivity of Additional Labor

PHN : Normal Daily Productivity

TKP : Acceleration Workforce (Person)

TKN : Normal Workforce (Person)

Based on Table 6, the calculation of the number of accelerated workers with an increase in working hours productivity of 11% of the initial workforce is 12 Person, with an increase in working hours productivity of 20% of the initial workforce of 21 Person, with an increase in productivity of working hours of 26% of the initial workforce of 28 Person, and with an increase

The value of productivity after adding manpower to the MV Alfa Trans Satu Ship repair project, which is in the critical path can be seen in Table 7.

TABLE 7.  
CALCULATION OF PRODUCTIVITY AFTER THE ADDITION OF LABOR ON THE CRITICAL PATH

ID	PHN	TKN (Person)	11%		20%		26%		30%	
			TKP (Person)	PPTK	TKP (Person)	PPTK	TKP (Person)	PPTK	TKP (Person)	PPTK
A1	1.00	10	1	1.11	2	1.20	3	1.26	3	1.30
A2	1.00	4	0	1.11	1	1.20	1	1.26	1	1.30
A3	1.00	8	1	1.11	2	1.20	2	1.26	2	1.30
A4	1.00	16	2	1.11	3	1.20	4	1.26	5	1.30
C1	55.00	5	1	61.19	1	66.00	1	69.44	2	71.50
C2	241.67	5	1	268.85	1	290.00	1	305.10	2	314.17
C3	450.00	7	1	500.63	1	540.00	2	568.13	2	585.00
D1	1666.67	16	2	1854.17	3	2000.00	4	2104.17	5	2166.67
D2	1400.00	18	2	1557.50	4	1680.00	5	1767.50	5	1820.00
E1	1.33	4	0	1.48	1	1.60	1	1.68	1	1.73
M4	0.50	3	0	0.56	1	0.60	1	0.63	1	0.65
M5	1.00	3	0	1.11	1	1.20	1	1.26	1	1.30
N1	1.00	3	0	1.11	1	1.20	1	1.26	1	1.30
N2	1.00	3	0	1.11	1	1.20	1	1.26	1	1.30

E. Calculation of Crash Duration

Crash duration is the time or duration of work required to shorten the initial or normal duration of project work to avoid time delays in the execution of project work. Crash duration is the minimum possible time or duration when the resources are maximized [13]. Calculating Crash Duration is necessary because of increased productivity after adding alternative working hours (overtime hours) and labor, which will affect the duration or time of project work.

The following is the equation for calculating the Crash Duration value:

$$\text{Crash Duration} = \frac{\text{Job Volume}}{\text{Accelerated Productivity}} \quad (6)$$

1) Calculation of Crash Duration After Additional Working Hours (Overtime Hours)

The crash duration value after additional working hours (overtime hours) on the MV Alfa Trans Satu Ship repair project, which is in a critical path, can be seen in Table 8.

TABLE 8.  
CALCULATION OF ALTERNATIVE CRASH DURATION FOR ADDITIONAL WORK HOURS ON CRITICAL PATHS

ID	Job Name	Job Volume	1 Hours		2 Hours		3 Hours		4 Hours	
			PPJK	CD	PPJK	CD	PPJK	CD	PPJK	CD
A1	Docking	1	1.11	1	1.20	1	1.26	1	1.30	1
A2	Ship in Dry Dock	12	1.11	11	1.20	10	1.26	10	1.30	9
A4	Ship Docked at Pier	13	1.11	12	1.20	11	1.26	10	1.30	10
A5	Sea Trial & Compasseren	1	1.11	1	1.20	1	1.26	1	1.30	1
C1	Scrapping	110	61.19	2	66.00	2	69.44	2	71.50	2
C2	High-Pressure Fresh Water Wash (Water Jet)	1450	268.85	5	290.00	5	305.10	5	314.17	5
C3	Sandblasting	1350	500.63	3	540.00	3	568.13	2	585.00	2
D1	Below the Waterline	10000	1854.17	5	2000.00	5	2104.17	5	2166.67	5
D2	Above the Waterline	7000	1557.50	4	1680.00	4	1767.50	4	1820.00	4
E1	Bolder Tali Mooring Single Bolder	16	1.48	11	1.60	10	1.68	10	1.73	9
M4	SpeedLog	1	0.56	2	0.60	2	0.63	2	0.65	2
M5	Gyro Compass	1	1.11	1	1.20	1	1.26	1	1.30	1
N1	Certificate Classes	1	1.11	1	1.20	1	1.26	1	1.30	1
N2	Statutory Certificate	1	1.11	1	1.20	1	1.26	1	1.30	1

Information:

PPJK : Productivity of Additional Working Hours

CD : Crash Duration (Days)

Based on the alternative crash duration calculation, working hours on critical paths with a total normal duration of 25 days are added. The acceleration duration by adding 1 hour of working hours per day, which is 23 days (8% faster than the normal duration). The acceleration duration by adding 2 hours per day is

the same as adding 3 hours of work per day, which is for 22 days (12% faster than the normal duration). The accelerated duration by adding 4 hours working hours per day, which is for 21 days (16% faster than the normal duration).

The following graph shows the alternative crash duration calculation results for additional working hours (overtime hours) for jobs in the critical path, which can be seen in Figure 1.

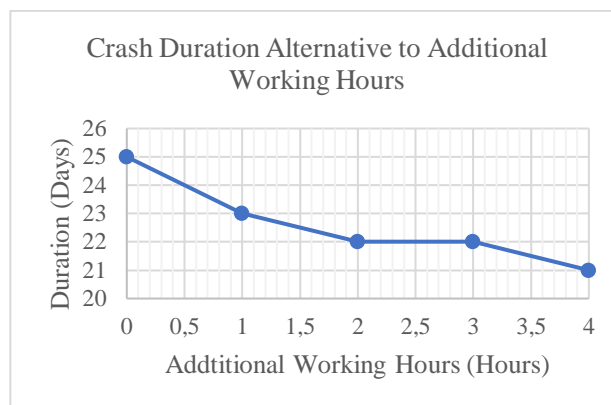


Figure 1. Crash Duration Alternative to Additional Working Hours

2) Calculation of Crash Duration after the addition of manpower

The crash duration value after adding manpower to

the MV Alfa Trans Satu Ship repair project, which is in a critical path can be seen in Table 9 below.

TABLE 9.  
 CALCULATION OF ALTERNATIVE CRASH DURATION FOR ADDING LABOR ON THE CRITICAL PATH

ID	Job Name	Job Volume	11%		20%		26%		30%	
			PPTK	CD	PPTK	CD	PPTK	CD	PPTK	CD
A1	Docking	1	1.11	1	1.20	1	1.26	1	1.30	1
A2	Ship in Dry Dock	12	1.11	11	1.20	10	1.26	10	1.30	9
A4	Ship Docked at Pier	13	1.11	12	1.20	11	1.26	10	1.30	10
A5	Sea Trial & Compasseren	1	1.11	1	1.20	1	1.26	1	1.30	1
C1	Scrapping	110	61.19	2	66.00	2	69.44	2	71.50	2
C2	High-Pressure Fresh Water Wash (Water Jet)	1450	268.85	5	290.00	5	305.10	5	314.17	5
C3	Sandblasting	1350	500.63	3	540.00	3	568.13	2	585.00	2
D1	Below the Waterline	10000	1854.17	5	2000.00	5	2104.17	5	2166.67	5
D2	Above the Waterline	7000	1557.50	4	1680.00	4	1767.50	4	1820.00	4
E1	Bolder Tali Mooring Single Bolder	16	1.48	11	1.60	10	1.68	10	1.73	9
M4	SpeedLog	1	0.56	2	0.60	2	0.63	2	0.65	2
M5	Gyro Compass	1	1.11	1	1.20	1	1.26	1	1.30	1
N1	Certificate Classes	1	1.11	1	1.20	1	1.26	1	1.30	1
N2	Statutory Certificate	1	1.11	1	1.20	1	1.26	1	1.30	1

Information:

PPTK : Productivity of Additional Labor

CD : Crash Duration (Days)

Based on the calculation of the alternative crash duration of additional labor on the critical path with a total normal duration of 25 days, the acceleration duration with the addition of 11% of the initial workforce is 23 days (8% faster than the normal

duration). The acceleration duration with the addition of 20% of the initial workforce is the same as the addition of 26%, which is for 22 days (12% faster than the normal duration). The duration of the acceleration with the addition of 30% of the initial workforce is 21 days (16% faster than the normal duration).

The following graph shows the results of calculating the alternative crash duration for adding labor to jobs in the critical path, which can be seen in Figure 2.

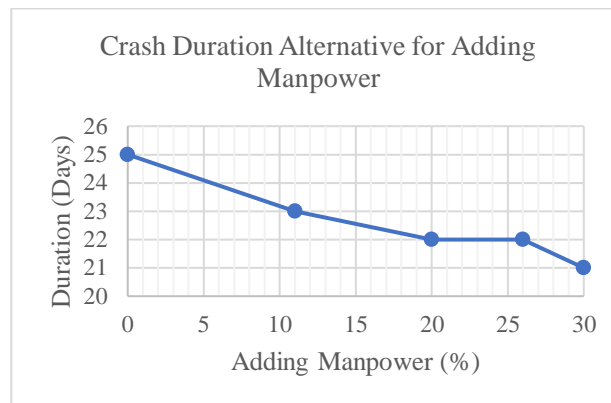


Figure 2. Crash Duration Alternative for Adding Manpower

#### F. Normal Cost Calculation

Normal cost is the cost that must be paid in carrying out a project within the normal time or duration of the project. The normal cost value is obtained from the formula:

$$NC = DN \times TK \times BTKN \quad (7)$$

Information:

NC : Normal Cost

DN : Normal Duration (Days)

TKN : Normal Workforce (Person)

BTKN : Normal Labor Costs

The following is the normal cost calculation for the MV Alfa Trans Satu Ship repair project, which is on a critical trajectory, as seen in Table 10.

TABLE 10.  
 CALCULATION OF NORMAL COST IN THE MV ALFA TRANS SATU SHIP REPAIR PROJECT

ID	Job Name	DN (Days)	TKN (Person)	BTKN	Normal Cost
A1	Docking	1	10	IDR 100,000	IDR 1,000,000
A2	Ship in Dry Dock	12	4	IDR 100,000	IDR 4,800,000
A3	Ship Docked at Pier	13	8	IDR 100,000	IDR 10,400,000
A4	Sea Trial & Compasseren	1	16	IDR 100,000	IDR 1,600,000
C1	Scrapping	2	5	IDR 100,000	IDR 1,000,000
C2	High-Pressure Fresh Water Wash (Water Jet)	6	5	IDR 100,000	IDR 3,000,000
C3	Sandblasting	3	7	IDR 100,000	IDR 2,100,000
D1	Below the Waterline	6	16	IDR 100,000	IDR 9,600,000
D2	Above the Waterline	5	18	IDR 100,000	IDR 9,000,000
E1	Bolder Tali Mooring Single Bolder	12	4	IDR 100,000	IDR 4,800,000
M4	SpeedLog	2	3	IDR 100,000	IDR 600,000
M5	Gyro Compass	1	3	IDR 100,000	IDR 300,000
N1	Certificate Classes	1	3	IDR 100,000	IDR 300,000
N2	Statutory Certificate	1	3	IDR 100,000	IDR 300,000

Information:

DN : Normal Duration (Days)

TKN : Normal Workforce (Person)

BTKN : Normal Daily Labor Costs

Based on the calculations in Table 10, the total normal cost for jobs in the critical path is IDR 48,800,000.

#### G. Crash Cost Calculation

Crash Cost is the cost that must be paid in carrying out a project after the acceleration of the duration has been carried out. The Crash Cost calculation is based

on two alternative additions to jobs in the critical path that have been implemented: additional working hours (overtime hours) and additional workforce.

#### 1) Calculation of Alternative Crash Cost for Additional Working Hours (Overtime Hours)

Based on Government Regulation no. 35 of 2021, Article 31 paragraph (1) states that companies that employ workers/laborers beyond their working hours, as required in Article 21 paragraph (2), are required to pay overtime wages with the following provisions [14]:



- a. For the first overtime hours of 1.5 (one point five) times the hourly wage; And  
b. For each subsequent overtime hour, 2 (two) times the hourly wage.

From the explanation above, the number of fees or wages for overtime hours per day, namely:

Normal fee per day = IDR 100,000  
Normal fee per hour = IDR 100,000/8 = IDR 12,500  
First hour overtime fee = 1.5 x IDR 12,500 = IDR 18,750 ≈ IDR 20,000  
Next hour overtime fee = 2 x IDR 18,750 = IDR 25,000  
2 hours overtime fee = IDR 20,000 + IDR 25,000 = IDR 45,000

3 hours overtime fee = IDR 20,000 + (2 x IDR 25,000) = IDR 75,000

4 hours overtime fee = IDR 20,000 + (3 x IDR 25,000) = IDR 95,000

The formula can calculate the Crash Cost of Additional Working Hours:

$$CC = NC + (TKN \times \text{Overtime Cost} \times CD) \quad (8)$$

Information:

TKN : Normal Workforce (Person)

CD : Crash Duration (Days)

CC : Crash Cost

The following is the calculation of overtime costs for the MV Alfa Trans Satu Ship repair project, which is on a critical trajectory, as seen in Table 11.

TABLE 11.  
CALCULATION OF ALTERNATIVE OVERTIME COSTS FOR ADDITIONAL WORKING HOURS (OVERTIME HOURS)

ID	Normal Cost	TKN	1 Hour		2 Hours		3 Hours		4 Hours	
			CD	TBL	CD	TBL	CD	TBL	CD	TBL
A1	IDR 1,000,000	10	1	IDR 200,000	1	IDR 450,000	1	IDR 700,000	1	IDR 950,000
A2	IDR 4,800,000	4	11	IDR 880,000	10	IDR 1,800,000	10	IDR 2,800,000	9	IDR 3,420,000
A4	IDR 10,400,000	8	12	IDR 1,920,000	11	IDR 3,960,000	10	IDR 5,600,000	10	IDR 7,600,000
A5	IDR 1,600,000	16	1	IDR 320,000	1	IDR 720,000	1	IDR 1,120,000	1	IDR 1,520,000
C1	IDR 1,000,000	5	2	IDR 200,000	2	IDR 450,000	2	IDR 700,000	2	IDR 950,000
C2	IDR 3,000,000	5	5	IDR 500,000	5	IDR 1,125,000	5	IDR 1,750,000	5	IDR 2,375,000
C3	IDR 2,100,000	7	3	IDR 420,000	3	IDR 945,000	2	IDR 980,000	2	IDR 1,330,000
D1	IDR 9,600,000	16	5	IDR 1,600,000	5	IDR 3,600,000	5	IDR 5,600,000	5	IDR 7,600,000
D2	IDR 9,000,000	18	4	IDR 1,440,000	4	IDR 3,240,000	4	IDR 5,040,000	4	IDR 6,840,000
E1	IDR 4,800,000	4	11	IDR 880,000	10	IDR 1,800,000	10	IDR 2,800,000	9	IDR 3,420,000
M4	IDR 600,000	3	2	IDR 120,000	2	IDR 270,000	2	IDR 420,000	2	IDR 570,000
M5	IDR 300,000	3	1	IDR 60,000	1	IDR 135,000	1	IDR 210,000	1	IDR 285,000
N1	IDR 300,000	3	1	IDR 60,000	1	IDR 135,000	1	IDR 210,000	1	IDR 285,000
N2	IDR 300,000	3	1	IDR 60,000	1	IDR 135,000	1	IDR 210,000	1	IDR 285,000

Information:

TKN : Normal Workforce (Person)

CD : Crash Duration (Days)

TBL : Total Overtime Cost

normal duration. The total crash cost of additional working hours (overtime) for 4 hours per day is IDR 86,230,000, an increase of 77% from the cost with normal duration.

## 2) Calculation of Alternative Crash Costs for Additional Labor

The formula can calculate the Crash Cost of Additional Labor:

$$CC = JTK \times BTKN \times CD \quad (9)$$

Information:

CC : Crash Cost

JTK : Number of Labor (Person)

BTKN : Normal Labor Costs

CD : Crash Duration (Days)

Based on the calculation results in Table 11, the total crash cost with the alternative of adding working hours (overtime) for 1 hour per day is IDR 57,460,000,000, an increase of 18% from the cost with normal duration. The total crash cost of additional working hours (overtime) for 2 hours per day is IDR 67,765,000, an increase of 38% from the cost with normal duration. The total crash cost of adding working hours (overtime) for 3 hours per day is IDR 76,940,000, an increase of 58% from the cost with

TABLE 12.  
 CALCULATION OF ALTERNATIVE CRASH COST FOR ADDITIONAL WORKING HOURS

ID	11%			20%			26%			30%		
	JTK	CD	CC	JTK	CD	CC	JTK	CD	CC	JTK	CD	CC
A1	11	1	IDR 1,100,000	12	1	IDR 1,200,000	13	1	IDR 1,300,000	13	1	IDR 1,300,000
A2	4	11	IDR 4,400,000	5	10	IDR 5,000,000	5	10	IDR 5,000,000	5	9	IDR 4,500,000
A4	9	12	IDR 10,800,000	10	11	IDR 11,000,000	10	10	IDR 10,000,000	10	10	IDR 10,000,000
A5	18	1	IDR 1,800,000	19	1	IDR 1,900,000	20	1	IDR 2,000,000	21	1	IDR 2,100,000
C1	6	2	IDR 1,200,000	6	2	IDR 1,200,000	6	2	IDR 1,200,000	7	2	IDR 1,400,000
C2	6	5	IDR 3,000,000	6	5	IDR 3,000,000	6	5	IDR 3,000,000	7	5	IDR 3,500,000
C3	8	3	IDR 2,400,000	8	3	IDR 2,400,000	9	2	IDR 1,800,000	9	2	IDR 1,800,000
D1	18	5	IDR 9,000,000	19	5	IDR 9,500,000	20	5	IDR 10,000,000	21	5	IDR 10,500,000
D2	20	4	IDR 8,000,000	22	4	IDR 8,800,000	23	4	IDR 9,200,000	23	4	IDR 9,200,000
E1	4	11	IDR 4,400,000	5	10	IDR 5,000,000	5	10	IDR 5,000,000	5	9	IDR 4,500,000
M4	3	2	IDR 600,000	4	2	IDR 800,000	4	2	IDR 800,000	4	2	IDR 800,000
M5	3	1	IDR 300,000	4	1	IDR 400,000	4	1	IDR 400,000	4	1	IDR 400,000
N1	3	1	IDR 300,000	4	1	IDR 400,000	4	1	IDR 400,000	4	1	IDR 400,000
N2	3	1	IDR 300,000	4	1	IDR 400,000	4	1	IDR 400,000	4	1	IDR 400,000

Information:

- JTK : Number of Labor (Person)
- CD : Crash Duration (Days)
- CC : Crash Cost

Based on Table 12, the total cost that must be paid with an alternative addition of labor (overtime) is 11% of the normal workforce, namely IDR 47,600,000, a decrease of 2% from the cost with normal duration. The total cost with the addition of labor (overtime) by 20% of the normal workforce, IDR 51,000,000, is an increase of 5% from the cost with normal duration.

The total cost with the addition of labor (overtime) is 26% of the normal workforce, IDR 50,500,000, a decrease of 3% from the cost with normal duration. The total cost with the addition of labor (overtime) by 30% of the normal workforce, IDR 50,800,000, is an increase of 4% from the cost with normal duration.

The following graph shows the results of alternative crash cost calculations for additional working hours (overtime hours) and additional labor for jobs in the critical path, which can be seen in Figure 3 and 4.

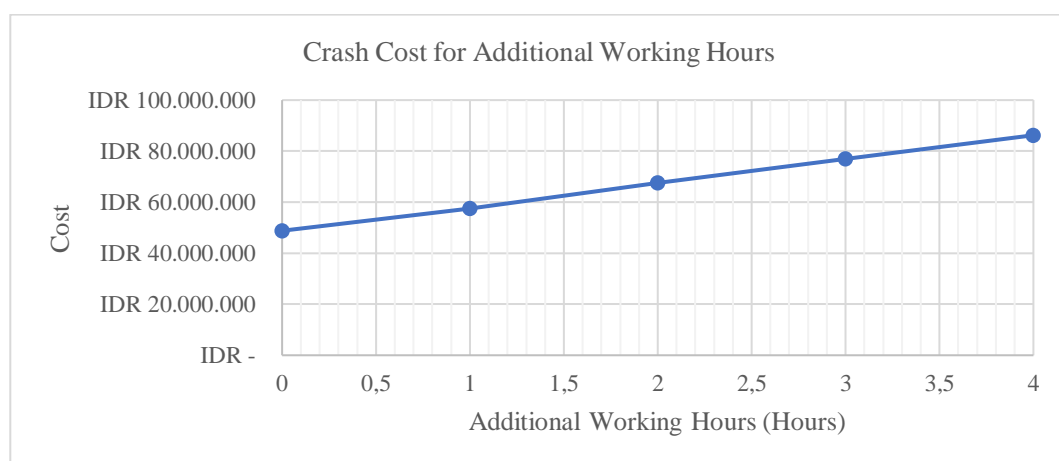


Figure 3. Crash Cost for Additional Working Hours

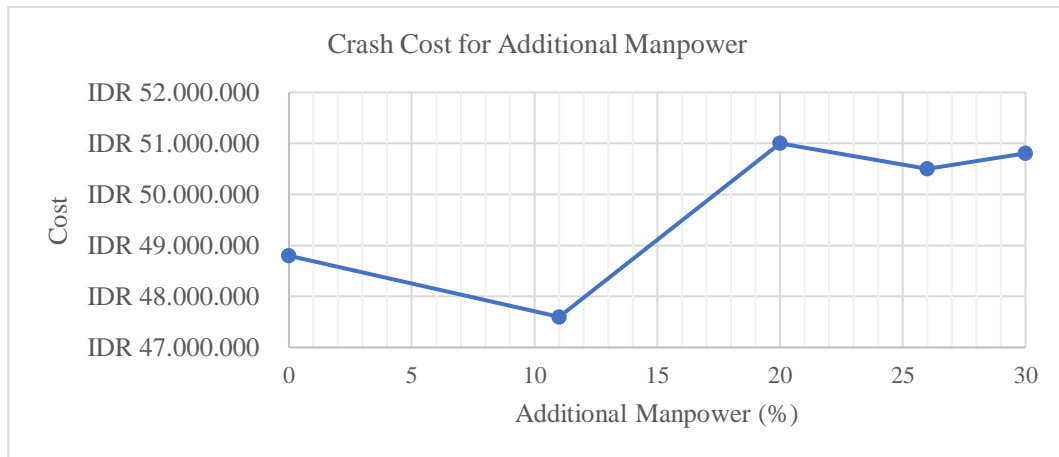


Figure 4. Crash Cost for Additional Manpower

H. Analysis with the Project Evaluation and Review Technique (PERT) Method

PERT uses a three-point estimate. Estimation of the activity period, namely the optimistic period (a), the realistic period (m), and the pessimistic period (b) [15]. This study uses the PERT method to calculate the probability or chance of success from crashing calculations that have been done before.

1) Expected Time, Variance, and Standard Deviation

Expected time is the time the work is expected to occur. Expected time can be calculated using the formula:

$$te = \frac{a + b + 4m}{6} \quad (10)$$

Example of expected time calculation for work that is in the critical path of MV Alfa Trans Satu Ship repair:

a (optimistic time) = 2 days  
m (realistic time) = 2 days  
b (pessimistic time) = 4 days

$$te = \frac{2+4+(4 \times 2)}{6} = 2$$

Determining the variance of work completion time can be calculated by the formula:

$$V(te) = \left(\frac{b - a}{6}\right)^2 \quad (11)$$

The standard deviation value is obtained from the total Variance value on jobs that are in the critical path, with the formula:

$$S = \sqrt{\left(\frac{b - a}{6}\right)^2} \quad (12)$$

Information:

te : Expected Time  
a : Optimistic Time  
m : Realistic Time  
b : Pessimistic Time  
V(te) : Variance  
S : Standard Deviation

TABLE 13.  
CALCULATION OF EXPECTED TIME VALUE AND VARIANCE ON CRITICAL PATH

ID	1 Hour & 11%					2 Hours & 20%					3 Hours & 26%					4 Hours & 30%				
	a	m	b	V(te)	te	a	m	b	V(te)	te	a	m	b	V(te)	te	a	m	b	V(te)	te
A1	1	1	2	0.03	1.17	1	1	2	0.03	1.17	1	1	2	0.03	1.17	1	1	2	0.03	1.17
A2	11	12	15	0.44	12.33	10	12	15	0.69	12.7	10	12	15	0.69	12.17	9	12	15	1.00	12.00
A3	12	13	15	0.25	13.17	11	13	15	0.44	13.00	10	13	15	0.69	12.83	10	13	15	0.69	12.83
A4	1	1	2	0.03	1.17	1	1	2	0.03	1.17	1	1	2	0.03	1.17	1	1	2	0.03	1.17
C1	2	2	4	0.11	2.33	2	2	4	0.11	2.33	2	2	4	0.11	2.33	2	2	4	0.11	2.33
C2	5	6	7	0.11	6.00	5	6	7	0.11	6.00	5	6	7	0.11	6.00	5	6	7	0.11	6.00
C3	3	3	4	0.03	3.17	3	3	4	0.03	3.17	2	3	4	0.11	3.00	2	3	4	0.11	3.00
D1	5	6	7	0.11	6.00	5	6	7	0.11	6.00	5	6	7	0.11	6.00	5	6	7	0.11	6.00
D2	4	5	6	0.11	5.00	4	5	6	0.11	5.00	4	5	6	0.11	5.00	4	5	6	0.11	5.00
E1	11	12	15	0.44	12.33	10	12	15	0.69	12.17	10	12	15	0.69	12.17	9	12	15	1.00	12.00
M4	2	2	3	0.03	2.17	2	2	3	0.03	2.17	2	2	3	0.03	2.17	2	2	3	0.03	2.17
M5	1	1	2	0.03	1.17	1	1	2	0.03	1.17	1	1	2	0.03	1.17	1	1	2	0.03	1.17
N1	1	1	2	0.03	1.17	1	1	2	0.03	1.17	1	1	2	0.03	1.17	1	1	2	0.03	1.17
N2	1	1	2	0.03	1.17	1	1	2	0.03	1.17	1	1	2	0.03	1.17	1	1	2	0.03	1.17

Information:

- a : Optimistic Time
- b : Pessimistic Time
- m : Realistic Time
- V(te) : Variance
- te : Expected Time

Based on Table 15, the calculation of the expected time and variance for critical path work on the MV Alfa Trans Satu Ship repair project, the total variance on the critical path with an additional working hour of 1 hour per day and an additional workforce of 11% of the initial workforce, namely 1.78 and a standard deviation value of 1.33. Total variance on the critical path with the addition of working hours for 2 hours per day and an additional workforce of 20% of the initial workforce, which is 2.47, and the standard deviation value obtained is 1.57. Total variance on the critical path with the addition of working hours for 3 hours per day and an additional workforce of 26% of the initial workforce, which is 2.81, and the standard deviation value obtained is 1.67. Total variance on the critical

path with the addition of working hours for 4 hours per day and an additional workforce of 30% of the initial workforce, which is 3.42, and the standard deviation value, which is 1.85.

2) Calculating Probability

Calculating a probability of the possibility that the project can be completed within the time limit of that day is done by using the formula equation:

$$Z = \frac{T(d) - TE}{S} \quad (12)$$

Information:

- Z : Probability
- T(d) : Normal Duration
- TE : Crash Duration
- S : Standard Deviation

The following is the probability calculation for the MV Alfa Trans Satu Ship repair project, as seen in Table 14.

TABLE 14.  
ACCELERATION PROBABILITY CALCULATION

	T(d) (Days)	TE (Days)	S	Z	Normal Distribution	Success Percentage (%)
A	25	23	1.33	1.50	0.9332	93.32%
B	25	22	1.57	1.91	0.9719	97.19%
C	25	22	1.67	1.79	0.9633	96.33%
D	25	21	1.85	2.16	0.9846	98.46%
E	25	23	1.33	1.50	0.9332	93.32%
F	25	22	1.57	1.91	0.9719	97.19%
G	25	22	1.67	1.79	0.9633	96.33%
H	25	21	1.85	2.16	0.9846	98.46%

Information:

- A : Acceleration with Additional Working Hours (Overtime Hours) For 1 Hour
- B : Acceleration with Additional Working Hours (Overtime Hours) For 2 Hours
- C : Acceleration with Additional Working Hours (Overtime Hours) For 3 Hours
- D : Acceleration with Additional Working Hours (Overtime Hours) For 4 Hours
- E : Acceleration with the addition of a workforce of 11% of the initial workforce

- F : Acceleration with the addition of a workforce of 20% of the initial workforce
- G : Acceleration with the addition of a workforce of 26% of the initial workforce
- H : Acceleration with the addition of a workforce of 30% of the initial workforce
- T(d) : Normal Duration
- TE : Crash Duration
- S : Standard Deviation
- Z : Probability

I. Analysis Results

The results of the analysis after the application of the Critical Path Method (CPM) and Project Evaluation and Review Technique (PERT) methods

with the alternative of additional working hours (overtime hours) and additional labor on the MV Alfa Trans Satu Ship repair project found on the critical path obtained the following data:

TABLE 15.  
CALCULATION RESULTS OF DURATION, PROBABILITY OF SUCCESS, AND COST

Variation	Additional Working Hours (Hours)	Additional Workforce (Person)	Duration (Days)	Percentage of Crash Duration (%)	Success Percentage (%)	Cost On Critical Path	Percentage Increase in Costs on Critical Path (%)
Normal	0	0	25	0	0	IDR 48,800,000	0
A	1	0	23	8	93.32	IDR 57,460,000	18
B	2	0	22	12	97.19	IDR 67,565,000	38
C	3	0	22	12	96.33	IDR 76,940,000	58
D	4	0	21	16	98.46	IDR 86,230,000	77
E	0	12	23	8	93.32	IDR 47,600,000	-2
F	0	21	22	12	97.19	IDR 51,000,000	5
G	0	28	22	12	96.33	IDR 50,500,000	3
H	0	32	21	16	98.46	IDR 50,800,000	4

Information:

- A: Acceleration with Additional Working Hours (Overtime Hours) For 1 Hour
- B: Acceleration with Additional Working Hours (Overtime Hours) For 2 Hours
- C: Acceleration with Additional Working Hours (Overtime Hours) For 3 Hours
- D: Acceleration with Additional Working Hours (Overtime Hours) For 4 Hours
- E: Acceleration with the addition of a workforce of 11% of the initial workforce
- F: Acceleration with the addition of a workforce of 20% of the initial workforce
- G: Acceleration with the addition of a workforce of 26% of the initial workforce
- H: Acceleration with the addition of a workforce of 30% of the initial workforce

Based on the calculation results in Table 15, the most optimal duration of acceleration with the addition of working hours is 4 hours per day, resulting in an acceleration duration of 21 days from the normal duration of 25 days. However, the cost increase for critical work was the greatest, amounting to IDR 86,230,000 or 77% of the normal cost. Meanwhile, the most optimal duration of acceleration is with the addition of a workforce of 32 Person (an increase of 30% from the initial workforce) because it produces a duration below the normal duration with a percentage increase in costs of only 4% of the normal cost for critical work, which is IDR 50,800,000.

After applying the PERT method based on the acceleration that was carried out in the previous method, where the initial duration of the project lasted 25 days to 21 days after the addition of working hours, namely 4 hours per day and also the addition of a workforce of 32 Person (an increase of 30% from the initial workforce), so, the two most optimum addition alternatives can be obtained, the probability of success

of this project can be completed within 21 days of 98.46%.

#### IV. CONCLUSION

Based on the crash duration calculation using the Critical Path Method (CPM), the most effective and efficient alternative that can be used to accelerate the MV Alfa Trans Satu Ship repair project is by adding a workforce of 32 Person (an increase of 30% from the initial workforce). This acceleration alternative produces a duration below the normal duration, 21 days from the initial 25 days.

The increase in costs for adding 32 Person (an increase of 30% from the initial workforce) is IDR 50,800,000 or 4% of the normal cost.

The probability of success for this project using the Project Evaluation and Review Technique (PERT) method can be completed within 21 days of 98.46%.

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