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Optimization of Time and Cost For Work Barge Repair Project Using Crashing Method With Trade-Off Cost At Pt Pasifik Karyasindo Perkasa

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Abstract: Ship repair projects are characterized by complex activities, interdependent work processes, and strict completion schedules. Delays in ship repair projects may result in increased operational costs, additional labor costs, and disruptions to the vessel's operational schedule. Therefore, an appropriate scheduling method is required to identify critical activities and determine efficient acceleration alternatives from both time and cost perspectives. This study aims to optimize the time and cost of a Work Barge repair project at PT Pasifik Karyasindo Perkasa by applying the Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), and the crashing method using the Time-Cost Trade-Off approach. The study focuses on accelerating the repair project through additional working hours or overtime without causing disproportionate increases in the project budget. CPM is applied to determine the project network, project duration, and critical activities, while PERT is used to estimate the expected project duration based on optimistic, most likely, and pessimistic time estimates and to determine the probability of project completion. Furthermore, crashing analysis is conducted by comparing normal and crash durations as well as normal and additional overtime costs. The efficiency of each acceleration alternative is determined based on the additional cost required for each unit of time reduction using the cost slope approach. The final analysis is intended to identify the optimal combination of project duration and cost, enabling project acceleration while maintaining cost efficiency and avoiding excessive budget increases.

Keywords: Critical Path Method, PERT, Crashing, Time-Cost Trade-Off, Ship Repair, Overtime

Indonesian Abstract: *Proyek perbaikan kapal ditandai dengan aktivitas yang kompleks, proses kerja yang saling bergantung, dan jadwal penyelesaian yang ketat. Keterlambatan* *dalam proyek perbaikan kapal dapat mengakibatkan kenaikan biaya operasional, biaya tenaga kerja tambahan, serta gangguan pada jadwal operasional kapal. Oleh karena itu, diperlukan metode penjadwalan yang tepat untuk mengidentifikasi aktivitas-aktivitas kritis dan menentukan alternatif percepatan yang efisien baik dari segi waktu maupun biaya. Penelitian ini bertujuan untuk mengoptimalkan waktu dan biaya proyek perbaikan Work Barge di PT Pasifik Karyasindo Perkasa dengan menerapkan Metode Jalur Kritis (CPM), Teknik Evaluasi dan Peninjauan Program (PERT), serta metode crashing menggunakan pendekatan Time-Cost Trade-Off. Penelitian ini berfokus pada percepatan proyek perbaikan melalui penambahan jam kerja atau lembur tanpa menyebabkan kenaikan anggaran proyek yang tidak proporsional. CPM diterapkan untuk menentukan jaringan proyek, durasi proyek, dan aktivitas kritis, sedangkan PERT digunakan untuk memperkirakan durasi proyek yang diharapkan berdasarkan perkiraan waktu optimis, paling mungkin, dan pesimis, serta untuk menentukan probabilitas penyelesaian proyek. Selain itu, analisis percepatan (crashing) dilakukan dengan membandingkan durasi normal dan durasi percepatan, serta biaya lembur normal dan biaya lembur tambahan. Efisiensi setiap alternatif percepatan ditentukan berdasarkan biaya tambahan yang diperlukan untuk setiap satuan pengurangan waktu menggunakan pendekatan cost slope. Analisis akhir ini bertujuan untuk mengidentifikasi kombinasi optimal antara durasi proyek dan biaya, sehingga memungkinkan percepatan proyek sambil mempertahankan efisiensi biaya dan menghindari kenaikan anggaran yang berlebihan.*

Keywords: Critical Path Method, PERT, Crashing, Time-Cost Trade-Off, Ship Repair, Overtime

INTRODUCTION

The shipbuilding and shipyard industry is one of the sectors characterized by project-based activities with relatively high levels of complexity. One of the major activities in the shipyard industry is ship repair, which involves various types of work, including inspection, docking, hull work, structural repair, mechanical work, piping, electrical work, painting, and final inspection. Each activity has a specific dependency relationship, meaning that delays in certain activities may affect subsequent activities and ultimately influence the overall project duration.

Ship repair projects also require relatively strict completion schedules because vessels undergoing repair cannot be used for operational activities during the repair process. The longer a vessel remains under repair, the greater the potential operational and financial losses incurred by both the vessel owner and the shipyard company. Therefore, time and cost control are important aspects in ensuring the successful implementation of ship repair projects.

In project implementation, schedule planning does not only determine the sequence of activities but also serves as a basis for controlling resource utilization. Identifying activities that have the greatest influence on project duration is necessary to ensure that acceleration efforts are properly targeted. One approach that can be applied is the Critical Path Method (CPM). CPM identifies the critical path based on the relationships among activities and their respective durations. Activities on the critical path have very limited time flexibility, meaning that delays in these activities may directly cause delays in the overall project.

In addition to CPM, the Program Evaluation and Review Technique (PERT) can be used to address uncertainty in activity durations. PERT applies three time estimates, namely optimistic, most likely, and pessimistic times. These estimates are used to determine the expected duration of each activity. Thus, PERT provides an estimation of the probability that a project can be completed within a specified target duration.

Previous studies on ship repair projects have demonstrated that the application of CPM and PERT can assist in identifying critical paths and evaluating project completion probabilities. A study of the MV Alfa Trans Satu repair project, for example, applied CPM and PERT to develop alternative schedules and accelerate the project through additional working hours and labor. Other research on ship repair projects has also shown that the Time-Cost Trade-Off approach can be used to evaluate acceleration alternatives through additional working hours and labor.

Project acceleration generally has cost implications. Additional working hours or overtime may shorten activity durations; however, they simultaneously increase labor costs. Therefore, acceleration decisions cannot be based solely on time considerations but must also account for the relationship between time and cost. This concept is known as Time-Cost Trade-Off, which refers to the analysis of the trade-off between reducing project duration and increasing costs resulting from acceleration.

The crashing method is one approach that can be used in Time-Cost Trade-Off analysis. Crashing is performed by allocating additional resources to selected activities in order to reduce their completion times. In this study, the acceleration alternative focuses on increasing working hours or overtime. Acceleration is prioritized for activities located on the critical path so that additional resources can directly contribute to reducing the overall project duration.

Previous research on ship repair and construction projects has also applied this approach. Studies on ship repair projects indicate that the Time-Cost Trade-Off method can be used to determine optimal acceleration alternatives through additional working hours. Other research on construction projects has shown that crashing through additional overtime hours can reduce project duration while considering changes in project costs.

PT Pasifik Karyasindo Perkasa, as a company involved in ship repair activities, requires effective schedule and cost control to ensure that the Work Barge repair project can be completed efficiently. The repair process consists of various activities with different levels of dependency, making a systematic approach necessary to determine which activities should be prioritized when acceleration is required.

Based on these conditions, this study integrates CPM, PERT, and the crashing method using the Time-Cost Trade-Off approach. CPM is applied to determine the project's critical path, PERT is used to estimate expected project duration and completion probability, while crashing is used to identify the most efficient acceleration alternative from a time and cost perspective.

The objectives of this study are:

1) To identify the project network and critical path of the Work Barge repair project at PT Pasifik Karyasindo Perkasa using the CPM method.
2) To determine the estimated project completion time using the PERT method.
3) To identify activities that can be accelerated through additional working hours or overtime.
4) To analyze the trade-off between project duration and cost resulting from acceleration using the crashing method and Time-Cost Trade-Off approach.
5) To determine the optimal project duration and cost alternative by considering acceleration efficiency and budget limitations.

METHODS

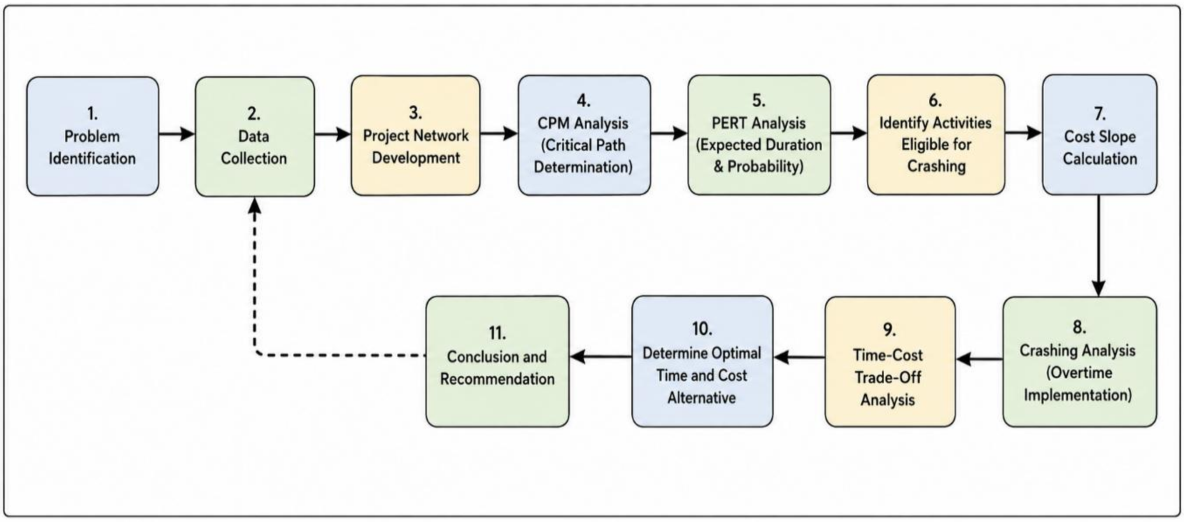
Research Design

This study employs a quantitative approach with a case study design applied to the Work Barge repair project at PT Pasifik Karyasindo Perkasa. The research is designed to optimize project duration and cost through the integration of the Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), and the crashing method using a Time-Cost Trade-

Off approach. The primary focus is to identify critical activities, accelerate project completion through additional overtime working hours, and evaluate the trade-off between time reduction and additional costs to determine the most efficient alternative.

The research data consist of primary and secondary data. Primary data are obtained through direct observation of the repair activities and semi-structured interviews with the project manager, supervisors, planners, and engineers involved in the project. Secondary data are obtained from project documents, including the Work Breakdown Structure (WBS), activity list, activity durations, precedence relationships, normal project costs, overtime costs, labor productivity, and project progress reports. These data are used as the basis for constructing the project network and conducting the subsequent time and cost analyses.

The research is conducted through a systematic sequence of analytical stages, beginning with problem identification and data collection, followed by project network development and CPM analysis to determine the critical path. PERT analysis is then conducted to estimate the expected project duration and probability of completion. Activities eligible for acceleration are subsequently identified, followed by cost slope calculation and crashing analysis through overtime implementation. Finally, a Time-Cost Trade-Off analysis is performed to compare alternative project durations and costs, resulting in the determination of the optimal time-cost combination and recommendations for project implementation.



Gambar 1.1 Research Design

Research Variables

The variables used in this study consist of project duration, project cost, project activities, critical activities, and project acceleration. These variables were selected to evaluate the relationship between project completion time and the additional costs incurred through overtime implementation.

Table 1. Research Variables

Variable	Indicator	Unit
Normal Duration	Activity completion time under normal working conditions	Days
Crash Duration	Minimum activity duration after acceleration	Days
Normal Cost	Activity cost under normal working conditions	IDR million
Crash Cost	Activity cost after acceleration	IDR million
Overtime Hours	Additional working hours per day	Hours
Overtime Cost	Additional cost resulting from overtime	IDR million
Critical Path	Activities with total float equal to zero	Activities
Cost Slope	Additional cost required for each day of time reduction	IDR million/day
Project Duration	Total project completion time	Days
Project Cost	Total project implementation cost	IDR million

Data Analysis Procedure

The data analysis was conducted through several systematic stages, beginning with the identification of project activities and continuing through CPM, PERT, crashing, and Time-Cost Trade-Off analysis.

Identification of Project Activities

The activities involved in the Work Barge repair project were identified based on the Work Breakdown Structure (WBS), project schedule, and sequence of work. Ten major activities were used in the analysis, consisting of preparation and inspection, hull cleaning, steel repair, mechanical repair, piping repair, welding and structural finishing, painting, electrical work, testing and commissioning, and final inspection.

Each activity was assigned a code, predecessor, normal duration, crash duration, normal cost, and crash cost.

Critical Path Method (CPM) Analysis

CPM was used to determine the Early Start (ES), Early Finish (EF), Late Start (LS), Late Finish (LF), and Total Float (TF) of each activity.

The Early Finish was calculated using:

$$EF = ES + D$$

Program Evaluation and Review Technique (PERT) Analysis

PERT was used to estimate the expected duration of the project by considering uncertainty in activity completion times. Three time estimates were applied: optimistic time (a), most likely time (m), and pessimistic time (b).

Identification of Activities for Crashing

Activities selected for crashing were activities located on the critical path and considered technically feasible for acceleration through overtime. The selection also considered the availability of labor, work characteristics, maximum overtime hours, and potential reduction in activity duration.

Cost Slope Calculation

The cost slope was calculated to determine the additional cost required to reduce the duration of each critical activity. The formula used was:

$$\text{Cost Slope} = (\text{Crash Cost} - \text{Normal Cost}) / (\text{Normal Duration} - \text{Crash Duration})$$

Activities with lower cost slopes were prioritized because they could provide greater time savings with relatively lower additional costs.

Crashing Through Additional Working Hours

The acceleration alternative was implemented through additional working hours. The analysis considered three overtime scenarios: one, two, and three additional working hours per day.

The revised duration was determined by considering the productivity obtained from normal working hours and additional overtime hours.

Time-Cost Trade-Off Analysis

Each acceleration scenario was compared based on project duration, time reduction, additional overtime cost, total project cost, and cost efficiency. The optimal alternative was determined by identifying the shortest feasible project duration while maintaining an acceptable increase in project cost.

RESULTS AND DISCUSSION

Results

Identification of Project Activities

Data were collected from one of the main production machines at PT Alcotraindo Batam during a six-month observation period (January–June 2026). The OEE calculation was conducted using the Availability Rate, Performance Rate, and Quality Rate indicators.

Table 2. Project Activity Data

Code	Activity	Pred	Normal Duration	Crash Duration	Normal Cost	Crash Cost
A	Preparation and Inspection	-	3	2	10.0	11.0
B	Hull Cleaning	A	4	3	8.0	8.8
C	Material Preparation	A	2	2	5.0	5.0
D	Steel Repair	B	5	3	12.0	13.4
E	Piping Repair	C	3	3	6.0	6.0
F	Welding and Structural Finishing	D, E	4	3	9.0	9.9
G	Painting	F	3	2	7.0	8.0
H	Electrical Work	G	4	2	8.0	10.0
I	Testing and Commissioning	H	3	2	6.0	7.0
J	Final Inspection	I	2	1	4.0	5.0
Total			33	23	75.0	84.1

The total normal direct project cost was IDR 75.0 million, while the total cost under the maximum crash condition was IDR 84.1 million. The total float of these activities is zero, indicating that any delay in these activities will directly affect the completion time of the entire project. Activities C and E are non-critical because they have positive float values of 2 and 4 days, respectively. Therefore, these activities are not prioritized for crashing.

PERT Analysis

PERT analysis was conducted using optimistic, most likely, and pessimistic duration estimates. The estimates for the critical activities are presented below.

Table 4. PERT Duration Estimation

Code	Activity	a	m	b	Te	Variance
A	Preparation and Inspection	2	3	5	3.17	0.25
B	Hull Cleaning	3	4	6	4.17	0.25
D	Steel Repair	4	5	7	5.17	0.25
F	Welding and Structural Finishing	3	4	6	4.17	0.25
G	Painting	2	3	5	3.17	0.25
H	Electrical Work	3	4	6	4.17	0.25
I	Testing and Commissioning	2	3	5	3.17	0.25
J	Final Inspection	1	2	4	2.17	0.25
Total					29.34	2.00

Based on the standard normal distribution, a Z value of approximately 0.47 corresponds to a completion probability of approximately 68.1%. This result indicates that the project has approximately a 68.1% probability of being completed within 30 days under the estimated PERT conditions.

Identification of Activities for Crashing

The activities considered for crashing were selected from the critical path. Activities C and E were excluded because they were not critical and therefore their acceleration would not directly reduce the overall project duration. The lowest cost slope was obtained for activity D (Steel Repair) at IDR 0.70 million/day, followed by activity B (Hull Cleaning) at IDR 0.80 million/day, and activity F (Welding and Structural Finishing) at IDR 0.90 million/day. Therefore, these activities were prioritized for the crashing process.

Time-Cost Trade-Off Analysis

The acceleration alternatives were then compared to determine the most efficient combination of project duration and cost.

Table 7. Time-Cost Trade-Off Analysis

Alternative	Overtime Scenario	Duration	Time Reduction	Total Cost	Additional Cost	Cost Increase
Normal	0 hours/day	28 days	0 day	75.00	0.00	0.00%
Alternative 1	1 hour/day	27 days	1 day	75.70	0.70	0.93%
Alternative 2	2 hours/day	26 days	2 days	76.40	1.40	1.87%
Alternative 3	2 hours/day + additional resource allocation	25 days	3 days	77.20	2.20	2.93%
Alternative 4	3 hours/day	24 days	4 days	78.10	3.10	4.13%

The results indicate that increasing overtime can reduce the project duration progressively. The normal project duration of 28 days can be reduced to 27 days with an additional cost of IDR 0.70 million. Further acceleration to 26 days requires a total additional cost of IDR 1.40 million.

The maximum analyzed acceleration reduces the project duration to 24 days, with a total project cost of IDR 78.10 million. This alternative provides a four-day reduction in project duration with an additional cost of only IDR 3.10 million, equivalent to 4.13% of the normal project cost.

From a time-cost perspective, the 24-day scenario provides the shortest project duration among the evaluated alternatives. However, the optimal alternative should ultimately be determined based on the actual project deadline and the company's maximum allowable budget for overtime.

If the project must be completed within 24–25 days, the 24-day acceleration scenario can be considered the most appropriate alternative because it provides the maximum time reduction while maintaining the total cost at IDR 78.10 million.

Discussion

The CPM analysis identified A–B–D–F–G–H–I–J as the critical path, with a normal project duration of 28 days. The existence of zero total float on these activities indicates that any delay in one of these activities will directly increase the overall project duration. Therefore, project control should primarily focus on these critical activities.

The PERT analysis resulted in an expected project duration of approximately 29.34 days, which is slightly longer than the deterministic CPM duration of 28 days. This difference occurs because PERT incorporates uncertainty through optimistic, most likely, and pessimistic duration estimates. The calculated standard deviation of 1.414 days indicates the variation associated with the estimated project duration.

With a 30-day completion target, the calculated Z value was 0.47, corresponding to a completion probability of approximately 68.1%. This indicates that although the deterministic CPM schedule indicates a 28-day duration, there remains uncertainty in the actual completion time. Consequently, schedule acceleration may be considered when the project has a strict completion deadline.

The cost slope analysis showed that Steel Repair (D) had the lowest cost slope of IDR 0.70 million/day. This means that reducing the duration of the steel repair activity by one day requires an additional cost of approximately IDR 0.70 million. Hull Cleaning (B) had the second-lowest cost slope at IDR 0.80 million/day, while Welding and Structural Finishing (F) had a cost slope of IDR 0.90 million/day.

Based on these results, the crashing sequence began with activity D, followed by activity B and activity F. This sequence is consistent with the Time-Cost Trade-Off principle because activities with lower additional costs per unit of time reduction are prioritized.

The crashing analysis demonstrated that the project duration could be reduced from 28 days to 24 days. The four-day reduction represents a 14.29% reduction in project duration. Meanwhile, the project cost increased from IDR 75.00 million to IDR 78.10 million, representing a cost increase of only 4.13%.

This finding demonstrates that overtime can provide a relatively efficient acceleration alternative when applied specifically to critical activities. However, increasing overtime indiscriminately across all activities would not necessarily produce the same efficiency. Acceleration should therefore be targeted at activities that directly influence the critical path.

The Time-Cost Trade-Off analysis also indicates that the shortest duration is not automatically the most economical alternative. The decision to accelerate should consider the relationship between the urgency of project completion and the additional costs that the company is willing to incur.

For PT Pasifik Karyasindo Perkasa, if the project completion target is 25 days, the third acceleration alternative with a project duration of 25 days and total cost of IDR 77.20 million can be selected. However, if the project requires the shortest possible duration within the analyzed scenarios, the 24-day alternative with a total cost of IDR 78.10 million provides the maximum time reduction.

Overall, the integration of CPM, PERT, crashing, and Time-Cost Trade-Off provides a systematic approach for optimizing the Work Barge repair schedule. CPM identifies the activities that determine project duration, PERT evaluates uncertainty, while crashing and Time-Cost Trade-Off determine the most efficient acceleration strategy.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the analysis, the optimization of the Work Barge repair project at PT Pasifik Karyasindo Perkasa can be conducted effectively by integrating the Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), crashing method, and Time-Cost Trade-Off analysis.

The CPM analysis identified the critical path as A–B–D–F–G–H–I–J, consisting of Preparation and Inspection, Hull Cleaning, Steel Repair, Welding and Structural Finishing, Painting, Electrical Work, Testing and Commissioning, and Final Inspection. These activities have a total float value of zero, indicating that any delay in one of these activities will directly affect the overall project completion time. Under normal conditions, the project requires 28 days with a total project cost of IDR 75.00 million.

The PERT analysis produced an expected project completion duration of approximately 29.34 days, with a project standard deviation of 1.414 days. With a target completion time of 30 days, the resulting Z-value was 0.47, corresponding to an estimated completion probability of approximately 68.1%. This finding indicates that project completion contains a degree of uncertainty and that schedule control is required to minimize the potential risk of delay.

The cost slope analysis showed that Steel Repair (Activity D) had the lowest cost slope, amounting to IDR 0.70 million/day, followed by Hull Cleaning (Activity B) at IDR 0.80 million/day and Welding and Structural Finishing (Activity F) at IDR 0.90 million/day. Therefore, these activities were prioritized during the crashing process because they provided relatively lower additional costs for each day of duration reduction.

The crashing analysis demonstrated that the project duration could be reduced from 28 days to 24 days, resulting in a total reduction of 4 days or 14.29%. This acceleration increased the total project cost from IDR 75.00 million to IDR 78.10 million, representing an additional cost of IDR 3.10 million or approximately 4.13% of the normal project cost. The results indicate that overtime-based acceleration can reduce project duration without causing a disproportionate increase in project cost when it is focused on critical activities.

The Time-Cost Trade-Off analysis showed that the 24-day alternative provides the shortest completion duration among the evaluated scenarios, with a total cost of IDR 78.10 million. However, the optimal alternative should be selected according to the actual project deadline and the maximum additional budget that can be allocated by the company. If the project requires completion within 24–25 days, the acceleration scenario resulting in a duration of 24 days can be considered the most appropriate alternative.

Overall, the integration of CPM, PERT, crashing, and Time-Cost Trade-Off provides a systematic approach to balancing project duration and cost. The results demonstrate that project acceleration should not be applied to all activities indiscriminately but should instead focus on critical activities with relatively low-cost slopes. This approach can assist PT Pasifik Karyasindo Perkasa in improving schedule reliability while maintaining cost efficiency in Work Barge repair projects.

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