JRSSEM 2025, Vol. 5, No. 01, 2090 – 2107
E-ISSN: 2807 - 6311, P-ISSN: 2807 - 6494

Analysis of Berths Acceleration Strengthening Project Regarding Time Control (Case Study of Container Terminal in Jakarta)

Irawan Jodarwanto*, Ervina Ahyudanari
Institut Teknologi Sepuluh Nopember, Indonesia
Email: irawanyod08@gmail.com*

Abstract.
Port infrastructure projects face unique challenges in maintaining operational continuity while executing complex structural modifications, especially in terminals operating 24 hours with strict time and technical constraints. The berthing reinforcement project at XYZ Container Terminal aimed to accommodate container ships up to 100,000 DWT and support the Super Post Panamax Quay Container Crane. Scheduled for 297 days, the project is located at an operational berth. During implementation, disruptions caused a -6.853% deviation in achievement weight in week 8 and risked delays. This research analyzes acceleration methods using the Critical Path Method, comparing Fast Track and Crashing techniques. Quantitative analysis with Microsoft Project includes adding drilling machines, adding labor (Crashing), and adjusting the Partial Hand Over (PHO) stages (Fast Track). Fast Track with PHO 2 stages accelerated completion to 296 days (0.34%) with a 0.10% cost increase; PHO 3 and 4 stages shortened it to 295 days (0.67%) with a 0.21% cost increase. Crashing shortened completion to 285 days (4.04%) but increased costs by 0.13%. The 4-stage PHO configuration shows superior operational efficiency by segmenting work areas to minimize disruptions, achieving faster completion than planned, and meeting Box Per Ship Per Hour (BSH) targets with minimal extra costs. This research offers a practical framework for selecting acceleration methods in port infrastructure projects requiring phased handovers and workspace optimization.

Keywords: Berth Strengthening; Crashing Project; Critical Path Method; Fast Track; Project acceleration.

INTRODUCTION

Cargo handling efficiency defined as the interplay between ship and port operations—is critical for maximizing cargo throughput, reducing ship turnaround times, and minimizing overall handling costs, thereby influencing global trade competitiveness (Burdzik et al., 2014; Luna et al., 2018; Onwuegbuchunam et al., 2021; Pérez et al., 2020; Pluhina et al., 2023; Val'kova et al., 2021). Modern ports must adopt advanced cargo handling systems to remain competitive internationally (Cao et al., 2018; Ivče et al., 2014; Nikolaieva et al., 2024; Oluwakoya & Ogundipe, 2022; Seo et al., 2024; Tubis et al., 2024). The Port of Tanjung Priok, operating its Container Terminal since 1978, expanded container throughput from 3,000 TEUs initially to over 2.2 million TEUs by 2004 (PT Pelabuhan Indonesia II).

Past studies have explored acceleration methods in construction, notably Fast Track and

DOI : 10.59141/jrssem.v5i1.969

Crashing, applied in port infrastructure and other sectors. These methods respectively prioritize phased handovers to maintain operations and resource intensification on critical activities to reduce project duration. This study uniquely integrates drill productivity optimization with Fast Track and Crashing techniques in a modular port project context—a first in port infrastructure project acceleration research. The case study focuses on the XYZ Container Terminal at Tanjung Priok, featuring a 32.73-hectare area and a 642-meter berth with -14 meters LWS depth. The Berthing Strengthening Project started on August 10, 2023, but by October 1 showed a -6.853% delay, particularly on the berth's east side, risking breach of the "Critical Contract" clause.

The research methodology involves leveraging Fast Track through Partial Hand Over (PHO) schemes by dividing the berth into segments, allowing simultaneous construction and operation to reduce operational disruption and enable partial revenue generation during construction. The Crashing method focuses on accelerating critical path activities by adding manpower and equipment to bottleneck tasks identified via Critical Path Method (CPM) analysis, providing cost-effective time reductions.

The study aims to analyze current project delays and critical factors; compare the effectiveness of Fast Track and Crashing methods in reducing duration; evaluate the cost implications of each; and recommend an optimal acceleration strategy balancing operational continuity, time savings, and cost efficiency. By developing a quantitative framework and decision matrix tailored for operational port environments with modular structures and 24-hour activity, this research supports practical decision-making in port infrastructure acceleration. It addresses urgent needs to minimize construction delays that threaten port competitiveness, vessel throughput, and long-term stakeholder relationships, thereby impacting Indonesia's position in global supply chains.

MATERIALS AND METHODS

The research aimed to accelerate the completion of the berthing reinforcement project with a minimum duration, as well as reduce the risk of lost revenue due to the borrowing of the berth and Quay Container Crane (QCC), as well as ad hoc ship berthing in the XYZ Container Terminal Berthing Strengthening Project. The methods used were Crashing and Fast Track to reduce project completion time through a planned, systematic, and analytical approach focused on testing all activities along the critical paths.

The research included planned and systematic steps to achieve optimal scheduling goals in maintenance. The process began with the collection of primary and secondary data, followed by data validation using the triangulation method, and the exploration of alternatives to accelerate project completion. Subsequently, the initial validation of the acceleration schemes was conducted, including the need for time control and the analysis of project acceleration methods.

Several Partial Hand Over (PHO) scenarios were analyzed, with emphasis on determining critical trajectories using Microsoft Project. Productivity and cost analyses were performed for each method, along with a comparison between the Crashing and Fast Track methods. Data validity was maintained through triangulation and interviews with sources to ensure accurate information.

This research was quantitative in nature, involving numerical data and statistical analysis to validate the results obtained. The study aimed to provide useful recommendations for project acceleration strategies.

RESULTS AND DISCUSSION

Crashing Method Analysis

Accelerated Work Duration and Cost Using the Crashing Method

The berthing strengthening project has activities that must be carried out systematically and interconnected. The explanation that the indirect cost is Rp 772,034,477.95 which includes Mobilization and Demobilization, Temporary Facilities (Project Office, Electricity, Working Water) and Insurance. Meanwhile, the direct cost of this berthing strengthening project is IDR 48,327,864,238.83.

Steps in the application of the Crashing method in this study:

1. Focus on reducing activities on critical lanes, considering that critical lanes are one of the causes of delays. Based on the analysis using Microsoft Project, the work of Reinforced Concrete Casting fc 35 Mpa for Concrete Beams and Slabs t=350 mm is in a critical trajectory, and is assumed to "have an impact in the acceleration of the project".
2. The application of the Crashing method uses the alternative of adding manpower to speed up the completion of activities. The assumption of increasing the number of workers is based on considering the area of work being done.

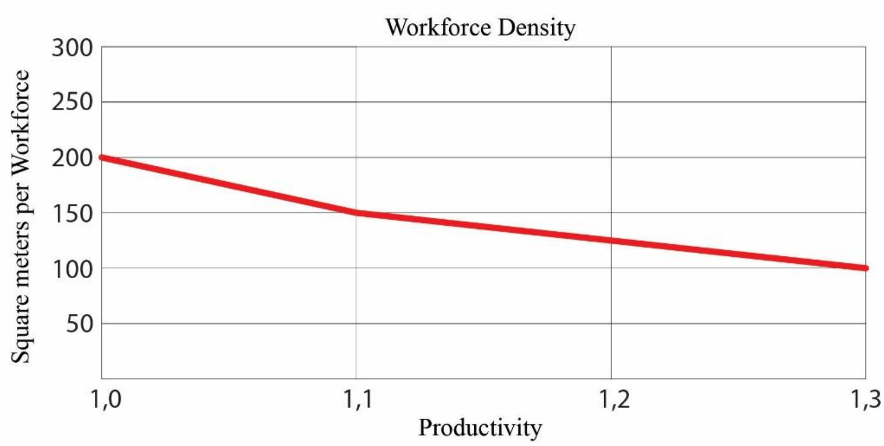


Figure 1. Labor Density with Productivity (Source: Suharto, 1995).

Figure 1, is the result of research for a medium-sized building project in the United States of America (USA), with an optimal point of 200 ft2/person with a maximum productivity index = 1, if the denser it is 150 ft2/person or 100 ft2/person, the productivity index will decrease.

The addition of labor for each segment is different, looking at working conditions and areas. In this berthing strengthening project, a "lumpsum" contract system is carried out for labor. Additional working hours are not calculated and the workforce is divided into 3 (three) shifts. For example, assuming the number of workers (including additions) in 1 work area is a maximum of 70 (seventy) people divided into 3 (three) shifts with 23 (twenty-three) shifts each as follows:

Scope of work area	=	11 m x 37 m	= 407 m2
Number of Workforce	=	23 people	
Area of work area	=	407/23	= 17.69 m2/person

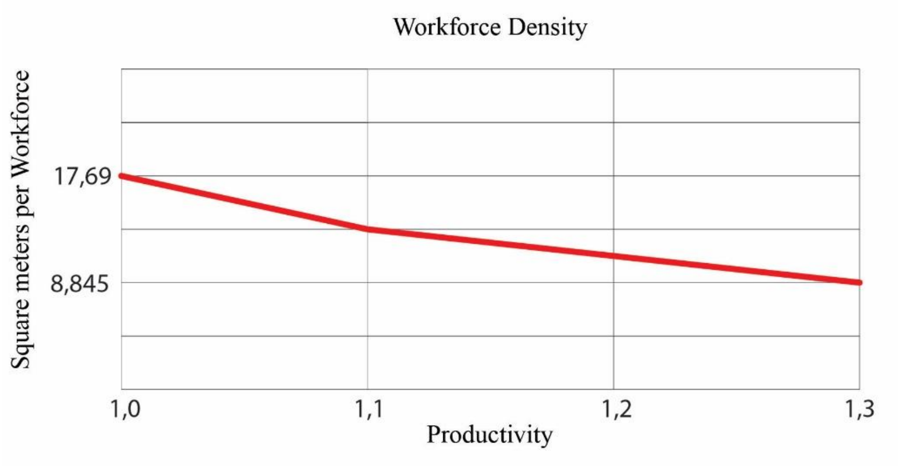


Figure 2. Labor Density with Productivity.

However, there has been no study on the effect of productivity decline with the density of the area of work per workforce for berthing projects in Indonesia (especially berthing projects that are carried out in "operating" loading and unloading conditions), so the maximum density basis is 17.69 m2/person with a productivity index = 1. If it is assumed that the decrease in labor productivity is 2 (two) times the addition of people, the area per workforce will be dense, namely 17.69/2 = 8.845 m2/person with a productivity index = 1.3 (figure 2).

Table 1. shows the amount of manpower used for the initial condition as well as the assumption of additional manpower, as the basis for calculating the Crashing method.

Table 1. Labor Addition on Critical Tracks.

No.	Job description	Initial Duration (days)	Number of Workers (people), Initial Conditions	Number of Workers (people), Additions	Additional Manpower (people)
I	**BERTH No # 1**				
	A **SEGMENT-1 (20 Points, BP No. 1-10)**				
	A5 Casting of reinforced concrete fc 35 Mpa				
	A5.4 Beam	23	18	29	11
	A5.5 **Slab t=350 mm**				
	A5.5.1 Berthing Slab	12	27	44	17
	A5.5.3 Lean Concrete	13	10	32	22
II	**BERTH No # 2**				
	A **SEGMEN-4 (20 Points, BP No. 30-39)**				
	A5 Casting of reinforced concrete fc 35 Mpa				
	A5.4 Beam	33	18	29	11
	A5.5 **Slab t=350 mm**				
	A5.5.1 Berthing Slab	27	27	44	17
	A5.5.3 Lean Concrete	33	10	70	60

Table 2. Initial Duration and Acceleration Duration (after the Crashing method).

No.	Job description	Initial Duration (days)	Acceleration Duration (days)
I	**BERTH No # 1**		
	A **SEGMEN-1 (20 Points, BP No. 1-10)**		
	A5 Casting of reinforced concrete fc 35 Mpa		
	A5.4 Beam	23	14
	A5.5 **Slab t=350 mm**		
	A5.5.1 Berthing Slab	12	7
	A5.5.3 Lean Concrete	13	4
II	**BERTH No # 2**		
	A **SEGMEN-4 (20 Points, BP No. 30-39)**		
	A5 Casting of reinforced concrete fc 35 Mpa		
	A5.4 Beam	33	20
	A5.5 **Slab t=350 mm**		
	A5.5.1 Berthing Slab	27	16
	A5.5.3 Lean Concrete	33	4
	B **SEGMEN-5 (20 Points, BP No. 40-49)**		
	B5 Casting of reinforced concrete fc 35 Mpa		
	B5.4 Beam	13	8
	B5.5 **Slab t=350 mm**		
	B5.5.1 Berthing Slab	12	7
	B5.5.3 Lean Concrete	12	4
IV	**BERTH No # 4**		
	A SEGMEN-7 (14 Points, BP No. 52-58)		
	A5.5 Beam	5	3
	A5.6 **Slab t=350 mm**		
	A5.6.1 Berthing Slab (Concrete, Fast Track 3 days)	2	1
	A5.6.3 Lean Concrete	2	1

Calculating Crash Duration, Crash Cost and Cost Slope

Table 3. Crashing daily Productivity value recapitulation.

No.	Job description			Normal Duration (Dn) (days)	Normal Duration (Dn) (m3/days)	Daily Productivity Crashing (m3/days)
I	**BERTH NO # 1**					
	A	**SEGMEN-1 (20 Points, BP No. 1-10)**				
	A5	Casting of reinforced concrete fc 35 Mpa				
	A5.4	Beam		23	1,71	2,76
	A5.5	**Slab t=350 mm**				
		A5.5.1	Berthing Slab	12	11,87	19,35
		A5.5.3	Lean Concrete	13	3,13	10,02
II	**BERTH NO # 2**					
	A	**SEGMEN-4 (20 Points, BP No. 30-39)**				
	A5	Casting of reinforced concrete fc 35 Mpa				
	A5.4	Beam		33	1,19	1,92
	A5.5	**Slab t=350 mm**				
		A5.5.1	Berthing Slab	27	5,28	8,60
		A5.5.3	Lean Concrete	33	1,23	8,63
	B	**SEGMEN-5 (20 Points, BP No. 40-49)**				
	B5	Casting of reinforced concrete fc 35 Mpa				
	B5.4	Beam		13	3,03	4,88
	B5.5	**Slab t=350 mm**				
		B5.5.1	Berthing Slab	12	11,87	19,35
		B5.5.3	Lean Concrete			
IV	**BERTH No # 4**					
	A	SEGMEN-7 (14 Points, BP No. 52-58)				
	A5.5	Beam		5	5,51	9,02
	A5.6	**Slab t=350 mm**				
		A5.6.1	Berthing Slab (Concrete, Fast Track 3days)	2	40,71	66,15
		A5.6.3	Lean Concrete	2	11,63	17,45

The calculation process to obtain the daily productivity of Crashing is followed by the calculation process of Crash Duration, Crash Cost and Cost Slope values for critical trajectory paths (table 4).

Table 4. A recapitulation of the values of Crash Duration, Crash Cost and Cost Slope.

No.	Job description			Acceleration Duration (Crash Duration, Cd) (days)	*Crash Cost* (CC) (Rp)	Duration = Dn - Cd (days)	*Cost Slope* (Rp/days)
I	**BERTH No # 1**						
	A	**SEGMEN-1 (20 Points, BP No. 1-10)**					
	A5	Casting of reinforced concrete fc 35 Mpa					
	A5.4	Beam		14,28	25.837.891	8,72	568.750
	A5.5	**Slab t=350 mm**					
		A5.5.1	Berthing Slab	7,36	722.432.240	4,64	856.250
		A5.5.3	Lean Concrete	4,06	20.853.798	8,94	625.000

No.	Job description			Acceleration Duration (Crash Duration, Cd) (days)	*Crash Cost* (CC) (Rp)	Duration = Dn - Cd (days)	*Cost Slope* (Rp/days)
	A	**SEGMEN-4 (20 Points, BP No. 30-39)**					
		A5	Casting of reinforced concrete fc 35 Mpa				
		A5.4	Beam	20,48	29.368.063	12,52	568.750
		A5.5	**Slab t=350 mm**				
		A5.5.1	Berthing Slab	16,57	730.313.632	10,43	856.250
		A5.5.3	Lean Concrete	4,71	24.723.218	28,29	1.359.375
	B	**SEGMEN-5 (20 Points, BP No. 40-49)**					
		B5	Pengecoran Casting of reinforced concrete fc 35 Mpa				
		B5.4	Beam	8,07	22.307.718	4,93	568.750
		B5.5	**Slab t=350 mm**				
		B5.5.1	Berthing Slab	7,36	722.432.240	4,64	856.250
		B5.5.3	Lean Concrete				
IV	**BERTH No # 4**						
	A	SEGMEN-7 (14 Points, BP No. 52-58)					
		A5.5	Beam	3,06	13.481.939	1,94	353.125
		A5.6	**Slab t=350 mm**				
		A5.6.1	Berthing Slab (Concrete, Fast Track 3 days)	1,23	409.949.328	0,77	512.500
		A5.6.3	Lean Concrete	1,33	10.705.699	0,67	178.125

Calculating Total Direct and Indirect Costs (Crashing)

From the calculation of the duration which refers to the value of the Cost Slope and Network Planning made based on the Crashing process, the calculation of direct costs, indirect costs and total costs for each duration of acceleration.

The stages of calculating total direct and indirect costs are as follows:

Table 5. Direct Cost (after the Crashing method).

No	Location	Direct Cost of Additional Labor (Rp)			Direct Cost (Rp) (d)	Direct Cost (after *Crashing)* (Rp) (a) + (b) + (c) + (d)
		Concrete Slab (a)	Concrete Beam (b)	Lean Concrete (c)		
1	Berth No # 1 segmen 1	6.825.000	10.275.000	7.500.000		
2	Bert No # 2 segmen 4	10.275.000	6.825.000	16.312.500		
3	Berth No # 2 segmen 5	10.275.000	6.825.000	7.050.000		
4	Berth No # 2 segmen 7	6.150.000	4.237.500	2.137.500		
	Total	33.525.000	28.162.500	33.000.000	48.327.864.238,83	48.422.551.739

Table 6. Indirect Costs (after the Crashing method).

No	Indirect Cost (Nomal Condition) (Rp) (a)	Project Duration (Normal Condition) (days) (b)	Project Duration (Acceleration) (days) (c)	Indirect Cost (after Crashing) (Rp) {(a) / (b)} x (c)
1	722.034.477,95	297	285	692.861.367,73

Table 7. Total Cost (after the Crashing method).

No	Direct Cost (after Crashing) (Rp) (a)	Indirect Cost (after Crashing) (Rp) (b)	Total Cost (after Crashing) (Rp) (a) + (b)
1	48.422.551.738,83	692.861.367,73	49.115.413.106,56

Recapitulation of Fast Track Method and Crashing Method

To provide a clear picture of the time and cost comparison between normal conditions and acceleration conditions, using the Fast Track method through Partial Hand Over (PHO) 2 (two) stages, 3 (three) stages and 4 (four) stages as well as the Crashing method, in terms of time and cost:

Table 8. Total Fast Track and Partial Hand Over (PHO) Cost 2 (two) stages to Normal Conditions.

No	Description	Normal Condition	**Fast Track PHO 2**	
			Total Cost (after Fast Track)	Cost Difference
1	Initial Cost (Rp)	49.049.898.716,78	49.100.657.673,53	50.758.956,76
2	Duration (days)	297	296	1

Table 9. Total Fast Track and Partial Hand Over (PHO) Cost 3 (three) stages against Normal Conditions.

No	Description	Normal Condition	**Fast Track PHO 3**	
			Total Cost (after Fast Track)	Cost Difference
1	Initial Cost (Rp)	49.049.898.716,78	49.151.416.630,29	101.517.913,51
2	Duration (days)	297	295	2

Table 10. Total Fast Track and Partial Hand Over (PHO) Costs 4 (four) stages against

Normal Conditions.

No	Description	Normal Condition	Fast Track PHO 4	
			Total Cost (after Fast Track)	Cost Difference
1	Initial Cost (Rp)	49.049.898.716,78	49.151.416.630,29	101.517.913,51
2	Duration (days)	297	295	2

Table 11. Total Cost (Crashing against Normal Conditions).

No	Description	Normal Condition	Crashing	
			Total Cost (after Crashing)	Cost Difference
1	Initial Cost (Rp)	49.049.898.716,78	49.115.413.106,56	65.514.389,78
2	Duration (days)	297	285	12

Analysis of Fast Track and Crashing Method Results

Normal Project Time and Cost Analysis

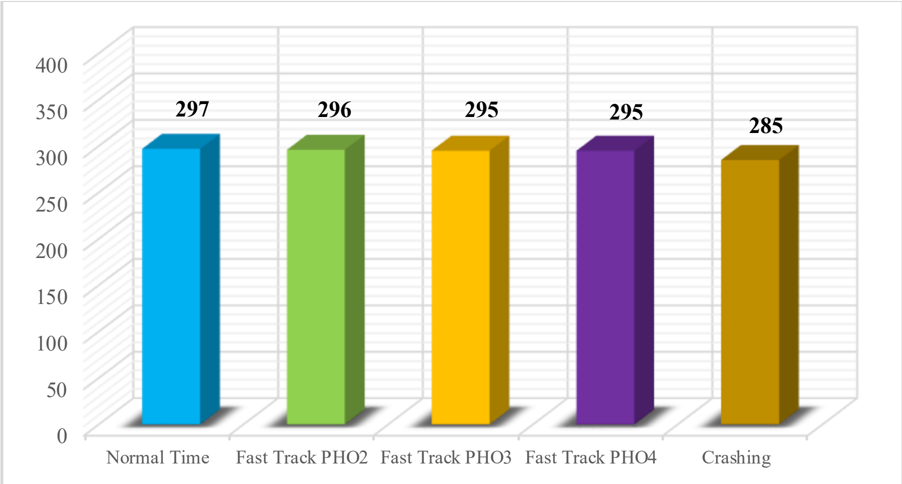
At the time of the research, the reinforcement project has a risk of delays. Based on the progress of week 8, there has been a delay because the achievement of the weight of achievement until October 1, 2023 (week 8) is – 6.853%.

If calculated with Microsoft Project according to the agreed upon work, the duration of the work is 297 (two hundred and ninety-seven) calendar days.

By creating a work network diagram in the form of a Precedence Diagram Method using Microsoft Project, critical activities that form a critical path (Critical Path) are obtained with a total cost of IDR 49,049,898,716.78, which consists of:

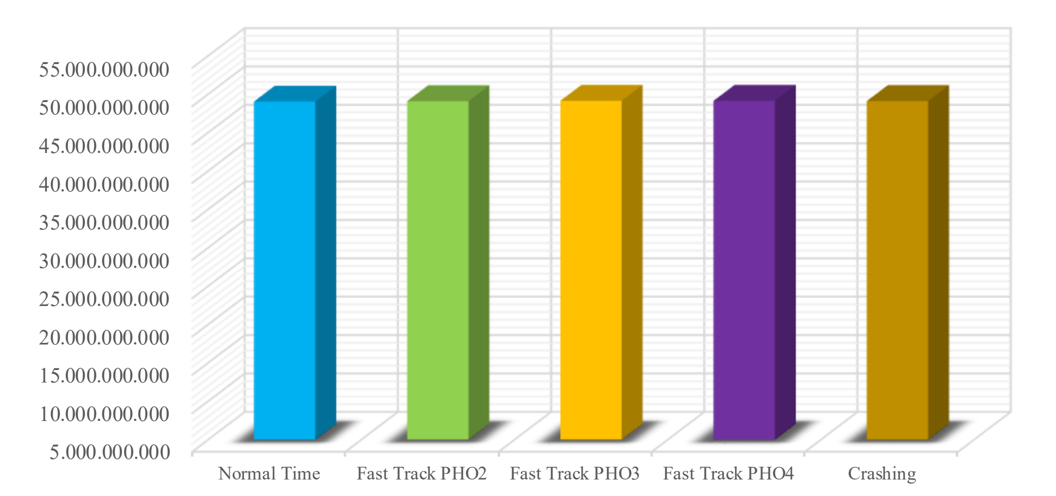
1. Direct Cost: IDR 48,327,864,238,83
2. Indirect Cost : IDR 722,034,477,95

Acceleration Time and Cost Analysis



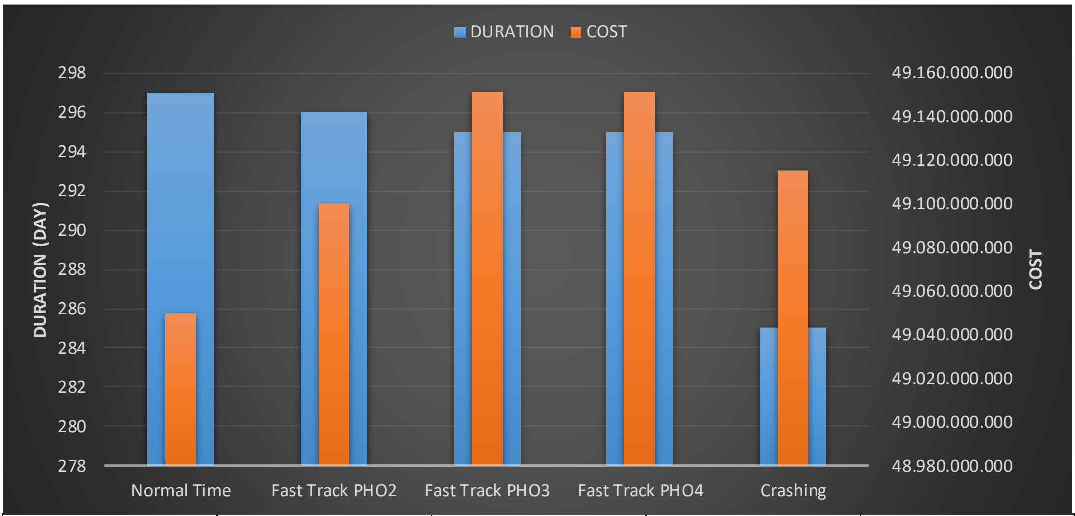
Normal Time	Fast Track PHO2	Fast Track PHO3	Fast Track PHO4	Crashing
297	296	295	295	285

Figure 3. Comparison of project durations.



Normal Time	Fast Track PHO2	Fast Track PHO3	Fast Track PHO4	Crashing
49.049.898.716	49.100.157.673	49.151.416.630	49.151.416.630	49.115.413.107

Figure 4. Project Cost Comparison.



Normal Time	Fast Track PHO2	Fast Track PHO3	Fast Track PHO4	Crashing
297	296	295	295	285
49.049.898.716	49.100.157.673	49.151.416.630	49.151.416.630	49.115.413.107

Figure 5. Comparison of Acceleration Duration versus Project Cost.

The acceleration process with the Fast Track method is carried out in 3 (three) stages of Partial Hand Over (PHO), namely:

1. With the Partial Hand Over (PHO) method 2 (two) stages, the project duration has accelerated to 296 (two hundred and ninety-six) from the initial plan of 297 (two hundred and ninety-seven) calendar days, or an acceleration of 0.34% from the initial plan. The total project cost changed to IDR 49,100,657,673.53 from the total initial cost of IDR 49,049,898,716.78 or an increase of 0.10%.
2. In the 3 (three) stage Partial Hand Over (PHO) method, there was an acceleration of the project duration to 295 (two hundred and ninety-five) days from the initial plan of 297 (two hundred and ninety-seven) days, or an acceleration of 0.67% from the initial plan. The total project cost changed to IDR 49,151,416,630.29 from the total initial cost of IDR 49,049,898,716.78 or an increase of 0.21%.
3. For the 4 (four) stage Partial Hand Over (PHO) method, the acceleration occurred in the project duration, namely the project duration to 295 (two hundred and ninety-five) days from the initial plan of 297 (two hundred and ninety-seven) days, or an acceleration of 0.67% from the initial plan. The total project cost changed to IDR 49,151,416,630.29 from the total initial cost of IDR 49,049,898,716.78 or an increase of 0.21%. In sub-chapter 4.3.3, it is explained that the duration of acceleration produced by Partial Hand Over (PHO) 3 (three) stages with Partial Hand Over (PHO) 4 (four) stages is the same, the handover of dock work 3 in Partial Hand Over (PHO) 4 stages, becomes a separate handover stage that is not affected by the handover of other dock works. This condition results in additions to the duration of the project.

In the Crashing acceleration process method, there is a change in the duration of the project with the following explanation:

1. Accelerating the duration of the project using the Crashing method is to add manpower to critical activities that have a significant impact on the duration of the project. The results obtained were that the project completion duration was 285 (two hundred and eighty-five) days (using Microsoft Project) from the initial plan of 297 (two hundred and ninety-seven) days, or an acceleration of 4.04% from the initial plan. The total project cost changed to IDR 49,115,413,106.56 from the total initial cost of IDR 49,049,898,716.78 or an increase of 0.13%.
2. The Crash Cost on the addition of labor for labor wages incurred due to the addition of labor is Rp 7,303,125, for 12 (twelve) days. The impact of changes in time and cost, from the conditions before the acceleration compared to the conditions after the acceleration was carried out, was an increase in the amount of direct costs by 0.20%, namely from IDR 48,327,864,238.83 to IDR 48,422,551,738. As for indirect costs, a decrease of 4.21%, from IDR 722,034,477.95 to IDR 692,861,367.73.

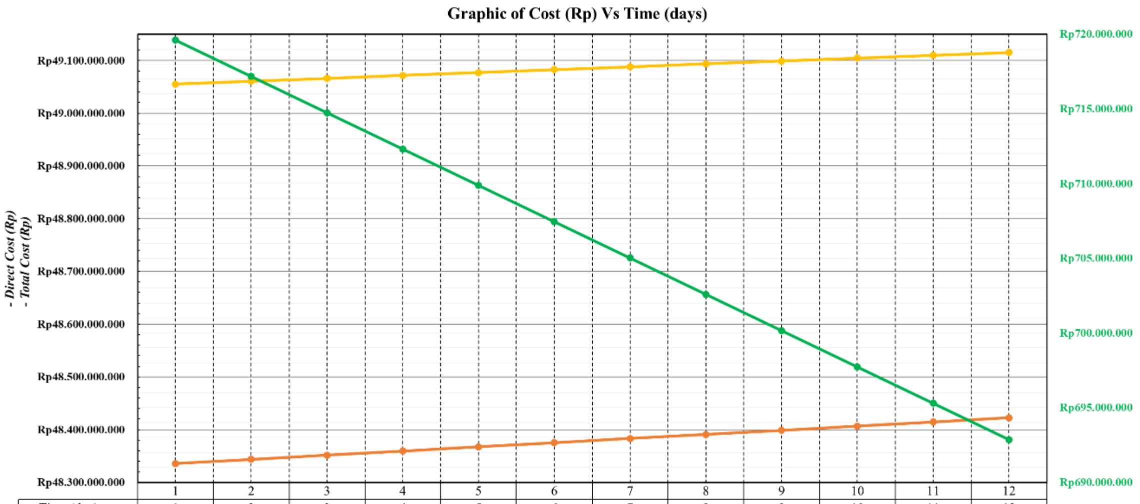
Time Cost Trade Off Analysis

Table 12. Direct Fees and Indirect Fees (12 days).

Duration (days)	Direct Cost (Rp)	Indirect Cost (Rp)	Total Cost (Rp)	Normal Cost (Rp)
1	48.335.754.864	719.603.385	49.055.358.249	49.049.898.716,78
2	48.343.645.489	717.172.293	49.060.817.782	49.049.898.716,78
3	48.351.536.114	714.741.200	49.066.277.314	49.049.898.716,78
4	48.359.426.739	712.310.108	49.071.736.847	49.049.898.716,78
5	48.367.317.364	709.879.015	49.077.196.379	49.049.898.716,78
6	48.375.207.989	707.447.923	49.082.655.912	49.049.898.716,78
7	48.383.098.614	705.016.830	49.088.115.444	49.049.898.716,78
8	48.390.989.239	702.585.738	49.093.574.977	49.049.898.716,78
9	48.398.879.864	700.154.645	49.099.034.509	49.049.898.716,78
10	48.406.770.489	697.723.553	49.104.494.042	49.049.898.716,78
11	48.414.661.114	695.292.460	49.109.953.574	49.049.898.716,78
12	48.422.551.739	692.861.368	49.115.413.107	49.049.898.716,78

Analysis Results:

1. Direct costs will increase, as the duration of the project increases. However, indirect costs will decrease if the project can be completed faster.
2. An increase in total costs does not necessarily provide an advantage in the implementation of accelerated project completion because the increase in direct costs is greater than the decrease in indirect costs.
3. The risk of acceleration can degrade quality, causing physical and mental fatigue which has an impact on decreasing motivation and performance of the workforce so that it is necessary to strengthen risk management and quality control.



Time (day)	1	2	3	4	5	6	7	8	9	10	11	12
Direct Cost (Rp)	48.335.754	48.343.645	48.351.536	48.359.426	48.367.317	48.375.207	48.383.098	48.390.989	48.398.879	48.406.770	48.414.661	48.422.551
Total Cost(Rp)	49.055.358	49.060.817	49.066.277	49.071.736	49.077.196	49.082.655	49.088.115	49.093.574	49.099.034	49.104.494	49.109.953	49.115.413
Indirect Cost (Rp)	719.603.38	717.172.29	714.741.20	712.310.10	709.879.01	707.447.92	705.016.83	702.585.73	700.154.64	697.723.55	695.292.46	692.861.36

Figure 6. Cost (Rp) versus Time (Day) Graph.

Discussion

The findings of this research align with several previous studies while contributing unique insights to port project acceleration. The achieved time acceleration of 4.04% through the Crashing method correlates with Ahmad Fajarsyah Akhirudin's (2018, 2020) findings that showed Fast Track methods could achieve 15-25% time savings in construction projects, though the modest acceleration in this study reflects the constraints of operational port environments where work areas are limited and construction must accommodate ongoing operations.

The effectiveness of Partial Hand Over (PHO) strategies demonstrated in this research supports the findings of Yeremia Brayen Mokalu et al. (2022), who showed that phased handover approaches could maintain operational continuity while achieving project acceleration. However, this study extends their work by quantifying the optimal number of PHO stages (4 stages proving most effective) and providing cost-benefit analysis specific to port infrastructure.

The productivity analysis using labor density calculations builds upon Suharto's (1995) foundational work on labor productivity relationships, but adapts these principles to the unique constraints of port construction where space limitations and safety requirements for operational terminals create different productivity parameters. The finding that 17.69 m^2/person provides optimal productivity aligns with international standards while accounting for the specialized nature of marine construction.

The time-cost trade-off analysis validates the theoretical framework established by Joseph J. Moder et al. (1983) in their seminal work on CPM applications, demonstrating that optimal acceleration requires balancing direct cost increases against indirect cost savings. The research extends this framework by incorporating operational revenue considerations specific to port facilities, where delayed completion results in measurable throughput losses.

The integration of Fast Track and Crashing methods addresses a gap identified in previous literature, where most studies examine these techniques in isolation. The research demonstrates that combined application can optimize results, with Fast Track providing operational continuity and Crashing addressing critical bottlenecks, supporting the integrated approach advocated by contemporary project management literature.

CONCLUSIONS

The analysis of acceleration methods for the berthing strengthening project successfully achieved the research objectives by demonstrating that both Fast Track and Crashing methodologies can effectively address project delays, with the 4-stage PHO configuration emerging as the optimal solution for balancing time acceleration, cost efficiency, and operational continuity. The research revealed that while the Crashing method achieved superior time acceleration (4.04% reduction to 285 days), the 4-stage PHO Fast Track approach provided better overall value by reducing duration to 295 days with minimal cost increase (0.21%) while maintaining operational flexibility and achieving BSH targets with reduced disruption. The study contributes to project management literature by providing the first integrated framework for comparing acceleration methods in operational port environments, establishing quantitative benchmarks for PHO optimization, and demonstrating the effectiveness of combined methodologies in complex infrastructure projects. Future research should explore the application of this integrated acceleration framework to other types of port infrastructure projects, investigate the long-term impacts of acceleration methods on structural performance and maintenance requirements, and develop automated decision-support systems for real-time optimization of acceleration strategies based on operational demands and resource availability, thereby advancing the field of port construction project management and providing practical tools for industry application in similar operational environments worldwide.

REFERENCES

Akhirudin, A. F. (2018). Percepatan waktu pengerjaan proyek konstruksi dengan menggunakan metode fast track. *Jurnal Teknis Sipil, 13*(1).

Akhirudin, A. F. (2020). Percepatan waktu pengerjaan proyek konstruksi dengan menggunakan metode fast track. *Jurnal Pendidikan Teknik dan Vokasional, 3*(2), 77–91. https://doi.org/10.21009/JPTV.3.2.77

Branch, A. E. (1986). *Elements of port operation and management*. Chapman and Hall.

Burdzik, R., Ciesla, M., & Sładkowski, A. (2014). Cargo loading and unloading efficiency analysis in multimodal transport. *Promet - Traffic and Transportation, 26*(4). https://doi.org/10.7307/ptt.v26i4.1356

Cao, J., Zhang, X., Yang, G., & Zou, X. (2018). Robust control of pressure for LNG carrier cargo handling system via mirror-mapping approach. *Complexity, 2018*. https://doi.org/10.1155/2018/7465391

Ivče, R., Jurdana, I., & Kos, S. (2014). Ship's cargo handling system with the optical fiber sensor technology application. *Pomorstvo, 28*(2).

Luna, J. H., Mar-Ortiz, J., Gracia, M. D., & Morales-Ramírez, D. (2018). An efficiency analysis of cargo-handling operations at container terminals. *Maritime Economics and Logistics, 20*(2). https://doi.org/10.1057/s41278-017-0074-8

Moder, J. J., Phillips, C. R., & Davis, E. W. (1983). *Project management with critical path method (CPM), PERT and precedence diagram*. Van Nostrand Reinhold Company Inc.

Mokalu, Y. B., Arsjad, T. T., & Malingkas, G. Y. (2022). Analisis percepatan proyek dengan menggunakan metode "fast track" (studi kasus: Proyek pembangunan mall pelayanan publik Manado). *Tekno, 20*(82).

Nikolaieva, L. L., Omelchenko, T. Y., & Haichenia, O. V. (2024). Hierarchical Management System for Container Vessels Automated Cargo Handling. *Journal of Eta Maritime Science, 12*(1). https://doi.org/10.4274/jems.2023.32858

Oluwakoya, A. O., & Ogundipe, S. (2022). Socioeconomic Characteristics and Perspectives on Cargo Handling: A Study of Tin Can Island Port, Apapa, Nigeria. *Transactions on Maritime Science, 11*(2). https://doi.org/10.7225/toms.v11.n02.016

Onwuegbuchunam, D. E., Okeke, K. O., Aponjolosun, M. O., Igboanusi, C., & Nwosu, A. C. (2021). Utilization of Cargo Handling Facilities in Nigerian Seaports. *Open Journal of Safety Science and Technology, 11*(04). https://doi.org/10.4236/ojsst.2021.114010

Pérez, I., González, M. M., & Trujillo, L. (2020). Do specialisation and port size affect port efficiency? Evidence from cargo handling service in Spanish ports. *Transportation Research Part A: Policy and Practice, 138*. https://doi.org/10.1016/j.tra.2020.05.022

Pluhina, T., Yefymenko, O., & Yefymenko, A. (2023). Increasing the efficiency of cargo handling at a modern warehouse terminal. *Bulletin of Kharkov National Automobile and Highway University, 2*(101). https://doi.org/10.30977/bul.2219-5548.2023.101.2.13-19

Seo, Y. S., Chung, S. M., & Park, J. C. (2024). Multiphase-thermal flow simulation in a straight vacuum-insulated LH2 pipe: Cargo handling system in LH2 carrier. *Ocean Engineering, 297*. https://doi.org/10.1016/j.oceaneng.2024.117030

Tubis, A. A., Jodejko-Pietruczuk, A., & Nowakowski, T. (2024). Use of Augmented Reality as a Tool to Support Cargo Handling Operations at the CARGO Air Terminal. *Sensors, 24*(4). https://doi.org/10.3390/s24041099

Val'kova, S. S., Stepanets, V. E., & Kiseleva, E. V. (2021). Comparative evaluation of efficiency and justification of choosing option of cargo handling in port. *Vestnik of Astrakhan State Technical University. Series: Marine Engineering and Technologies, 2021*(3). https://doi.org/10.24143/2073-1574-2021-3-107-115