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Acceleration of Modular Oil and Gas Project Duration Using the Time-Cost Trade-Off Method

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Abstract

Floating Production Storage and Offloading (FPSO) is an offshore floating platform designed to process and store oil Floating Production Storage and Offloading (FPSO) is a type of floating offshore platform that functions to process and store oil and gas before being distributed to consumers. A critical component of the FPSO, designed to ensure the product can be safely processed and transported, is the topside module. Currently, the Seawater Filtration Module project is facing delay challenges that impact both project cost and completion time. Using the existing case study, this research applies the Critical Path Method (CPM) to identify the critical path within the overall project schedule, as well as the Program Evaluation and Review Technique (PERT) to manage uncertainties in the completion time of critical activities. To evaluate the acceleration strategy with consideration of additional costs, the Time-Cost Trade-Off (TCTO) method is employed. The research findings indicate that the project experienced a 51-day delay from the original schedule, which targeted completion by January 31, 2024. A total of 11 activities were identified as part of the critical path contributing to the delay. To address this issue, acceleration was carried out by adding labor based on the productivity of each activity. The results show that the addition of 17 workers successfully reduced the duration of critical activities from 721 days to 670 days. Probability analysis indicated a success rate of 82.64% for the acceleration effort. Meanwhile, the cost calculation showed that the acceleration required an additional expense of Rp 30,913,709.

Introduction

Floating Production Storage and Offloading (FPSO) is an alternative to fixed platforms in offshore oil and gas production, with the modular topside being a crucial structure for processing, storage, and distribution of production output (Mufti et al., 2014; Oluwatayo et al., 2024; Rodrigues et al., 2025). These modules are constructed separately and installed in stages to enhance installation efficiency (Terpstra et al., 2001; Rajanayagam et al., 2024; Li et al., 2024). Modular projects require collaboration between engineering disciplines and project management, as delays can significantly impact project costs and completion (Shehata & El-Gohary, 2011). Although delays are common and difficult to predict (Yang & Kao, 2012), various project management strategies are needed to minimize their effects (Babu & Suresh, 1996). Numerous methods have been developed to analyze delays, yet none are

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perfect due to inherent assumptions and subjective judgments (Bordoli & Baldwin, 1998; Kim et al., 2005; Farrow, 2007).

Delay analysis in FPSO projects has shown that construction disruptions, weak management systems, and engineering design delays are the main causes of delays in FPSO conversion projects, with a probability of delay reaching 0.045 (Silvianita et al., 2025a). These risks not only affect project timelines but also pose potential financial losses of over USD 20 million if not properly addressed. In the context of other offshore structures, such as the loadout of jacket structures, fuzzy logic methods and Fuzzy Failure Mode and Effect Analysis (FFMEA) have been successfully used to systematically identify and mitigate workplace accident risks (Silvianita et al., 2024; Jamaluddin et al., 2024; Feng et al., 2024).

Project acceleration can be achieved through crashing, but cost factors must be considered (Andiyan et al., 2021; Farchan et al., 2025; Sari et al., 2025). Especially for large and complex projects that demand significant time and financial resources (Belay et al., 2016; Olorunyomi et al., 2024; Shahzad & Jasińska, 2024). One effective method to address delays is network analysis, such as the Critical Path Method (CPM), which identifies critical activities and determines the minimum project completion time (Zareei, 2018; Kusumadarma et al., 2020). CPM develops project schedules through activity networks and monitors project progress (Fox & Spence, 1998). Critical activities those with zero float (TF = 0) must be closely managed to prevent project duration extensions (Zareei, 2018; Chen et al., 2025; Xue et al., 2025).

To manage uncertainty in activity durations, the Program Evaluation and Review Technique (PERT) is used because it offers a probabilistic approach with three time estimates: optimistic, most likely, and pessimistic. PERT has been shown to improve scheduling accuracy in dynamic project environments (Joslin & Müller, 2016). In addition to time, project scheduling must also account for cost. The Time-Cost Trade-Off (TCTO) method is effective for evaluating acceleration alternatives for critical activities by considering additional costs (Ammar, 2011; Baptiste & Demassey, 2004). In complex modular projects, acceleration can be achieved by adding resources, though this comes with increased cost implications.

Previous studies have applied CPM, PERT, and TCTO methods across various sectors. Purnomo et al. (2023) and Adam et al. (2023) used CPM and TCTO to accelerate building and electrical network projects; Zareei (2018) explored CPM efficiency in a biogas project; Mazlum & Güneri (2015) applied fuzzy-PERT to reduce time uncertainty; and Doloi et al. (2012) analyzed delay factors using a risk-based approach in construction projects. Furthermore, Anderson et al. (2011) highlighted project acceleration in highway projects through stakeholder collaboration, and Farrow (2007) reviewed the legal and conceptual evolution of delay analysis methods.

However, no previous studies have comprehensively integrated CPM, PERT, and TCTO methods in complex, high-risk FPSO modular projects. This research adopts a quantitative approach based on actual field data and applies probabilistic methods to address uncertainty. The integration of these three methods is expected to provide a more realistic and practical solution to the challenges of project duration acceleration and cost control in offshore oil and gas modular projects.

Limitations

To maintain focus and avoid discussions beyond the research scope, this study applies several assumptions. First, the analysis focuses on the stages from modular structural fabrication to the loadout process in the fabrication yard. Second, cost calculations only include direct costs related to ongoing critical activities. Third, extreme weather factors that may affect the overall process are excluded from this analysis.

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Literature Review

The study conducted by Purnomo et al. (2023) on the construction project of the OPD Raci Office Building emphasized time and cost analysis using the Critical Path Method (CPM) and Time-Cost Trade-Off (TCTO) methods. By implementing an overtime strategy on critical activities, the project duration was successfully reduced by 8 days. This study is relevant as it demonstrates how time and cost analysis can be utilized for acceleration, even though the project context differs building construction compared to modular FPSO projects. Meanwhile, Adam et al. (2023) applied TCTO in a 275 kV SUTET interconnection network project as a solution to delays in tower erection. This acceleration reduced the project duration from 42 to 36 days. The commonality lies in the use of TCTO for time efficiency, although the power infrastructure project belongs to a different sector than the more complex oil and gas sector.

Furthermore, Zareei (2018) examined biogas plant project scheduling using CPM and emphasized the importance of identifying the critical path. Although the approach proved effective for mid-scale projects, the deterministic method used lacks adaptability to the high uncertainty present in modular FPSO projects. Therefore, this study integrates CPM with the probabilistic PERT approach and TCTO analysis to accommodate time and cost variability. Mazlum and Güneri (2015) also developed a scheduling approach combining CPM, PERT, and fuzzy methods. While the fuzzy approach offers additional insights for managing uncertainty, this study opts for a purely probabilistic approach without fuzzy logic to maintain simplicity and practicality in large-scale, complex projects like modular FPSO.

In a broader context, Doloi et al. (2012) evaluated factors contributing to delays in construction projects in India using a regression model. Although they did not directly use CPM or TCTO, their study highlights the importance of risk identification and delay causes, which inspired the strengthening of the risk management aspect in this research. Anderson et al. (2011) emphasized the importance of stakeholder collaboration as well as incentives and disincentives in highway project acceleration in the United States. Although their approach is more managerial, the strategic value of collaboration remains relevant for modular FPSO projects, even though this study focuses primarily on technical and field-data-based approaches. Lastly, Farrow (2007) discussed delay analysis in construction projects from a legal and qualitative perspective. While his research contributes conceptually, this study, in the context of modular FPSO projects that require high precision, reinforces the approach with empirical data through CPM, PERT, and TCTO to offer more measurable and practical acceleration solutions.

Methods

This study employs an integration of CPM, PERT, and TCTO methods to address uncertainty in the Seawater Filtration Module project by enabling more accurate scheduling and acceleration solutions with optimal costs. The research is exploratory in nature, as it investigates actual delay phenomena in modular projects within the offshore oil and gas industry, as well as their impact on time and cost. A quantitative approach is used to objectively and measurably analyze numerical field data, allowing for modeling and simulation of various project acceleration scenarios. With valid data, the outcomes of this research are expected to serve as a strong foundation for better-informed decision-making in similar future project management cases.

A visual representation that illustrates the stages of the research process from start to finish is known as a research flowchart. This diagram aids in organizing and communicating the methods, steps, and decisions involved throughout the study. Accordingly, systematic and detailed steps are carried out as illustrated in the diagram below.

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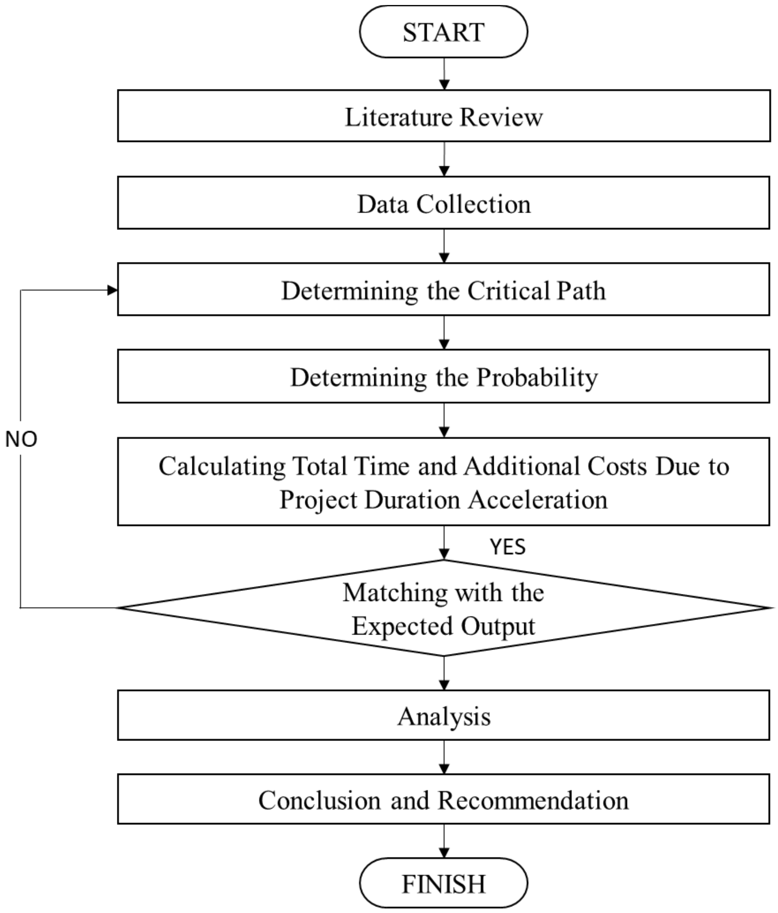

Figure 1. Research Flowchart

The methodology of this study begins with a literature review to understand the theoretical foundations and identify research gaps in previous studies. This is followed by the collection of primary data from the Seawater Filtration Module project and secondary data from scientific references. The data is used to develop the project schedule and analyze deviations that resulted in delays of up to two months. The Critical Path Method (CPM) is applied to identify critical activities. This is followed by the PERT approach, which calculates time estimates based on three possible durations optimistic, most likely, and pessimistic and assesses the probability of completing the project within a specified timeframe. Network planning is developed to calculate the start and finish times of each activity, as well as the total float. Subsequently, the Time-Cost Trade-Off (TCTO) method is used to determine the total acceleration time and the additional costs associated with accelerating critical path activities. The cost analysis focuses on improving productivity by adding labor resources starting in October 2023 to recover delays and complete the project according to the original schedule.

After conducting a literature review, the next step was data collection. The data collected by the researchers was divided into two categories: primary and secondary data. Primary data was taken directly from the Seawater Filtration Module project, including the project scheduling plan and actual implementation conditions, the project budget, and other data relevant to the research needs. Secondary data, which is supporting data, consisted of research-related references, including books, lecture notes, scientific articles, and journals.

To create a project schedule, the initial step was to identify all activities to be undertaken and then determine their completion sequence, as each activity must be interconnected. Time estimates were also provided to determine the overall project duration, as shown in Table 3.2. Based on this table, the project consists of several main stages, starting with milestones,

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engineering and yard readiness, construction, electrical and instrumentation, mechanical completion and ITR, and ending with the module handover. Each stage has a number of structured activities, but during implementation, many activities deviated from the established schedule.

The resulting delays delayed the project's loading from the fabrication area by up to two months beyond the planned schedule. This was due to the delays not being properly anticipated, which impacted all project activities.

Tabel 1. Seawater Filtration Module Project Schedule

Task Name	Baseline Start	Baseline Finish	Actual Start	Actual Finish
Sea Water Filtration Module	2/1/2023	1/31/2024	2/1/2023	3/30/2024
Milestone	2/1/2023	1/31/2024	2/1/2023	2/1/2023
Contract Awards	2/1/2023	2/1/2023	2/1/2023	3/30/2024
First Cutting	5/1/2023	5/1/2023	5/2/2023	5/2/2023
Equipment Installation Complete	10/16/2023	10/16/2023	10/24/2023	10/24/2023
Piping Hydrotest Start	10/30/2023	10/30/2023	11/3/2023	11/3/2023
Mechanical Completion & Itr Start	10/17/2023	10/17/2023	10/30/2023	10/30/2023
Module Delivery	1/31/2024	1/31/2024	3/30/2024	3/30/2024
Engineering & Yard Readiness	2/1/2023	5/31/2023	2/1/2023	6/30/2023
Yard Engineering	2/1/2023	5/31/2023	2/1/2023	6/30/2023
Structure	2/1/2023	4/14/2023	2/1/2023	4/26/2023
Piping	3/3/2023	5/15/2023	3/6/2023	5/29/2023
Mechanical	3/3/2023	4/29/2023	3/19/2023	5/20/2023
Eict	3/11/2023	5/31/2023	4/2/2023	6/30/2023
Yard Readiness	2/27/2023	4/1/2023	3/10/2023	4/14/2023
Construction	5/1/2023	1/24/2024	5/2/2023	2/28/2024
Structure	5/1/2023	11/1/2023	5/2/2023	11/15/2023
Structural Fabrication	5/1/2023	10/10/2023	5/2/2023	10/18/2023
Structural Painting & Blasting	5/1/2023	10/24/2023	5/6/2023	10/31/2023
Structural Installation	9/14/2023	11/1/2023	9/18/2023	11/15/2023
Piping	6/6/2023	1/12/2024	6/12/2023	2/28/2024
Pipe Support & Pipe Spool Fabrication	6/6/2023	9/30/2023	6/12/2023	11/2/2023
Piping Blasting & Painting	6/30/2023	10/7/2023	7/3/2023	11/13/2023
Piping Installation	9/25/2023	12/20/2023	9/28/2023	1/6/2024
Piping Hydrotest	10/30/2023	12/27/2023	11/3/2023	1/3/2024
Piping Flushing & Drying	10/30/2023	12/27/2023	11/1/2023	12/30/2023
Piping Chemical Cleaning	12/1/2023	12/14/2023	12/5/2023	12/20/2023
Piping Reinstatement	11/2/2023	1/7/2024	11/8/2023	12/15/2023
Piping Flange Management	11/3/2023	1/9/2024	11/10/2023	12/23/2023
Piping Insulation	12/5/2023	1/12/2024	12/13/2023	2/28/2024
Mechanical	9/1/2023	11/30/2023	9/8/2023	12/15/2023
Equipment Installation	9/1/2023	11/30/2023	9/8/2023	12/15/2023
Equipment Insulation	10/16/2023	11/30/2023	10/18/2023	12/15/2023
Electrical & Instrumentation	8/1/2023	1/9/2024	8/5/2023	2/19/2024
E&I Support Fabrication	8/1/2023	10/16/2023	8/5/2023	10/31/2023
E&I Support Installation	10/2/2023	11/30/2023	10/5/2023	12/18/2023

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E&I Cable Tray/Ladder Installation	11/1/2023	12/15/2023	11/7/2023	1/11/2024
E&I Equipment/Devices Installation	11/15/2023	12/20/2023	11/20/2023	1/6/2024
Cable Pulling	12/1/2023	12/30/2023	1/12/2024	2/19/2024
Cable Glanding & Termination	12/15/2023	1/4/2024	12/19/2023	1/15/2024
Eit Testing	12/27/2023	1/9/2024	1/5/2024	1/30/2024
Mechanical Completion & Itr	10/17/2023	1/24/2024	10/30/2023	2/14/2024
Structure	1/8/2024	1/15/2024	1/15/2024	2/6/2024
Piping	11/6/2023	1/20/2024	11/9/2023	2/14/2024
Mechanical	10/17/2023	12/14/2023	10/30/2023	1/6/2024
Eict	12/19/2023	1/24/2024	12/23/2023	1/31/2024
Module Delivery	1/25/2024	1/31/2024	2/5/2024	3/30/2024
Loadout Preparation	1/25/2024	1/30/2024	2/5/2024	2/15/2024
Module Loadout	1/31/2024	1/31/2024	3/30/2024	3/30/2024

After knowing the conditions of the delay that occurred, the grouping of project activities depicted in Figure 3.2 from (Project Management Institute (PMI), 2013) needs to be known as the basis for making a schedule. Work begins from the initiation phase which aims to determine the scope of the project, namely from the availability of the project land as a fabrication location to the modular sail away. The result of the initiation phase is a document called a project, which describes what problems will be addressed by the project, the goals and objectives of the project, the costs incurred, the benefits generated, how success will be measured, as well as potential risks and obstacles that may be faced.

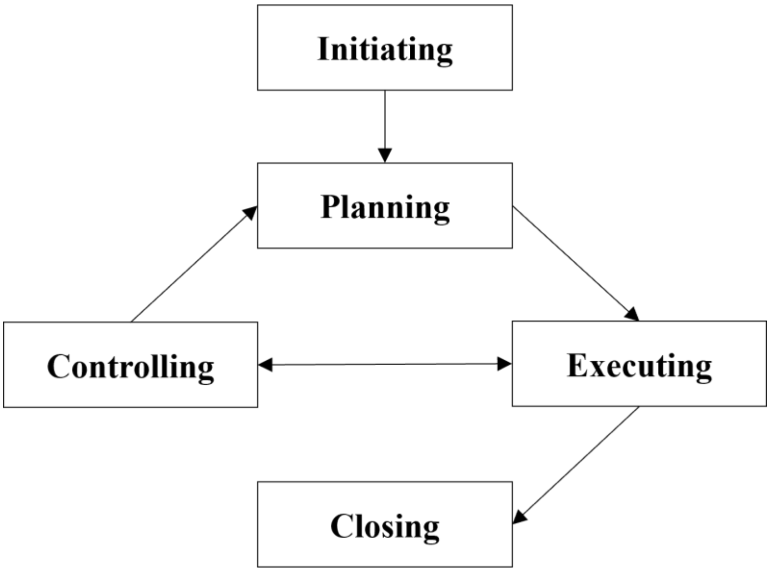

Figure 2. Project Management Phase Diagram

Once the project proposal has been approved by the organization's management, the next phase is the planning phase. This phase establishes a detailed project team, including a project schedule, overall activities, workers, milestones, and modular delivery deadlines. This is followed by the project execution phase, where all activities in the fabrication area are reviewed and approved, including modular design, assembly, and testing. The monitoring and control phase is conducted concurrently with the execution phase. This serves as part of the quality control process. Therefore, if changes occur that affect time, cost, and resources, the project plan must be adjusted, and a feedback loop is activated. Finally, the project closure phase includes a complete modular inspection, the transfer of the modular onto the barge, and the preparation of a final project report.

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Results and Discussion

Collecting Research Data

The Seawater Filtration Module project was carried out by PT. XYZ in Batam, starting on February 1, 2023, and completed on March 30, 2024. The project aimed to build a seawater filtration system consisting of 24 filtration pumps, which will operate in Alaska. The final activity was the loadout process using a Self-Propelled Modular Transporter (SPMT), which has proven to be an efficient and safe method for transporting heavy modules. Previous studies support the use of SPMT due to its advantages in efficiency, safety, and cost.

The project duration was calculated based on regular working hours, which is 40 hours per week, with Sundays and national holidays considered official non-working days. The total actual duration of the project was 364 days, indicating a delay of 51 days from the planned baseline duration of 313 days. Table 4.1 presents a comparison of the duration of each activity between the planned schedule and the actual execution.

The final activity in this project is the loadout process, which is carried out after the fabrication and installation stages are declared complete. Figure 4.1 shows the application of the Self-Propelled Modular Transporter (SPMT) in the loadout process. The SPMT functions as a modular transporter capable of carrying loads with a capacity of up to 10,000 tons. This system is designed to enable the movement of heavy loads with a high degree of precision and ensure safety, even in confined areas or difficult-to-reach terrain.

Research conducted by (Stogdill et al., 2022) revealed that the use of SPMTs has several advantages over conventional methods such as cranes. These advantages include increased safety, efficiency, and reduced operational costs. This research aligns with the application of SPMTs in large projects such as power plants and the oil and gas industry. In this study, the SPMT can work efficiently to support the movement and positioning of modules, ensuring that the loadout process can be carried out quickly and without causing damage to the structure of the moved modules.

Table 2. Planned and Actual Duration of Each Project Activity

Code	Activity Description	Planned Duration (days)	Actual Duration (days)
A	Yard Engineering Structure	63	73
B	Yard Engineering Piping	63	65
C	Yard Engineering Mechanical	50	54
D	Yard Engineering EICT	70	77
E	Yard Readiness	30	31
F	Structural Fabrication	140	146
G	Structural Painting & Blasting	152	153
H	Structural Installation	42	51
I	Pipe Support & Pipe Spool Fabrication	101	124
J	Piping Blasting & Painting	112	115
K	Piping Installation	84	87
L	Piping Hydrotest	51	53
M	Piping Flushing & Drying	51	52
N	Piping Chemical Cleaning	12	14

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O	Piping Reinstatement	31	33
P	Piping Flange Management	32	38
Q	Piping Insulation	34	67
R	Equipment Installation	39	40
S	Equipment Insulation	40	51
T	E&I Support Fabrication	66	75
U	E&I Support Installation	52	64
V	E&I Cable Tray/Ladder Installation	39	57
W	E&I Equipment/Devices Installation	31	42
X	Cable Pulling	26	33
Y	Cable Glanding & Termination	18	24
Z	EIT Testing	12	22
AA	MC & ITR Structure	7	20
BB	MC & ITR Piping	66	84
CC	MC & ITR Mechanical	51	60
DD	MC & ITR EICT	32	34
EE	Module Delivery	6	10

Determining the Critical Path with CPM

The Critical Path Method (CPM) is used to analyze project scheduling by identifying the critical path, total float, and estimated completion time. This analysis includes forward pass and backward pass calculations, as well as an evaluation of the dependency relationships between activities.

Determining Activity Dependencies

The initial step is to identify the relationships between project activities to determine the execution sequence. This information is presented in Table 3 which outlines the overall workflow according to the project's baseline plan.

Table 3. Activity Dependency Relationships

Code	Activity Description	Predecessor Activity	Normal Duration (days)
A	Yard Engineering Structure	-	73
B	Yard Engineering Piping	A	65
C	Yard Engineering Mechanical	A	54
D	Yard Engineering EICT	A, B	77
E	Yard Readiness	A	31
F	Structural Fabrication	A, E	146
G	Structural Painting & Blasting	F	153
H	Structural Installation	G	51
I	Pipe Support & Pipe Spool Fabrication	B, E	124
J	Piping Blasting & Painting	I	115
K	Piping Installation	J	87
L	Piping Hydrotest	K	53

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M	Piping Flushing & Drying	L	52
N	Piping Chemical Cleaning	M	14
O	Piping Reinstatement	N	33
P	Piping Flange Management	O	38
Q	Piping Insulation	P	67
R	Equipment Installation	C, G	40
S	Equipment Insulation	R	51
T	E&I Support Fabrication	D	75
U	E&I Support Installation	T	64
V	E&I Cable Tray/Ladder Installation	U	57
W	E&I Equipment/Devices Installation	V	42
X	Cable Pulling	W	33
Y	Cable Glanding & Termination	X	24
Z	EIT Testing	Y	22
AA	MC & ITR Structure	H	20
BB	MC & ITR Piping	L	84
CC	MC & ITR Mechanical	S	60
DD	MC & ITR EICT	Z	34
EE	Module Delivery	AA, BB, CC, DD	10

Calculating Forward Pass, Backward Pass, and Total Float

The forward pass calculation is used to determine the earliest start (ES) and earliest finish (EF) times, while the backward pass is used to determine the latest start (LS) and latest finish (LF) times. The difference between these values yields the total float (TF), which indicates the time flexibility of an activity. Activities with TF = 0 are considered critical because they have no delay tolerance. The complete results of the forward pass, backward pass, and total float calculations for all project activities are presented in Table 4.

Table 4. Results of Forward Pass, Backward Pass, and Total Float Calculations

Code	Activity Description	Normal Duration (days)	Earliest Start (days)	Earliest Finish (days)	Latest Start (days)	Latest Finish (days)	Total Float (days)
A	Yard Engineering Structure	73	0	73	0	73	0
B	Yard Engineering Piping	63	73	138	73	138	0
C	Yard Engineering Mechanical	54	73	127	506	560	433
D	Yard Engineering EICT	77	138	215	283	360	145
E	Yard Readiness	31	73	104	107	138	34
F	Structural Fabrication	146	104	250	261	407	157
G	Structural Painting & Balsting	153	250	403	407	560	157
H	Structural Installation	51	403	454	640	691	237
I	Pipe Support & Pipe Spool Fabrication	124	138	262	138	262	0
J	Piping Blasting & Painting	115	262	377	262	377	0
K	Piping Installation	87	377	464	377	464	0
L	Piping Hydrotest	53	464	517	464	517	0
M	Piping Flushing& Drying	52	517	569	517	569	0
N	Piping Chemical Cleaning	14	569	583	569	583	0
O	Piping Reinstatement	33	583	616	583	616	0
P	Piping Flange Management	38	616	654	616	654	0
Q	Piping Insulation	67	654	721	654	721	0
R	Equipment Installation	40	403	443	560	600	157
S	Equipment Insulation	51	443	494	600	651	157
T	E&I Support Fabrication	75	215	290	360	435	145
U	E&I Support Installation	64	290	354	453	499	145

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V	E&I Cable Tray/Ladder Installation	57	354	411	499	556	145
W	E&I Equipment/Devices Installation	42	411	453	556	598	145
X	Cable Pulling	33	453	486	598	631	145
Y	Cable Glanding & Termination	24	486	510	631	655	145
Z	EIT Testing	22	510	532	655	677	145
AA	MC & ITR Structure	20	454	474	691	711	237
BB	MC & ITR Piping	84	517	601	627	711	110
CC	MC & ITR Mechanical	60	494	554	651	711	157
DD	MC & ITR EICT	34	532	566	677	711	145
EE	Module Delivery	10	601	611	711	721	110

Determining the Critical Path

After calculating the total float, data from 31 activities revealed that several of them have no time flexibility (TF = 0). These activities are considered critical because any delay will directly impact the overall project completion. Based on the analysis conducted, the critical path in the Seawater Filtration Module project consists of 11 activities, labeled A, B, I, J, K, L, M, N, O, P, and Q. The total duration for all activities on this critical path amounts to 732 days. Below is the network diagram based on actual conditions, showing the identified critical path.

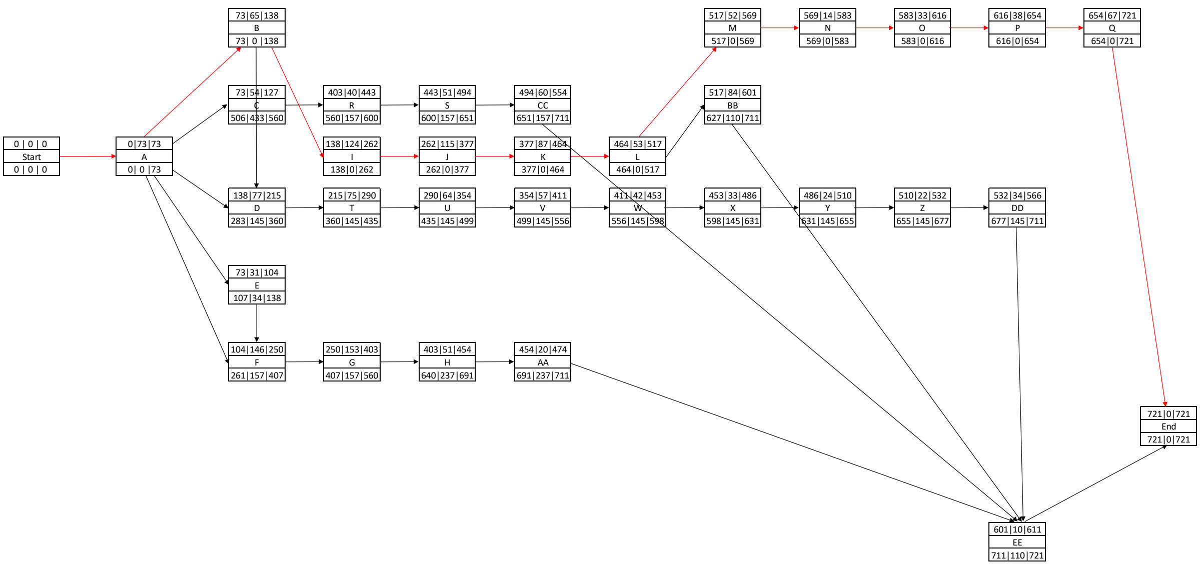

Figure 2. Network Diagram of the Critical Path

Probability Analysis Using PERT

The Program Evaluation and Review Technique (PERT) method is used in this study to generate more accurate estimates of project completion time, especially in dealing with uncertainties that often arise in the field. By considering three types of time estimatesoptimistic, most likely, and pessimistic PERT allows the researcher to gain a more realistic picture of activity durations. This approach is not only theoretical but also reflects the actual dynamics and risks of the project. The estimated durations for each activity are summarized in Table 5

Calculating TE Values

Time Estimation (TE) is calculated for all activities in the project to provide a realistic picture of execution durations. This estimation incorporates three time scenarios and produces predictions that are adaptive to field conditions. The TE value serves as the foundation for developing the overall project schedule, as it reflects the expected time by taking into account

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risks and uncertainties during implementation. The complete results of the TE calculations are presented in Table 6 and visualized in the form of a distribution chart

Table 5. Time Estimation of All Activities

Code	Activity Description	O	M	P
A	Yard Engineering Structure	63	73	78
B	Yard Engineering Piping	63	65	75
C	Yard Engineering Mechanical	49	54	55
D	Yard Engineering EICT	70	77	80
E	Yard Readiness	30	31	35
F	Structural Fabrication	140	146	158
G	Structural Painting & Blasting	150	153	161
H	Structural Installation	36	51	51
T	Pipe Support & Pipe Spool Fabrication	114	124	132
I	Piping Blasting & Painting	113	115	125
K	Piping Installation	80	87	99
L	Piping Hydrotest	45	53	63
M	Piping Flashing & Drying	45	52	59
N	Piping Chemical Cleaning	10	14	20
O	Piping Reinstatement	29	33	48
P	Piping Flange Management	31	38	40
Q	Piping Insulation	55	67	73
R	Equipment Installation	35	40	44
S	Equipment Insulation	40	51	54
T	E&I Support Fabrication	72	75	90
U	E&I Support Installation	38	64	77
V	E&I Cable Tray/Ladder Installation	45	57	60
W	E&I Equipment/Devices Installation	31	42	48
X	Cable Pulling	26	33	38
Y	Cable Glanding & Termination	18	24	29
Z	EIT Testing	12	22	28
AA	MC & ITR Structure	14	20	22
BB	MC & ITR Piping	75	84	85
CC	MC & ITR Mechanical	35	60	61
DD	MC & ITR EICT	31	34	38
EE	Module Delivery	6	10	12

Table 6. Time Estimation Calculation Results for Critical Activities

Code	Activity Description	O	M	P	TE (days)
A	Yard Engineering Structure	63	73	78	72.17
B	Yard Engineering Piping	63	65	75	66.33
T	Pipe Support & Pipe Spool Fabrication	114	124	132	123.67
I	Piping Blasting & Painting	113	115	125	116.33
K	Piping Installation	80	87	99	87.83
L	Piping Hydrotest	45	53	63	53.33
M	Piping Flashing & Drying	45	52	59	52.00
N	Piping Chemical Cleaning	10	14	20	14.33
O	Piping Reinstatement	29	33	48	34.83
P	Piping Flange Management	31	38	40	37.17
Q	Piping Insulation	55	67	73	66.00

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Calculating Standard Deviation and Variance

After obtaining the time estimates for each activity, the next step is to calculate the standard deviation and variance for the critical activities. These two values are essential for measuring the level of uncertainty in the time estimates, and the calculation results are presented in Table 7 These values are then used in the project probability calculation stage.

Table 7. Calculation Results of Standard Deviation and Variance

Code	Activity Description	Standard Deviation (S)	Variance (V)
A	Yard Engineering Structure	2,50	6,25
B	Yard Engineering Piping	2,00	4,00
I	Pipe Support & Pipe Spool Fabrication	3,00	9,00
J	Piping Blasting & Painting	2,00	4,00
K	Piping Installation	3,17	10,03
L	Piping Hydrotest	3,00	9,00
M	Piping Flushing & Drying	2,33	5,44
N	Piping Chemical Cleaning	1,67	2,78
O	Piping Reinstatement	3,17	10,03
P	Piping Flange Management	1,50	2,25
Q	Piping Insulation	3,00	9,00

Calculating Probability Value

Acceleration probability analysis is conducted by calculating the Z-score, which indicates the likelihood that the project will be completed within the target duration. This calculation takes into account the target duration, expected time (TE), and total variance of the critical activities. With a target duration of 732 days, TE = 724 days, and a total variance of 71.78, the resulting Z-score is 0.94. This Z-score is then used to determine the project acceleration probability based on the normal distribution. From this Z-score, the probability of successful project acceleration is 82.64%, while the probability of failure is 17.36%. This suggests a high likelihood of completing the project earlier, making acceleration strategies such as increasing manpower feasible. Compared to the study by Kholil et al. (2018), which stated that probabilities above 70% are considered feasible, the results of this study indicate an even stronger potential for acceleration, despite the large scale and high complexity of the project under review.

Cost Analysis of Acceleration Using TCTO

At this stage, an analysis is conducted on the additional costs arising from project acceleration using the Time-Cost Trade-Off (TCTO) method. The main focus of this analysis is to calculate the cost increase for critical activities through additional manpower, and to compare normal costs with the costs after acceleration.

Work Volume on Critical Activities

The volume of work on critical activities, along with the total duration that needs to be accelerated, serves as the basis for estimating both normal and accelerated costs. This information is presented in Table 8 as the primary data for the subsequent cost analysis.

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Table 8. Work Volume Data on Critical Activities

Code	Activity Description	Normal Duration (days)	Volume	Unit
A	Yard Engineering Structure	73	67	*Shop drawing*
B	Yard Engineering Piping	65	142	*Shop drawing*
I	Pipe Support & Pipe Spool Fabrication	124	6732	*Dia-inch*
J	Piping Blasting & Painting	115		
K	Piping Installation	87		
L	Piping Hydrotest	53		
M	Piping Flushing & Drying	52		
N	Piping Chemical Cleaning	14		
O	Piping Reinstatement	33		
P	Piping Flange Management	38		
Q	Piping Insulation	67		

Determining Additional Workers

The number of additional workers is determined based on the productivity rate of each critical activity. The objective is to assess the relationship between the number of workers, output increase, and completion time. According to the principle of diminishing marginal returns, adding more workers does not always result in proportional output and may even reduce efficiency. Therefore, the number of workers is increased proportionally to achieve optimal acceleration while maintaining cost-efficiency and effectiveness.

Acceleration Duration Due to Additional Workers

The acceleration duration is measured as the difference between the completion time with the initial number of workers and the time after adding more workers. This calculation involves daily productivity under both normal and accelerated conditions. A full summary of the calculations is presented in Tables 9 and 10

The results show that the higher the daily productivity value, the greater the volume of work completed per worker per day. This indicates optimal use of labor in supporting project acceleration. Conversely, low productivity reflects a decrease in work output per worker, which may result from exceeding the ideal labor capacity for an activity. This situation aligns with the concept of diminishing marginal returns, where increasing labor input no longer produces a proportional increase in output. The following are the acceleration results based on additional workers, referring to the productivity of each critical activity.

Table 9. Results of Normal and Accelerated Productivity Calculations

Code	Productivity/Day (output/worker)	Normal Worker Productivity (output/worker)	Additional Worker Productivity (output/worker)	Daily Acceleration Productivity (output/worker)
A	0,08	0,92	0,15	1,07
B	0,14	2,18	0,55	2,73
I	1,60	54,29	3,19	57,48
J	3,08	58,54	3,08	61,62
K	1,76	77,38	3,52	80,90
L	5,29	127,02	5,29	132,31

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M	5,39	129,46	5,39	134,86
N	16,58	480,86	16,58	497,44
O	8,50	204,00	8,50	212,50
P	8,05	177,16	8,05	185,21
Q	5,29	100,48	5,29	105,77

Based on the data from critical activities under normal duration, the total time required to complete the critical activities reached 721 days, while the overall project duration was recorded at 1,849 days. This resulted in a schedule deviation of 51 days from the original plan, which began to be identified in October 2023. An additional 17 workers were assigned to the critical activities, with consideration given to the productivity of each activity to support the acceleration of project completion.

The calculation results show that the total duration of the critical activities decreased from 721 days to 670 days after the labor adjustments. Thus, this acceleration enables the project to realign with the baseline plan without compromising the previously established time targets. This demonstrates that adjusting the workforce based on productivity analysis plays a significant role in strategically and measurably correcting project delays.

Table 10. Normal and Accelerated Durations

Code	Normal Duration (days)	Durasi yang Dipercepat (hari)
A	73	63
B	65	52
I	124	117
J	115	109
K	87	83
L	53	51
M	52	50
N	14	14
O	33	32
P	38	36
Q	67	64

Acceleration Cost

The normal cost refers to the total expenditure required to complete the project on schedule without acceleration. This cost is calculated by multiplying the daily wage of workers by the number of workers and the duration of work per activity. For example, for the *yard engineering structure* activity, with 12 workers and a daily wage of Rp3,400,000, the total cost over 73 days amounts to Rp248,200,000. The normal cost calculations for all activities are summarized in Table 12.

Table 11. Daily Worker Wage Data

Department	Job List	Basic Wage per Day
Engineering	Drafter	Rp 270.833
	Lead Drafter	Rp 458.333
	Structure Eng.	Rp 333.333
	Piping Eng.	Rp 333.333
	Mech Eng.	Rp 333.333
	E&I Eng.	Rp 333.333
	Lead Project Eng.	Rp 625.000
Production Monitoring & Control (PMC)	PMC Asst.	Rp 195.833
	Planner Asst.	Rp 229.167

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	Senior Planner	Rp 416.667
	Production Manager	Rp 833.333
Yard	Helper	Rp 195.833
	Fitter	Rp 195.833
	Welder	Rp 270.833
	Supervisor	Rp 354.167
	Superintendent	Rp 625.000
Warehouse	Admin	Rp 195.833
	Material Control	Rp 270.833
	Lead Warehouse	Rp 458.333
Quality Control (QC)	Structure QC	Rp 354.167
	Piping QC	Rp 354.167
	Mech QC	Rp 354.167
	E&I QC	Rp 354.167
Blasting & Painting (BP)	Painter	Rp 354.167
	Sandblaster	Rp 354.167
	Lead BP	Rp 500.000
Health Safety Environment (HSE)	HSE Officer	Rp 291.667
	HSE Yard	Rp 333.333

Table 12. Worker Wages for Normal Duration

Code	Upah Normal / Hari (Rp)	Normal Cost (Rp)
A	Rp 3.400.000	Rp 248.200.000
B	Rp 4.333.333	Rp 281.666.667
I	Rp 10.091.667	Rp 1.251.366.667
J	Rp 5.383.333	Rp 619.083.333
K	Rp 12.800.000	Rp 1.113.600.000
L	Rp 7.383.333	Rp 391.316.667
M	Rp 7.383.333	Rp 383.933.333
N	Rp 7.654.167	Rp 107.158.333
O	Rp 7.383.333	Rp 243.650.000
P	Rp 6.841.667	Rp 259.983.333
Q	Rp 6.029.167	Rp 403.954.167

The acceleration cost is calculated based on the addition of labor to the critical activities. While this shortens the project duration, it also results in increased expenses. For instance, in the *yard engineering structure* activity, after adjusting the number of workers, a recalculation was conducted to determine the change in total cost. The results show that accelerating all critical activities requires an additional cost of Rp30,913,709, as shown in Table 4.12. This acceleration successfully reduced the duration of the critical activities from 721 days to 670 days, bringing the project back in line with the original schedule.

Table 13. Comparison of Normal Cost and Acceleration Cost

Code	Total Normal Cost (Rp)	Additional Worker Cost (Rp)	Total Cost Due to Additional Workers (Rp)
A	Rp 248.200.000	Rp 5.648.810	Rp 253.848.810
B	Rp 281.666.667	Rp 14.083.333	Rp 295.750.000
I	Rp 1.251.366.667	Rp 3.731.481	Rp 1.255.098.148
J	Rp 619.083.333	Rp 1.587.292	Rp 620.670.625
K	Rp 1.113.600.000	Rp 2.048.912	Rp 1.115.648.912
L	Rp 391.316.667	Rp 574.167	Rp 391.890.833

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M	Rp 383.933.333	Rp 629.167	Rp 384.562.500
N	Rp 107.158.333	Rp 500.000	Rp 107.658.333
O	Rp 243.650.000	Rp 0	Rp 243.650.000
P	Rp 259.983.333	Rp 447.464	Rp 260.430.797
Q	Rp 403.954.167	Rp 1.535.417	Rp 405.489.583

These findings indicate that the acceleration strategy through the addition of labor is effective in reducing delays, but it also leads to increased costs. This aligns with the findings of Senses & Kumral (2023), who stated that adding labor to critical activities is effective in shortening project duration, although it comes with the consequence of higher costs. Therefore, acceleration strategies should be designed selectively and based on productivity analysis to ensure they remain economically efficient.

Conclusion

Based on the analysis conducted, it can be concluded that the Seawater Filtration Module project, which started on February 2, 2023, and was completed on March 30, 2024, experienced a delay of 51 days from the original planned schedule, which targeted completion by January 31, 2024. The total project duration was 1,849 days and consisted of 31 modular fabrication and installation activities. The analysis using the Critical Path Method (CPM) identified 11 critical activities as the main contributors to the delay. Through the addition of 17 workers, adjusted according to the productivity levels of these activities, the project duration could be realigned with the baseline plan. Furthermore, probability analysis using the Program Evaluation and Review Technique (PERT) showed a success rate of 82.64% for the acceleration effort, indicating a high likelihood of completing the project on time. This acceleration, based on calculations using the Time-Cost Trade-Off (TCTO) method, required an additional cost of Rp 30,913,709.

Suggestion

As a follow-up to the conclusions drawn, several recommendations can be made to improve future research. Project duration acceleration analysis can be expanded by using alternative methods such as Fast Tracking or Fuzzy-CPM, which would provide broader perspectives on the effectiveness of acceleration techniques. The use of project scheduling software such as Primavera (P6) can also be incorporated to enhance the comprehensiveness and accuracy of project planning and control processes. In addition, project acceleration efforts may consider alternative strategies such as adding overtime hours, calculating indirect costs, and optimizing the capacity of rented equipment to further improve execution efficiency.

References

Adam, I., Witjaksana, B., & Tjendani, H. T. (2023). Time and Cost Analysis on Procurement of Sutet 275 Kv 2CCT Quadruple Zebra Gumawang – Gitet Lampung 1 Using Time Cost Trade Off Method. *Asian Journal of Engineering, Soacial, and Health*, *2*(12), 1772–1778.

Ammar, M. A. (2011). Optimization of Project Time-Cost Trade-Off Problem with Discounted Cash Flows. *Journal of Construction Engineering and Management*, *137*(1), 65–71. https://doi.org/10.1061/(asce)co.1943-7862.0000256

Anderson, S., Shane, J. S., & Schexnayder, C. (2011). Strategies for Planned Project Acceleration. *Journal of Construction Engineering and Management*, *137*(5), 372–381. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000289

Andiyan, A., Putra, R. M., Rembulan, G. D., & Tannady, H. (2021). Construction Project Evaluation Using CPM-Crashing, CPM-PERT and CCPM for Minimize Project

ISSN: 2716-3865 (Print), 2721-1290 (Online)

Delays. *Journal of Physics: Conference Series*, *1933*(1). https://doi.org/10.1088/1742-6596/1933/1/012096

Babu, A. J. G., & Suresh, N. (1996). Project management with time, cost, and quality considerations. *European Journal of Operational Research*, *88*(2), 320–327. https://doi.org/https://doi.org/10.1016/0377-2217(94)00202-9

Baptiste, P., & Demassey, S. (2004). Tight LP bounds for resource constrained project scheduling. *Or Spectrum*, *26*, 251–262. https://doi.org/10.1007/s00291-003-0155-1

Belay, A. M., Torp, O., Thodesen, C., & Odeck, J. (2016). A framework for Organizing a Resilient Cost Benefit Analysis for Construction Projects. *Procedia Engineering*, *145*, 1169–1176. https://doi.org/10.1016/j.proeng.2016.04.151

Bordoli, D. W., & Baldwin, A. N. (1998). A methodology for assessing construction project delays. *Construction Management and Economics*, *16*(3), 327–337. https://doi.org/10.1080/014461998372358

Chen, X., Feng, J., Zhao, Y., & Lu, T. (2025). Feasibility of a Program Delay Claims Scheme: Synergistic Effect and Risk–Cost Optimization. *Journal of Construction Engineering and Management*, *151*(10), 04025151. https://doi.org/10.1061/JCEMD4.COENG-16532

Doloi, H., Sawhney, A., Iyer, K. C., & Rentala, S. (2012). Analysing factors affecting delays in Indian construction projects. *International Journal of Project Management*, *30*(4), 479–489. https://doi.org/10.1016/j.ijproman.2011.10.004

Farchan, M., Witjaksana, B., & Sajiyo, S. (2025). Analysis of the Acceleration of Implementation Time Using the Crashing Method in the Construction of the Purworejo Bridge, Mojokerto Regency. *Enrichment: Journal of Multidisciplinary Research and Development*, *3*(4), 784-796. https://doi.org/10.55324/enrichment.v3i4.458

Farrow, T. (2007). Developments in the analysis of extensions of time. *Journal of Professional Issues in Engineering Education and Practice*, *133*(3), 218–228. https://doi.org/10.1061/(ASCE)1052-3928(2007)133:3(218)

Feng, Q. D., Xia, J. S., Wen, L., & Yazdi, M. (2024). Failure analysis of floating offshore wind turbines based on a fuzzy failure mode and effect analysis model. *Quality and Reliability Engineering International*, *40*(5), 2159-2177. https://doi.org/10.1002/qre.3505

Fox, T. L., & Spence, J. W. (1998). Tools of the Trade: A Survey of Project Management Tools. *Project Management Journal*, *29*(3), 20–27. https://doi.org/10.1177/875697289802900305

Jamaluddin, F. N., Dhanistha, W. L., & Satrio, D. (2024). Fuzzy Logic Approach to Risk Management and Control for Safe Work in Jacket Structure Load Out Process. *International Review of Automatic Control*, *17*(4), 157-164. https://doi.org/10.15866/ireaco.v17i4.25435

Joslin, R., & Müller, R. (2016). The relationship between project governance and project success. *International Journal of Project Management*, *34*(4), 613–626. https://doi.org/10.1016/j.ijproman.2016.01.008

Kholil, M., Nurul Alfa, B., & Hariadi, M. (2018). Scheduling of House Development Projects with CPM and PERT Method for Time Efficiency (Case Study: House Type 36).

ISSN: 2716-3865 (Print), 2721-1290 (Online)

IOP Conference Series: Earth and Environmental Science, *140*(1). https://doi.org/10.1088/1755-1315/140/1/012010

Kim, S.-K., Roh, M., & Kim, K.-S. (2017). Arrangement Method of Offshore Topside Based on an Expert System and Optimization Technique. *Journal of Offshore Mechanics and Arctic Engineering*, *139*(2), 1–19. https://doi.org/10.1115/1.4035141

Kim, Y., Kim, K., & Shin, D. (2005). Delay Analysis Method Using Delay Section. *Journal of Construction Engineering and Management*, *131*(11), 1155–1164. https://doi.org/10.1061/(asce)0733-9364(2005)131:11(1155)

Kusumadarma, I. A., Pratami, D., Yasa, I. P., & Tripiawan, W. (2020). Developing project schedule in telecommunication projects using critical path method (CPM). *International Journal of Integrated Engineering*, *12*(3), 60–67. https://doi.org/10.30880/ijie.2020.12.03.008

Li, S., Zhou, X., Cheng, G., Teng, W., Zeng, Y., Wei, G., & Chen, Y. (2024). A scheme of installing ALC wall panels based on autonomous mobile robot. *Journal of Building Engineering*, *94*, 109991. https://doi.org/10.1016/j.jobe.2024.109991

Mazlum, M., & Güneri, A. F. (2015). CPM, PERT and Project Management with Fuzzy Logic Technique and Implementation on a Business. *Procedia - Social and Behavioral Sciences*, *210*, 348–357. https://doi.org/10.1016/j.sbspro.2015.11.378

Mufti, F. M., Afrizal, E., Djatmiko, E. B., Murdjito, & Jaswar. (2014). Fracture of scantling support structure of gas processing module on FPSO. *Jurnal Teknologi (Sciences and Engineering)*, *66*(2), 53–59. https://doi.org/10.11113/jt.v66.2484

Olorunyomi, T. D., Sanyaolu, T. O., Adeleke, A. G., & Okeke, I. C. (2024). Integrating FinOps in healthcare for optimized financial efficiency and enhanced care. *International Journal of Frontiers in Science and Technology Research*, *7*(2), 20-28.

Oluwatayo, M., Atebe, O., Okafor, F., Nebo, O., Etuk, O., Nwaonu, S., ... & Onukwugha, P. (2024, April). Bonga FPSO: Corrosion Management in the First Deep Water FPSO in the Gulf of Guinea–A Methodical Approach to Inspections and Fabric Maintenance. In *Offshore Technology Conference* (p. D041S045R008). OTC. https://doi.org/10.4043/35184-MS

Purnomo, D., Oetomo, W., & Marleno, R. (2023). Study of Cost and Time Analysis Using the Time Cost Trade Off (TCTO) Method in the Construction Project of the Office Building of a Government Agency (OPD) in Pasuruan. *International Journal on Advanced Technology, Engineering, and Information System (IJATEIS)*, *2*(4), 376–386. https://doi.org/10.55047/ijateis.v2i4.1007

Rajanayagam, H., Beatini, V., Poologanathan, K., & Nagaratnam, B. (2024). Comprehensive evaluation of flat pack modular building systems: Design, structural performance, and operational efficiency. *Journal of Building Engineering*, *95*, 110099. https://doi.org/10.1016/j.jobe.2024.110099

Rodrigues, T. C., Pereira, N. N., & da Cunha Jácome Vidal, P. (2025). Feasibility analysis of recycling an offshore oil and gas platform in Brazil. *Marine Systems & Ocean Technology*, *20*(3), 32. https://doi.org/10.1007/s40868-025-00179-8

Sari, N. P., Yasri, D., & Ovirizalni, N. (2025). Analysis of Acceleration of Completion of Palapa Market Revitalization Project Using Crash Program Method. *Jurnal Vokasi Manajemen Dan Rekayasa Infrastruktur Sipil*, *2*(1), 29-38. https://doi.org/10.56208/jvmatriks.v2i1.17

ISSN: 2716-3865 (Print), 2721-1290 (Online)

Senses, S., & Kumral, M. (2023). Managing trade-off between cost and time in project scheduling problems using discrete event simulation. *Proceedings of the International Conference on Simulation and Modeling Methodologies, Technologies and Applications*, *1*(Simultech), 178–185. https://doi.org/10.5220/0012004900003546

Shahzad, S., & Jasińska, E. (2024). Renewable revolution: A review of strategic flexibility in future power systems. *Sustainability*, *16*(13), 5454.

Shehata, M. E., & El-Gohary, K. M. (2011). Towards improving construction labor productivity and projects' performance. *Alexandria Engineering Journal*, *50*(4), 321–330. https://doi.org/10.1016/j.aej.2012.02.001

Silvianita, S., Anggara Rahmadhani, N. D., & Satrio, D. (2025). Risk assessment of project delay analysis on FPSO conversion. *International Journal on Engineering Applications, 13*(1), 92–98. https://doi.org/10.15866/irea.v13i1.25185

Silvianita, S., Jamaluddin, F. N., Dhanistha, W. L., Suntoyo, S., Satrio, D., & Wahyudi, W. (2024). Fuzzy logic approach to risk management and control for safe work in jacket structure load out process. *International Review of Automatic Control, 17*(4), 157–164. https://doi.org/10.15866/ireaco.v17i4.25435

Terpstra, T., D'Hautefeuille, B. B., & Macmillan, A. A. (2001). FPSO Design and Conversion: A Designer's Approach. *Offshore Technology Conference (Pp. OTC-13210)*. https://doi.org/10.4043/13210-MS

Xue, Y., Le, Y., Jia, F., & Peng, T. (2025). Delays in Large Infrastructure Projects Transitioning to Operations: Analysis Based on a Schedule–Risk Network Coupling Model. *Journal of Management in Engineering*, *41*(5), 04025035. https://doi.org/10.1061/JMENEA.MEENG-6726

Yang, J. Bin, & Kao, C. K. (2012). Critical path effect based delay analysis method for construction projects. *International Journal of Project Management*, *30*(3), 385–397. https://doi.org/10.1016/j.ijproman.2011.06.003

Zareei, S. (2018). Project scheduling for constructing biogas plant using critical path method. *Renewable and Sustainable Energy Reviews*, *81*, 756–759.

ISSN: 2716-3865 (Print), 2721-1290 (Online)