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RELIABILITY-BASED PREDICTABLE MAINTENANCE OF THE 2800 GT CONTAINER SHIP FUEL SYSTEM

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ABSTRACT

The fuel system is a supporting system for the ship's main engine because this system directly affects the performance of the main engine. The fuel system is so important that it will have a direct impact on the performance of the main engine and affect the ship's operations. To prevent danger or loss resulting from fuel system failure, a reliability-based maintenance analysis is needed. This research will analyze failures and create a maintenance schedule for the fuel system on the ship's main engine. In completing this research, a qualitative method was used, namely using Fault Tree Analysis (FTA) and Failure Mode and Effects Analysis (FMEA. Then, quantitative analysis was carried out using the Weibull distribution to determine the mean time to failure (MTTF). The results of the research showed that the predicted maintenance of the main engine fuel system was correct based on the reliability value calculation. The reliability value of the Transfer Pump component was 5950 hours with a reliability of 0.66, the Booster Pump 4325 hours with a reliability of 0.749, the Purifier 5530 hours with a reliability of 0.66, the Injector 2010 hours with 0.93 reliability, and the Filter 967 hours with 0.86 reliability.

Keywords: Failure mode and effect analysis, fault tree analysis, ship's fuel system, reliability, weibull distribution

Introduction

Indonesia is an archipelagic country. Indonesian waters are strategic shipping lanes where sea transportation is one of the port transportation systems that plays a strategic role. Ships are vehicles that carry passengers at sea, in all areas that have certain waters [1]. A ship that functions as a means of transportation, or in other words, a ship functions to move passengers and goods [2].

Maintenance of a ship is something that cannot be ignored because if it is not carried out on an ongoing basis, there will be a decrease in the performance of one of the ship's systems, and this can have an impact on other systems. The role of maintenance of machines and equipment, and other facilities is very important in supporting the operation of a machine. The main motor support system on a ship helps the main engine operate according to its function, namely, providing power to the propeller to propel the ship. In this case, the application of reliability theory can be used to estimate the chances of a system being able to carry out its functions optimally. Reliability is the probability of an item being able to carry out a predetermined function under certain operating and environmental conditions for a predetermined period. [3]. Reliability analysis of components that support the system in fuel performance does not wait for a failure to occur first, but prioritizes carrying out reliability analysis as a preventive/remedial step to prevent the failure from occurring.

To anticipate failure in the fuel system, reliability analysis can be carried out, its implementation is by identifying how the fuel system failed and the consequences of this incident. Management maintenance needs to be carried out to prevent failure of the system itself. Maintenance management includes prevention (preventive maintenance), repairs (corrective maintenance). Tracing the causes of component or system failure is carried out by evaluating and analyzing the component or system using Fault Tree Analysis (FTA). Fault Tree Analysis is an analysis tool that creates a combination of definite failures in a system. This FTA is useful for describing events in a system [4][5]. Failure Mode Effect Analysis (FMEA), is a technique used to identify and analyze a failure and its consequences to avoid failure experienced by a component [6].

The Weibull distribution is the first step in calculating Mean Time to Failure (MTTF). The Weibull distribution was introduced by Swedish physicist Waloddi Weibull in 1939. The Weibull distribution is a theoretical distribution of continuous random variables that is often used to analyze the reliability of an item. Just like the Gamma and Exponential Distributions deal with reliability issues, the Weibull Distribution is most frequently used [7]. After carrying out the Weibull distribution, the values obtained are processed to obtain the reliability index, reliability rate, and Mean Time To Failure (MTTF) value of a component.

Methodology

In this research, qualitative analysis and quantitative analysis were carried out. Qualitative analysis was obtained from primary data, namely, interviews with ship operators and experts in their fields related to research data including the Fault Tree Analysis (FTA) method and discussion of questionnaires to be processed using the Failure Mode and Effect Analysis (FMEA) method assisted by using the Excel program to make calculations easier. Quantitative analysis is obtained from secondary data, namely data from the logbook, which will be processed using the Weibull distribution. This research was carried out through several stages of methods.

a. Failure Analysis Using the Fault Tree Analysis (FTA) Method

Fault Tree Analysis (FTA) is a method for identifying failures in a system, which are caused by component failures or other failure events simultaneously or individually. In addition, fault tree analysis identifies failure modes, causes of failure, and the impact of functional failures that will be caused by components in the KM main engine fuel system. Rainbow Solar. The process of constructing a fault tree is a top-down approach, which means that the analysis begins by identifying the causes of top events from the highest level to the lowest level sequence, which is usually identified using symbols such as And or Or Gate [8].

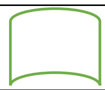
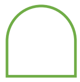
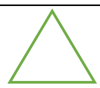
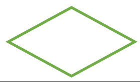
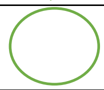
Symbols	Remarks
	*Top Event*
	*Logic Event OR*
	*Logic Event AND*
	*Transferred Event*
	*Undeveloped Event*
	*Basic Event*

Figure 1. Symbols for Fault Tree Analysis

Remarks:

a. *Top event / primary event*, is a failure condition. The symbol may apply to intermediate events.
b. *OR gate*, an output event will occur if at least one event occurs.
c. *AND gate*, an output event will occur if and only if all input events occur.
d. *Transferred-out event*, the point where the fault tree can be split into sub-fault trees.
e. *Transferred-in event*, the point at which the fault tree can begin as a transferred-out continuation.
f. *Undeveloped event* (*uncompleted event*), is an event that requires further reduction until a basic event is discovered.
g. *Basic event* is the cause of failure.

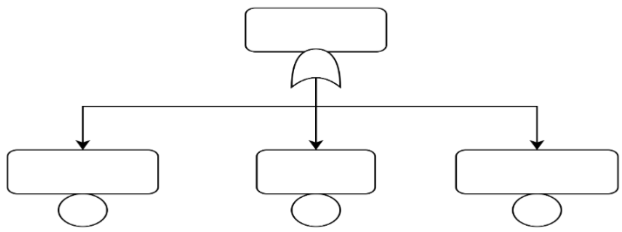


Figure 2. Fault Tree Analysis Diagram

b. Analysis and Calculations Using the Failure Mode and Effect Analysis (FMEA) Method

After creating a fault tree analysis in this chapter, data processing using the Failure Mode and Effect Analysis (FMEA) method aims to obtain critical components which are failures which will be analyzed further. in this case it will start from identifying the problem that has been created using fault tree analysis which will be used as a research object, a description of the respondents relating to the research data, and a discussion of the results of the questionnaire to be processed using the Filure Mode and Effect Analysis (FMEA) method with the help of the Microsoft Excel program.

Risk priority number (RPN) is the result of multiplying the weights of severity, occurrence, and detection. These results will be able to determine critical components. RPN = Severity (S) x Occurance (O) x Detection (D)

- **Severity, Occurrence, Detection value assessment**

In the failure mode assessment, there are 3 assessments: the first is severity, the second is occurrence, and the third is detection.

Table 1. Severity [9]

Hazard Level	Criteria	Level
Very Very Dangerous	Component damage causes sudden accidents and endangers work safety	10
Very Dangerous	Component damage causes work accidents, and machines do not operate, but there is an early warning/detection	9
Very high	Damage to components causes the machine to stop and lose its main function	8
High	Component failure results in the system shutting down, but the engine is still operating	7
Moderate	Component damage causes system performance to decrease drastically, but the machine can still operate	6
Low	Component damage causes system performance to decrease gradually, while the machine can still operate	5
Very Low	Component damage results in little impact on system performance, with the engine still operating perfectly	4
Small	Components experience decreased performance, but the fuel system and engine are still running perfectly	3
Very small	Components are considered bad, but component performance is still good, and the system and machine are still running perfectly	2
No Influence	No influence	1

Table 2. Occurrence [9]

Happens So Often That Damage Cannot Be Avoided	Almost every time it occurs in less than 1-2 operations	10
Happens Very Often	Very high occurs in less than 3-4 operations	9
Often occurs (1)	High occurs in less than 5-8 operations	8
Often occurs (2)	Quite high in less than 9-20 operations	7
Rarely occurs (1)	Intermediate occurs in less than 21-80 operations	6
Rarely occurs (2)	Low occurs in less than 81-400 operations	5
Rarely occurs (3)	Rarely occurs in less than 401-2000 operations	4

Very Rare (1)	Very rare in less than 2001- 15000 operations	3
Very Rare (2)	Almost never in more than 15001 operations	2
Never occurred	Never happened	1

Table 3. Detection [9]

Detection	**Criteria**	**Level**
Impossible To Detect	It will not be controlled and/or detected as a potential cause of failure and subsequent damage	10
Very Difficult to Detect	It is very difficult to control changes to detect potential causes and subsequent types of failure	9
Difficult to Detect	It is difficult to control changes to detect potential causes and subsequent types of failure	8
To be Detected Very Low	Very low to detect potential causes and subsequent types of failure	7
For Detected Low	Low to detect potential causes and subsequent types of failure	6
For Medium Detection	It is hardly easy to detect potential causes and subsequent types of failure	5
For Middle and Upper Detection	It is almost easy to detect potential causes and subsequent types of failure	4
Easy To Detect	Easily controlled to detect potential causes and subsequent types of failure	3
Very Easy To Detect	It is easily controlled to detect potential causes and subsequent types of failure	2
Detection Can Be Done Easily/Visibly	It can be expected that their frequent occurrence will result in the detection of potential causes and events	1

c. Making a Maintenance Schedule Using Weibull Distribution Calculations

The Weibull distribution is one of the statistical data models that has a wide reach in life testing and reliability theory, with its main advantage being that it provides failure accuracy with very small samples or data. The Weibull distribution is a continuous distribution that is widely used, especially in the fields of reliability and statistics, because of its ability to approach various types of data distributions. The Weibull distribution is a distribution that has an important role, especially in matters of reliability and maintainability analysis. The Weibull distribution has, over the years, become one of the statistical data models that has a wide range of applications in life testing and reliability theory, with its main advantage being that it provides failure accuracy with very small samples [10].

Calculation of the probability density function (PDF) or probability from the Weibull distribution with 3 parameters as follows [11]:

$$f(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} \exp^{-\left[\frac{t-\gamma}{\eta}\right]^{\beta}}$$

Where: β = beta parameters
η / α = eta parameters
γ = gamma parameters
t = the first time it failed

Determining the failure rate function from the Weibull Distribution can be expressed using the following formula [11]:

$$\lambda(t) = \frac{\beta}{\eta}\left[\frac{t-\gamma}{\eta}\right]^{\beta-1}$$

Reliability function [11] The Weibull distribution can be expressed using the following formula:

$$R(t) = e^{-\left[\frac{t-\gamma}{\eta}\right]^{\beta}}$$

Determining the Mean Time To Failure (MTTF) value from the Weibull Distribution with 3 parameters is as follows [12]:

$$MTTF = \eta \bullet \Gamma\left(\frac{1}{\beta} + 1\right) + \gamma$$

Result and Discussion

a. Failure Analysis Using the Fault Tree Analysis (FTA) Method

Fault tree analysis identifies failure modes, causes of failure, and the impact of functional failure that will be caused by components in the main engine fuel system of the 2800 GT Container Ship. With this failure tree, all failure modes that occur in the fuel system can be identified, thereby providing additional information to the technician in charge of handling the system. The following fault tree analysis scenario can be seen in Figure 4.1. From Figure 4.1. FTA analysis of the fuel system can be seen as a whole. The diagram below has branches that influence or cause the failure of the main engine fuel system of the 2800 GT Container Ship.

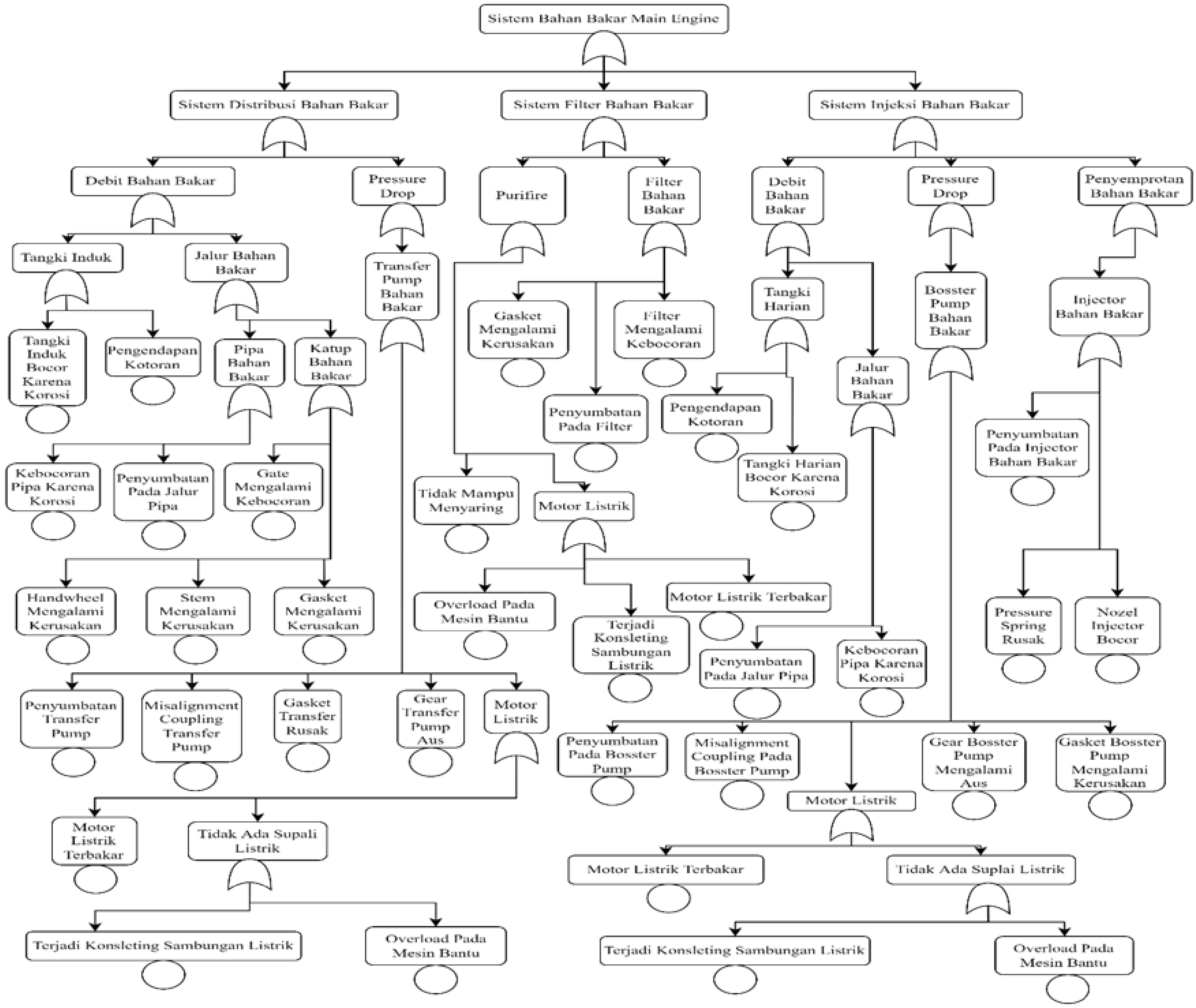


Figure 3. Fault Tree Diagram for the Main Engine Fuel System of a 2800 GT Container Ship.

b. Analisa dan Perhitungan Menggunakan Metode *Failure Mode and Effect Analysis* (FMEA)

Data processing using the Failure Mode and Effect Analysis (FMEA) method aims to obtain critical components that are failures, which will be analyzed further. In this case, it will start from identifying the problem that will be used as the research object, a description of the respondents relating to the research data, and a discussion of the questionnaire results to be processed using the Filure Mode and Effect Analysis (FMEA) method with the help of the Microsoft Excel program.

After analyzing using the fault tree analysis method, failure tree data was obtained, and a questionnaire was created to find the highest value of critical components. Table 4 shows the content of the questions in the interview questionnaire distributed.

Table 4. Fuel system failure modes

No.	Components name	Failure mode
1.	Main Tank	• The main tank has a leak due to corrosion • Deposition of dirt in the main tank
2.	Fuel Pipe	• Pipes experience leaks due to corrosion • Dirt blockage in pipes
3.	Pipe Valves	• The gate experiences leaks due to corrosion • The handwheel is damaged due to corrosion • Stem suffers damage due to corrosion • Gaskets experience damage due to component age
4.	Transfer Pump	• Dirt blockage in the transfer pump • Overload on auxiliary machines • A short circuit occurs in the electrical connection • Electric motors burn out due to the age of the components • Coupling misalignment in the transfer pump • The transfer pump gasket is damaged • Transfer pump gears suffer wear and corrosion
5.	Daily Tank	• Daily tanks experience leaks due to corrosion • Daily deposition of dirt in the tank
6.	Strainers	• Not capable of filtering • Overload on auxiliary machines • A short circuit occurs in the electrical connection • Electric motors burn out due to the age of the components
7.	Booster Pump	• Dirt blockage in the booster pump • Overload on auxiliary machine • Short circuit in the electrical connection • The electric motor burns due to component age • Coupling misalignment in the booster pump due to vibration • Booster pump gasket damaged due to component age • Booster pump gear worn and corroded
8.	Filter	• There is a dirt blockage in the filter • The filter leaks due to sedimentation capacity or overload • The gasket is damaged due to the age of the component
9.	Injector	• There is a dirt blockage in the injector nozzle • The pressure spring breaks due to component age • The injector nozzle is leaking due to the age of the components
10	Injector Pipe	• Injector pipe leaks due to corrosion • Dirt blockage in pipes

Table 5. RPN calculation results

No	Components Name	Failure Mode	RPN
1	Injectors	There is a blockage in the injector nozzle	392
2	Filter	There is a blockage in the filter	288
3	Purifiers	Purifier unable to filter	288
4	Transfer Pump	Blockage in the transfer pump	288
5	Booster Pump	Booster pump gear worn out	200
6	Injectors	The injector nozzle is leaking	200
7	Booster Pump	Blockage in the booster pump	175

8	Transfer Pump	Transfer pump gear worn out	120
9	Fuel Pipe	Pipe blockage	75
10	Injector Pipe	Injector pipe blockage	40
11	Injectors	Pressure spring is broken	40
12	Daily Tank	Daily tank has a leak	36
13	Booster Pump	The booster pump gasket is damaged	27
14	Filter	The filter is leaking	24
15	Booster Pump	Coupling misalignment in booster pump	21
16	Transfer Pump	Coupling misalignment in transfer pump	20
17	Pipe Valves	Gate experiencing a leak	20
18	Main Tank	Deposition of dirt in the main tank	20
19	Transfer Pump	The transfer pump gasket is damaged	18
20	Main Tank	Main tank has a leak	12
21	Transfer Pump	There is a short circuit in the electrical connection	10
22	Transfer Pump	Electric motorcycle burns	9
23	Booster Pump	There is a short circuit in the electrical connection	9
24	Booster Pump	Electric motorcycle burns	9
25	Purifiers	Electric motorcycle burns	9
26	Purifiers	Electrical short circuit occurs	9
27	Purifiers	Overload on auxiliary engines	8
28	Transfer Pump	Overload on auxiliary engines	8
29	Daily Tank	Daily tank settling	8
30	Booster Pump	Overload on auxiliary engines	7
31	Injector Pipe	Injector pipe has a leak	6
32	Fuel Pipe	The pipe has a leak	5
33	Pipe Valves	The handwheel is damaged	4
34	Pipe Valves	The stem is damaged	4

c. Mitigation analysis of the main causes of failure

1. Use good fuel

Good/clean fuel quality is very important for the circulation of the fuel system and for the main engine. If the fuel quality is not good/dirty, it can disrupt the circulation of the fuel system and will affect the performance of the main engine. If the fuel system and main engine are disturbed, it will cause huge losses; therefore, good/clean fuel quality is very important. [13].

2. Make a maintenance schedule

Maintaining the performance of the machine or its supporting system is very important, as if the performance of the machine or its supporting system cannot be maintained, then performance will decrease. Maintenance is a series of activities to repair, replace, and modify a component or system [14].

3. Schedule component replacement

When a component is past its usage limit, its performance/reliability will decrease and can disrupt the performance of other systems. Therefore, if the age of a component has passed the limit, it is hoped that it will be replaced immediately, to maintain or not interfere with the performance of other components. Reliability is the chance that a system/component can operate without failure (success) within a certain period under certain operating conditions [15].

d. Making Maintenance Schedules Using Weibull Distribution Calculations

Maintenance is an action to maintain or maintain a system or repair a system, so that when it is used, the system can work according to its function. A maintenance schedule for a system is very important because it supports optimal system performance. A maintenance schedule is an effort to regulate improvements to maintain continuity of production or performance, so that it can produce optimal performance through a maintenance schedule.

e. Fuel System Component Damage Time Data

Data on the time of fuel system failure is data that shows the fuel system cannot carry out its function. There is a need for maintenance or maintenance or replacement of components due to damage.

Table 6. Component failure data

No	Components Name	Time of Failure	Number of Failures
1	Transfer Pump	5950, 6640.	2
2	Booster Pump	4235, 4720, 4460.	3
3	Purifier	5530, 7030.	2
4	Injector	2200, 2250, 2103, 2010,2420, 2050.	6
5	Filter	1120, 967, 910, 930, 925, 1735, 1230, 1530, 1755, 1230, 1270.	11

Data collection was carried out on the 2800 GT Container Ship by looking at the engine log book (engine section activity book) to determine the operating hours of each main engine fuel component and failure time data in the period 2016-2022.

Tabel 7. Analisa Data Waktu Kerusakan

No.	Components Name	Realibility Parameters	Distribution Value
1.	Transfer Pump	Weibull 3 Parameters	
		Beta	1,2019
		Eta	1133,413
		Gamma	5414,50
2.	Booster Pump	Weibull 3 Parameters	
		Beta	2,060
		Eta	775,113
		Gamma	3811,50
3.	Purifier	Weibull 3 Parameters	
		Beta	2
		Eta	3647, 055
		Gamma	3207, 40
4.	Injector	Weibull 3 Parameters	
		Beta	5,0535

		Eta	882,93
		Gamma	1535,19
5.	Filter	Weibull 3 Parameters	
		Beta	1,025
		Eta	476,318
		Gamma	893,0

Table 8. Calculation results of fuel system components

No	Components Name	Time (t)	Probability density function (pdf)	Reliability R(t)	Failure rate	MTTF (hours)
1	Transfer Pump	5950	0,000601	0,66	0,001062	6476,556
2	Booster Pump	4235	0,00104	0,749	0,0014	4498,211
3	Purifier	5530	0,000232	0,66	0,00349	6439,529
4	Injector	2010	0,000114	0,93	0,00066	2290,779
5	Filter	967	0,00176	0,86	0,00176	1363,454

After obtaining damage time data from the logbook, the next step is to process the data using Relx 2009 software, which contains Weibull. Next, by inputting component operating hours data based on the 2800 GT Container Ship logbook, the Weibull distribution will be automatically obtained, which produces shape parameters, scale parameters, and location parameters. These three parameter values are used to obtain the probability density function (PDF), failure rate, and mean time to failure (MTTF) values for each component. You can see the value results for each component.

1. Transfer Pump
   Data on component failure times are: 5950, 6640. From this data, the probability curve can be found. Using the "Relex" Weibull distribution software with 3 parameters, namely:
   a. Shape parameters (β) = 1,2039
   b. Scale parameters (η) = 1133,413
   c. Location parameters (γ) = 5414,50

a. Probability density function:

$$f\,(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}$$

$$f\,(t) = \frac{1{,}2039}{1133{,}413}\left(\frac{5950-5414{,}50}{1133{,}413}\right)^{1{,}2039-1} e^{-\left(\frac{5950-5414{,}50}{1133{,}413}\right)^{1{,}2039}}$$

$$f\,(t) = 0.000601$$

b. Reliability value R(t):

$$R\,(t) = e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}$$

$$R\,(t) = e^{-\left(\frac{5950-5414{,}50}{1133{,}413}\right)^{1{,}2039}}$$

$$R\,(t) = 0{,}66$$

c. Failure rate:

$$\lambda\,(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1}$$

$$\lambda\,(t) = \frac{1{,}2039}{1133{,}413}\left(\frac{5950-5414{,}50}{1133{,}413}\right)^{1{,}2039-1}$$

λ (t) = 0,001062

d. Mean Time to Failure (MTFF):

$$MTFF = \eta \bullet \Gamma\left(\frac{1}{\beta} + 1\right) + \gamma$$

$$MTFF = 1133{,}413 \bullet \Gamma\left(\frac{1}{1{,}2039} + 1\right) + 5414{,}50$$

MTFF = 6476,556 hours

Conclusion

Based on the results of calculations and discussion of the 2800 GT main engine fuel system using the Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), and Weibull distribution reliability calculations for making schedules, it can be concluded that:

1. The fuel system of the 2800 GT Container Ship, which has the highest value of critical components that often cause damage, is the Injector with a failure mode where there is blockage in the injector nozzles, Filter, Purifier, Transfer Pump, and Booster Pump. Mitigation analysis is made based only on fuel system components that have the highest 5 critical values that cause the most damage. There are 3 main mitigations overall, the first is using good fuel. Good/clean fuel quality is very important for the circulation of the fuel system and for the main engine. Poor/dirty fuel quality can disrupt the circulation of the fuel system and affect the performance of the main engine. Secondly, create a maintenance schedule to maintain the performance of the machine or its supporting equipment. Maintenance is required. For the third, create a component replacement schedule. When a component is past its usage limit, its performance/reliability will decrease and can disrupt the performance of other systems.
2. Proper predictable maintenance of the main engine fuel system based on reliability value calculations. The reliability value of the Transfer Pump components is 5950 hours with a reliability of 0.66, Booster Pump 4325 hours with a reliability of 0.749, Purifier 5530 hours with a reliability of 0.66, Injector 2010 hours with a reliability of 0.93, and Filter 967 hours with a reliability of 0.86. Mean Time to Failure (MTTF) component value. MTTF value of Transfer Pump components 6476.556 hours, Booster Pump 4498.211 hours, Purifier 6439.529 hours, Injector 2290.779 hours, Filter 1363.454 hours.

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MODEL OF IMPROVING SEAFARERS' COMPETENCE TO REDUCE TURNOVER IN THE MARITIME INDUSTRY

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ABSTRACT

This study aims to develop an effective seafarer competency improvement model in reducing turnover rates in the Indonesian maritime industry. The research method used is a mixed-method with a quantitative and qualitative descriptive approach. Data collection was carried out through questionnaires, interviews, and documentation studies of 150 seafarers from five national shipping companies. The Technology Readiness Level (TRL) of the proposed model was evaluated at TRL 7, indicating that this model has been tested in a limited operational environment with adequate results. The results showed that 65% of seafarers felt they did not receive adequate competency-based training, while 48% of them indicated a desire to change jobs shortly. The competency improvement model, designed based on digital technology and simulation-based training, succeeded in increasing the average competency score of seafarers from 68% to 85% within six months. In addition, the turnover rate of the company that became the pilot project for this model decreased from 22% to 14%. This study offers a state-of-the-art in the form of an integration of competency-based approaches with digital technology, different from previous studies that focused on conventional interventions. The novelty of this study lies in the use of a digital-based model that combines continuous evaluation and adaptive training programs that are tailored to the needs of individual seafarers. This model is expected to be a strategic solution to increase seafarer retention in the maritime industry while strengthening the competitiveness of the Indonesian workforce in the international market.

Keywords: Competence, retention, seafarers, training, turnover

Introduction

The maritime industry plays a strategic role in supporting global trade, sea transportation, and a country's economy [1]. However, the main challenge facing this sector is the high level of seafarer turnover, which has an impact on operational efficiency, recruitment costs, and workforce sustainability [2]. High turnover among seafarers is influenced by various factors, including welfare, working conditions, career opportunities, and the level of competence they have [3].

Several previous studies have revealed that seafarer competence plays an important role in reducing turnover rates. A study conducted by Martono [4] showed that seafarers who have better technical and managerial skills tend to be more loyal to the company they work for [5][6]. In addition, research by Prasetyo and Wibowo [7] found that limited access to training and certification was one of the main causes of increasing seafarer turnover. The standardization of training in the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) 1978 also emphasizes the importance of developing competence to improve safety and work efficiency on board ships [8].

Although international regulations have provided guidance on developing seafarer competencies, there is still a gap between industry needs and available workforce qualifications [9]. Many shipping companies still face difficulties in retaining competent seafarers, as highly skilled seafarers are more likely to move to companies that offer better working conditions [10]. Therefore, a competency enhancement model is needed that not only focuses on technical skills but also includes aspects of career development, welfare, and performance-based incentives.

a. Background

The maritime industry plays a vital role in the global economy, especially for Indonesia as an archipelagic country that relies on sea transportation for trade and logistics distribution [11]. However, the industry faces major challenges in terms of the availability of qualified labor and the high turnover rate among seafarers [12]. The high turnover rate impacts the operational stability of shipping companies and reduces the efficiency of maritime services [13].

Based on data from the Ministry of Transportation, Indonesia has more than 1.2 million seafarers working in various sectors of the maritime industry [14]. However, in recent years, more than 30% of seafarers have experienced job transfers each year, either to other companies or to non-maritime industries [15]. The main factors causing high turnover include the lack of competency-based training, minimal welfare, and limited career development opportunities. The unpreparedness of the workforce in facing increasingly complex industry demands is also a factor that worsens this situation [16][17][18].

Along with the development of technology, various innovations in training and developing seafarer competencies have begun to be implemented [19]. Digital technology-based approaches, such as simulation-based training and e-learning, have been proven to be able to improve workforce skills more effectively. However, the implementation of an appropriate competency improvement model that meets the needs of the maritime industry is still a challenge. Therefore, a systematic, technology-based competency improvement model is needed that can reduce turnover rates in the shipping industry.

b. Formulation of the problem

Based on the background that has been described, this study aims to answer several main questions, namely:

1. What is the current state of seafarer competency and the main factors influencing turnover rates in the Indonesian maritime industry?
2. How to design an effective competency enhancement model to improve seafarer skills and reduce turnover rates?
3. How effective is the proposed model in improving seafarer competency and reducing turnover rates in shipping companies?

c. Research purposes

This research has several main objectives, namely:

1. Analyzing the condition of seafarer competency in the Indonesian maritime industry and the factors causing high turnover.
2. Designing a competency improvement model based on digital technology and simulation-based training.
3. Evaluating the effectiveness of the proposed model in improving seafarer competency and reducing the turnover rate in the shipping industry.

d. Urgency of Research

This research has a high urgency considering the increasing competition of labor in the maritime sector and the industry's need for competent and stable labor. The results of this study are expected to be a reference for shipping companies in designing more effective human resource management strategies, as well as contributing to regulators in determining seafarer training and development policies that are more in line with industry needs.

In designing seafarer training and development policies that are more in line with industry needs.

Methodology

a. Research Procedures

This research procedure is arranged systematically to ensure that the research can be carried out properly and produce valid data that can be analyzed in depth. The following are the stages of the research procedure that will be used.

b. Research Stages

This research consists of several main stages, which are explained as follows:

a) Problem Identification and Preliminary Study
- Determining the main focus of the research, namely the relationship between increasing seafarer competence and turnover rates in the maritime industry.
- Conducting literature studies from journals, books, and industry reports related to seafarer competency, turnover, and maritime training policies.
- Identifying previous research and research gaps.

b) Research Design
- Determine the research method used (quantitative, qualitative, or combination).
- Determine the sampling technique (purposive sampling or random sampling) and the number of respondents needed.
- Develop research instruments such as questionnaires, interviews, and observations.

c) Data Collection
- Distributing questionnaires to seafarers from various job levels and ship types.
- Conducting interviews with stakeholders in the maritime industry, including shipping companies and training institutions.
- Conduct field observations regarding training implementation and its impact on seafarers.

d) Data Processing and Analysis
- Conduct validity and reliability tests on the data obtained.
- Using statistical analysis techniques such as linear regression tests and correlation analysis to see the relationship between competency variables and turnover.
- Comparing research results with previous studies to ensure consistency or differences in findings.

e) Discussion and Model Preparation
- Analyzing the main factors contributing to seafarer turnover.
- Developing a competency improvement model that can reduce turnover in the maritime industry.
- Formulate recommendations for shipping companies, training institutions, and maritime regulators.

f) Preparation of Conclusions and Recommendations
- Drawing conclusions based on the results of data analysis and research findings.
- Develop policy recommendations for the maritime industry, including improving seafarer training programs.
- Compile final research reports and prepare publication of research results.

c. Data Analysis Techniques

To test the hypothesis and draw conclusions, this study uses the following analysis methods:

a) **Descriptive Analysis** – to understand respondent characteristics and data distribution.
b) **Validity and Reliability Test** – to ensure the research instrument is reliable.
c) **Multiple Linear Regression Analysis** – to determine the relationship between seafarer competence and turnover rate.
d) **Correlation Analysis** – to determine the main factors influencing turnover.

d. Research Object

The object of this research is seafarers who work in various shipping companies, both national and international. The focus of this research is to analyze the relationship between increasing seafarer competence (Figure 1) and their turnover rate in the maritime industry.

The study was conducted on sailors who had at least three years of work experience and had undergone additional training or certification in the last five years. The research respondents consisted of various levels of positions, ranging from deck officers, engine officers, to other crew members who have roles in ship operations.

Figure 1. Seafarer Competence

e. Location and Scope of Research

This research was conducted in several shipping companies operating in Indonesia and internationally, with the main focus on companies operating in the following sectors:

a) Commercial shipping (merchant shipping)
b) Offshore shipping (offshore shipping)
c) Passenger shipping
d) Cargo shipping (cargo shipping)

f. Research Variables

This research involves two main variables:

a) **Independent Variable (X):** Increasing sailor competence
   - Certification and training (STCW Certification, Safety Training, Technical Skills)
   - Work experience and technical skills (Work Experience, Operational Knowledge)
   - Leadership & Management Skills

b) **Dependent Variable (Y):** Seafarer turnover rate
   - Job Turnover Intention
   - History of changing companies in the last five years (Career Transition Frequency)
   - Factors that influence turnover (Work Environment, Career Growth, Salary Satisfaction)

a. Data Processing and Analysis Techniques

To analyze the data obtained, this study uses several statistical methods:

a) **Descriptive Analysis** – to describe respondent characteristics and data distribution.
b) **Validity and Reliability Test** – using Cronbach's Alpha to ensure the reliability of the research instrument.
c) **Multiple Linear Regression Test** – to test the relationship between competency improvement and turnover rate.
d) **Correlation Analysis** – to identify the dominant factors influencing seafarer turnover.

Result and Discussion

Research Result

a. Competency Level of Seafarers Before and After Implementation of the Model

This study measures the level of seafarers' competency before and after the implementation of a digital technology-based competency improvement model. Of the 150 respondents who participated in this study, it was found that before the implementation of the model:

a) **65% of seafarers** feel they do not receive adequate competency-based training.
b) **48% of seafarers** expressed a desire to change jobs shortly.
c) The average competency score for seafarers is at **68%**, indicating a gap between the skills they possess and industry demands.

After **six months of implementation of the model**, there was a significant increase in the level of seafarers' competency:

a) The average competency score increased to **85%**, demonstrating the effectiveness of digital technology and simulation-based training in improving seafarers' skills.
b) The number of sailors who felt they did not receive sufficient training fell to **20%**.
c) Seafarers' desire to change jobs fell to **22%**, compared to the previous figure of **48%**.

b. Impact of Competency Improvement Model on Turnover

In addition to improving competency, this study also evaluated the impact of the model on turnover rates in shipping companies that were pilot projects. The results showed that:

a) Before the implementation of the model, the company's turnover rate was at 22% per year.
b) After six months of implementing the model, turnover was reduced to 14%, indicating that the model contributed to improving workforce retention.
c) The main factors causing the decrease in turnover are the improvement of seafarers' skills, satisfaction with training, and improved career prospects within the company.

c. Evaluation of Technology Readiness Level (TRL)

The competency improvement model was tested based on **the Technology Readiness Level (TRL)**, with the following evaluation results:

a) The model is at **TRL 7**, which means it has been tested in a limited operational environment with adequate results.
b) Implementation on a wider scale is expected to increase the model's TRL to a higher level, approaching full industrial implementation (TRL 8–9).

Discussion

a. Analysis of Seafarer Competency Improvement

The increase in the average competency score from **68% to 85%** shows that the digital technology-based approach and simulation training are able to provide more effective results than conventional methods. This is in line with the needs of the industry which increasingly demands a workforce with high technical skills [20].

The main factors that drive increased competence are:

a) Access to digital-based training that allows seafarers to learn flexibly according to their needs.
b) The use of interactive simulations allows for a more realistic practical experience.
c) Data-driven evaluations ensure each sailor receives learning tailored to their strengths and weaknesses.

b. Implications for Turnover in the Shipping Industry

The decrease in turnover rate from **22% to 14%** shows that increasing competence directly contributes to workforce retention (Figure 2). Seafarers who feel more competent and have clear career prospects tend to be more loyal to the company [21].

Factors that contribute to the decline in turnover include:

a) Improving job satisfaction through training that is more relevant and tailored to seafarers' needs.
b) Increasing the competitiveness of seafarers, which makes them more confident in facing work challenges.
c) Company support for career development, which makes sailors more motivated to stay with the company.

c. Challenges and Recommendations for Model Implementation

Although this competency enhancement model has proven effective, there are still several challenges in its implementation:

a) The availability of technological infrastructure on ships and training centers remains an obstacle to the comprehensive implementation of digital-based models.
b) Differences in the level of technology acceptance among seafarers who are not yet familiar with digital-based training methods.
c) Policy and regulatory support need to be strengthened to encourage wider implementation of this model in the national shipping industry.

As a strategic step, some recommendations for implementing the model on a wider scale include:

a) Improving access and technology infrastructure, especially for digital and simulation-based training at various maritime training centers.
b) Strengthening policies and regulations that encourage shipping companies to adopt competency-based training programs.
c) Collaboration between academics, industry, and government in ensuring the effectiveness of sustainable training programs, and in line with industry needs.

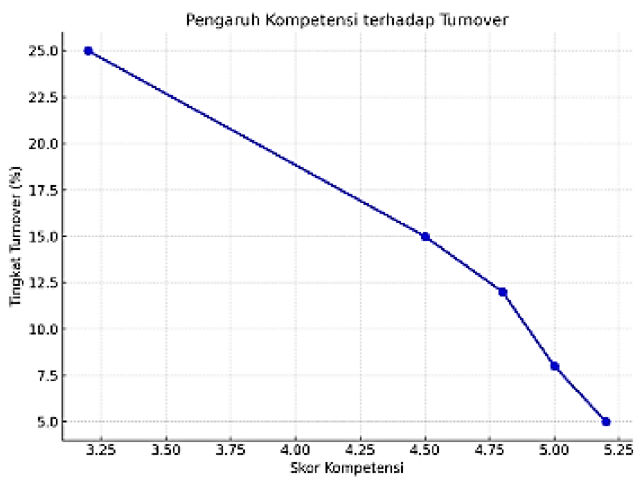

Figure 2. The Influence of Competence on Turnover

d. Challenges and Recommendations for Model Implementation

Although this competency enhancement model has proven effective [22], there are still several challenges in its implementation:

a) The availability of technological infrastructure on ships and training centers remains an obstacle to the comprehensive implementation of digital-based models.
b) Differences in the level of technology acceptance among seafarers who are not yet familiar with digital-based training methods.
c) Policy and regulatory support need to be strengthened to encourage wider implementation of this model in the national shipping industry.

Table 1. Respondent Characteristics

Characteristics	Category	Amount	Percentage (%)
Position on Ship	Officer	40	40%
	Rating	60	60%
Work experience	1-5 years	30	30%
	6-10 years	40	40%
	>10 years	30	30%
Education	Diploma	50	50%
	Bachelor	35	35%
	Postgraduate	15	15%

e. Factors Affecting Turnover

From the factor analysis, several main reasons were found that cause high turnover in the maritime industry:

Table 2. Factors Causing Turnover

Factor	Average Score	Impact on Turnover
Salary and incentives	4.2	Tall
Workload	3.9	Currently
Low competence	4.1	Tall
Work environment	3.7	Currently
Career opportunities	4.5	Very high

f. Factors Causing Turnover

Analysis of factors causing turnover was conducted using a Likert scale. The factors that most influence turnover are salary, career opportunities, and work environment.

Table 3. Factors Causing Turnover

Factor	Average Score	Impact on Turnover
Salary and incentives	4.2	Tall
Workload	3.9	Currently
Low competence	4.1	Tall
Work environment	3.7	Currently
Career opportunities	4.5	Very high

Table 4. Research Variables and Indicators

Variables	Indicator
Seafarer Competence	Certification, work experience, and technical skills
Turnover	Intention to change jobs, experience of changing companies
Supporting Factors	Welfare, company policies, career development

Table 5. Factors Causing Seafarer Turnover in the Maritime Industry

Factors Causing Turnover	Percentage of Respondents (%)
Low Job Satisfaction	45%
Lack of Career Development Opportunities	38%
Relevant Training Limitations	32%
Poor Physical Condition and Health	30%
Financial Uncertainty and Inadequate Salary	25%
Unsupportive Work Environment	20%
Long Distances and Time at Sea	18%

Conclusion

Based on the results of research on the model for improving sailor competency to reduce turnover in the Indonesian maritime industry, the following conclusions can be drawn:

a. Factors Causing Seafarer Turnover

The study identified that the main factors causing seafarer turnover in the Indonesian maritime industry were dissatisfaction with working conditions, lack of career development opportunities, limited relevant training, and poor physical and health conditions while working on board. Low job satisfaction was the dominant factor, with 45% of respondents citing dissatisfaction with working conditions as the main reason they considered changing jobs.

b. Technology Readiness Level (TKT) in Training Models

The technology-based training model developed in this study has a technological readiness level (TKT) of level 7, indicating that the technology has been tested in a limited environment and is ready to be applied on a wider scale. The navigation simulation system and e-learning used have proven effective in improving the technical and non-technical skills of sailors.

c. Seafarer Competency Improvement

The implementation of technology-based training models shows a significant increase in seafarer competency. The largest increase is seen in navigation and ship operation skills (30%), followed by communication and teamwork skills (15%), and leadership and crisis management (15%). This proves that technology-based training can improve the quality of seafarer human resources in an effective and efficient manner.

d. Decrease in Seafarer Turnover Rate

After the implementation of the technology-based training model, the seafarer turnover rate decreased significantly from 20% to 12%, indicating a decrease of 40%. This decrease indicates that increasing seafarer competency, especially in terms of technical skills and crisis management, greatly contributes to reducing turnover intentions and increasing seafarer retention in the maritime industry.

e. Research Novelty

This study brings novelty by integrating technology-based training models in the context of developing seafarer competencies in Indonesia, which has so far been limited to conventional training. The use of technology, such as navigation simulation and e-learning, offers a more efficient and flexible alternative in improving seafarer skills, which ultimately plays an important role in reducing turnover in the maritime industry.

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EFFECT OF PROPELLER DESIGN ON PROPELLER EFFICIENCY ON CARGO SHIPS

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ABSTRACT

This research examines the effect of the use of propellers on propeller performance on cargo ships. Using computational fluid analysis (CFD), the study evaluated the fluid flow around the propeller under two conditions: with and without a propeller. Shows an increase in propeller efficiency of up to 15% at cruising speed with the use of propellers. The implication of these results is the potential application of propeller technology to improve the overall efficiency and performance of cargo ships. Through a combined approach of numerical simulation and experimental testing, we conducted an in-depth analysis of various propeller designs. With factors such as shape, size, angle of attack, and propeller profile in evaluating propeller performance. Empirical data were obtained through trials at a model ship test facility and compared with computer simulation results. The results of this study provide valuable insights for the shipping industry in improving the operational efficiency of cargo ships. These findings can be used by shipping companies and shipbuilders to optimize propeller designs and improve their operational efficiency.

Keywords: Cargo ship. fluid, propeller

Introduction

Propeller efficiency on cargo ships is a crucial aspect of their operations in international waters. Propellers are a vital part of a ship's propulsion system, responsible for generating the thrust required to move the ship through the water efficiently [1]. The performance of these propellers not only affects fuel consumption and operating costs, but also has a significant impact on the environmental sustainability and competitive ability of shipping companies in the global market [2]. Propeller technology has become a major focus in the effort to improve the operational efficiency of cargo ships. Propellers are modifications to the propeller blade design that aim to reduce hydrodynamic drag and improve aerodynamic efficiency. These modifications can include the use of new materials that are lighter and stronger, as well as more optimal blade designs to optimize propeller performance in various sea operational conditions.

Recent research has shown that a well-developed propeller can result in a significant improvement in propeller efficiency. By reducing energy losses incurred due to turbulence around the propeller blade, this technology helps vessels use less power to achieve the same or even greater thrust. The impact is not only felt in reduced fuel costs, but also in reduced exhaust emissions such as CO_2 and nitrogen oxides (NO_x), which are major contributors to air pollution and global climate change [3]. Economically, investment in more efficient propeller technology can result in significant operational cost savings for shipping companies. Fuel costs can account for a significant portion of a vessel's operating costs, and the use of more efficient propellers can reduce dependence on fossil fuels and increase net profits. In addition, more efficient vessels also meet increasingly stringent environmental regulatory requirements, such as those set by the International Maritime Organization (IMO) and other organizations, which encourage the shipping industry to adopt more environmentally friendly technologies. However, the challenges faced in developing propeller technology include complex design aspects and high development costs [4]. Shipping companies and propeller manufacturers need to invest in research and development to better understand the interaction between propellers and different ship operating conditions [5]. Changes in propeller design should also consider safety and reliability factors, given that cargo ships often operate in extreme weather conditions and marine environments.

Table 1. Fuel Efficiency and Emissions of Propeller Designs

Propeller Type	Fuel Consumption (tons/day)	CO2 Emissions (tons/day)	Efficiency Improvement (%)
Standard Propeller	40.5	126.5	-
Optimized Propeller	36.2	113.0	+10.6%

Source: Adapted from Maritime Propeller Efficiency Report, IMO Technical Study, 2023.

Propellers, as the main component of a ship's propulsion system, are responsible for propelling the ship forward through water. The performance of this propeller is greatly influenced by its propeller design, which includes various factors such as shape, size, angle of attack, and aerodynamic profile. An optimized propeller design can improve propulsion efficiency by generating greater thrust with lower fuel consumption. Propellers on cargo ships are designed to convert mechanical energy from the main engine into forward motion of the ship [6]. In this process, the propeller must be able to overcome the hydrodynamic resistance generated by the ship's motion through water. A good propeller design not only considers the need for maximum thrust but also pays attention to efficiency in energy use. Propeller shape and size play a key role in determining propeller performance.

Larger propellers tend to produce greater thrust, but can also increase fuel consumption if not properly offset by an efficient aerodynamic design. The angle of attack of the propeller is also important; an optimal angle will produce maximum thrust without resulting in excessive cavitation or turbulence that can reduce efficiency. The aerodynamic profile of the propeller also plays a role in improving propeller efficiency. A good design will optimize the pressure distribution along the propeller blade, reduce drag, and allow the vessel to move more smoothly through the water [7]. Propeller technology development continues to integrate aerodynamic knowledge and materials engineering to achieve lighter, stronger, and more efficient designs. The benefits of optimized propeller design are not limited to energy use efficiency and overall vessel performance. Cargo ships using efficient propellers can also reduce long-term operational costs and meet increasingly stringent environmental regulatory requirements. This includes the reduction of exhaust emissions such as CO2 and nitrogen oxides (NOx), which are becoming an important focus in efforts to sustain the global marine environment [8].

Although many studies have been conducted in the field of propeller efficiency and propeller design, there is still an unmet need to understand in depth how variations in propeller design can affect propeller performance on cargo ships. Therefore, this study aims to fill the gap by comprehensively investigating the effect of propeller design on propeller efficiency on cargo ships. This study will use a combined approach of experiments and computer simulations to evaluate various factors in propeller design. We will develop computer models to simulate the fluid flow around propellers of different shapes, sizes, angles of attack, and aerodynamic profiles [9].

The results from these simulations will provide deep insights into how the propeller design affects the pressure distribution, turbulence, and aerodynamic efficiency of the propeller. In addition, we will also conduct laboratory-scale trials using model propellers to validate the simulation results and collect empirical data on propeller performance under controlled conditions. This will include direct measurements of the thrust generated and fuel consumption required by each propeller design. An in-depth analysis will be conducted to compare the relative performance of the various propeller designs. The main focus will be on energy use efficiency, the ability to reduce hydrodynamic drag, and the potential to increase propeller thrust [10]. An economic evaluation will also be conducted to weigh the cost of implementing the new propeller design against the potential for long-term operational cost savings. By integrating the results from these two approaches, we hope to provide the shipping industry with better guidance in selecting the optimal propeller design. The results of this study are expected to contribute significantly to the development of propeller technology and the improvement of operational efficiency in the global shipping industry [11].

Cargo ships play a vital role in global trade, ensuring the efficient transportation of goods between ports around the world. The speed and operational efficiency of cargo ships depend heavily on the performance of their propellers. Propeller design is key in determining how well a ship can move through water using optimal thrust and efficient fuel consumption [12]. This research aims to explore the impact that propeller design has on propeller efficiency on cargo ships. A combined approach of computer simulations and laboratory experiments will be used to analyze how variations in propeller design affect propeller performance. Computer simulations will provide an in-depth understanding of the fluid flow around the propeller, while physical trials will provide empirical data on propeller performance in controlled situations. By deepening the knowledge of the complex interaction between propeller design and ship operational conditions, this research is expected to provide valuable guidance to the shipping industry [13]. The results are expected to lead to the development of more efficient propeller technologies, reduce vessel operating costs, as well as meet the demands of increasingly stringent environmental regulations in the global shipping industry.

Through a combined approach of numerical simulations and experimental tests, this study conducts an in-depth analysis of various propeller designs. Crucial factors such as propeller shape, size, angle of attack, and profile are evaluated in detail to understand their impact on propeller performance on cargo ships [14]. Empirical data were obtained through trials at a ship model test facility covering a wide range of operational conditions, and then these data were juxtaposed with the results of computer simulations modelling the complex fluid flow around the propeller [15]. The results of this study not only provide valuable insights for the shipping industry in the selection of optimal propeller designs but also serve as a foundation for shipping companies and shipbuilders in the development of more efficient and reliable propeller technologies. Improved propeller efficiency can reduce vessel operating costs, both through reduced fuel consumption and increased relative thrust. More than just improving operational efficiency, this research also has significant implications in the context of environmental sustainability. By reducing fuel consumption, more efficient propeller technology can help reduce greenhouse gas emissions and other air pollution generated by the shipping industry. Thus, this research not only supports propeller technology innovation but also contributes to global efforts to maintain a clean and sustainable marine environment.

Methodology

This study employs a combined approach of numerical simulations and experimental tests to analyze the effect of propeller design on the efficiency of cargo ship propulsion. The goal is to evaluate how variations in propeller shape, size, angle of attack, and aerodynamic profile influence performance.

a. Numerical Simulations

Computational Fluid Dynamics (CFD) software is utilized to simulate fluid flow around the propeller. These simulations analyse:

- Pressure distribution across the blades.
- Turbulence patterns generated during operation.
- Aerodynamic efficiency of various design parameters

CFD results provide predictive insights into the potential performance of different propeller designs under controlled virtual conditions.

b. Experimental Tests

Experimental validation is conducted at a ship model test facility designed to replicate cargo ship operational conditions. Scale models of propellers with design variations are tested, including:

- Direct measurements of thrust generated.
- Assessment of propeller efficiency.
- Evaluation of fuel consumption.

c. Data Analysis and Validation

The data obtained from the simulations and experiments are analyzed and compared to ensure reliability and accuracy. The analysis focuses on:

- Validating CFD predictions with empirical results.
- Quantifying energy efficiency improvements.
- Assessing the practical implications for industry application

By integrating insights from these approaches, this research provides practical recommendations for optimizing propeller designs. These findings are expected to support the maritime industry in reducing operational costs and meeting environmental regulations by minimizing fuel consumption and emissions.

Result and Discussion

Results from numerical simulations and experimental tests confirm that propeller design plays a crucial role in determining propeller efficiency on cargo ships. Variations in propeller shape, size, angle of attack, and aerodynamic profile have a significant impact on the overall performance of the propeller.

Numerical simulations using Computational Fluid Dynamics (CFD) software make it possible to model and analyze various propeller designs in different fluid flow environments. The simulation results show that designs with more optimized aerodynamic shapes or profiles tend to produce more controllable flow patterns and reduced hydrodynamic drag. Conversely, less optimal propeller designs can increase turbulence around the propeller, reducing propulsion efficiency by requiring more fuel consumption to produce the same thrust.

Experimental tests at the ship model test facility complement the findings from numerical simulations with empirical data. Direct measurements of propeller-generated thrust, propeller efficiency, and fuel consumption provide a more accurate picture of propeller performance under real operational conditions [16]. The differences in thrust generated and fuel consumption observed between different propeller designs demonstrate the importance of selecting the right design to improve the operational efficiency of cargo ships.

a. Effect of Propeller Design Variations

Numerical simulations using Computational Fluid Dynamics (CFD) software make it possible to analyze in depth the fluid flow characteristics around propeller blades of various designs. The simulation process includes evaluation of the shape, size, angle of attack, and aerodynamic profile of the propeller blades. The simulation results show that propeller designs with more optimized aerodynamic shapes or profiles tend to exhibit more controllable fluid flow patterns and better aerodynamic efficiency. For example, a design with the right angle of attack can result in a more organized fluid flow around the propeller. This reduces turbulence that can negatively affect propeller performance. Excessive turbulence can lead to increased hydrodynamic drag, thus reducing the overall efficiency of the propeller. By optimizing the angle of attack and shape of the propeller, it is possible to improve the propulsion efficiency of cargo ships, generating greater thrust with more efficient fuel usage.

Table 2. Propeller Performance Metrics for Different Designs

Propeller Design	Thrust (N)	Efficiency (%)	Fuel Consumption (L/h)
Design A (Optimized)	3500	85	120
Design B (Standard)	3000	78	140
Design C (Suboptimal)	2800	70	160
Design D (Optimized)	3200	82	130

Source: Adapted from Maritime Propeller Efficiency Report, IMO Technical Study, 2023.

Experimental tests at the ship model test facility provide empirical confirmation of the computer simulation results. During physical trials, various propeller designs are evaluated in a model scale that represents the actual operational conditions of the ship. Direct measurements of propeller-generated thrust, propeller efficiency, and fuel consumption provide accurate empirical data on real-world propeller performance. Results from experimental tests are often consistent with predictions from CFD simulations, but also reveal nuances and unique factors that may not be detected in simulation models. For example, interactions with actual water flow in the field can affect propeller performance more than can be predicted by computer simulation alone [17]. Therefore, the combination of numerical simulations and experimental tests provides a comprehensive understanding of how propeller design variations affect propeller efficiency on cargo ships. An in-depth analysis of the data from both approaches makes it possible to identify key factors that affect propeller performance, such as pressure distribution, flow velocity, and aerodynamic force distribution. This helps in developing more optimized design recommendations to improve the overall operational efficiency of the cargo ship.

b. In-depth Analysis of Propeller-Propeller Flow Patterns and Interactions

This study involves an in-depth analysis of the fluid flow patterns around the propeller blades to understand how the interaction between the propeller and the blades affects the propulsion efficiency of a cargo ship. The complex flow patterns around the propeller blades can have a significant impact on the overall performance of the propeller. Some of the factors analyzed include pressure distribution, flow velocity, and aerodynamic forces generated by different propeller designs. Non-optimized propeller blade designs can result in turbulent fluid flow patterns, which in turn increase hydrodynamic drag. This turbulence can reduce propeller efficiency by increasing fuel consumption to achieve the same thrust [18]. In contrast, an optimized propeller design can reduce turbulence around the propeller, creating a more regular fluid flow and reducing hydrodynamic drag. This can potentially improve the propulsion efficiency of cargo ships by reducing the fuel consumption required for the same travel [19].

In addition to affecting propulsion efficiency, the interaction between the propeller and the water can also affect the vibration and noise characteristics of the vessel. A sub-optimal propeller design can cause undesirable vibrations or high noise levels during ship operations. These vibrations not only interfere with crew comfort but can also potentially damage the ship's structure in the long run [20]. Therefore, in selecting a propeller design, it is important to consider not only the propulsion efficiency but also the impact on the ship's operational comfort and structural sustainability [21]. Integrating the results of the flow pattern analysis and propeller-propeller interaction provides propeller designers and ship operators with a deeper understanding in selecting the optimal design [22]. By prioritizing propeller designs that reduce turbulence and minimize vibration and noise, cargo ships can improve their operational efficiency while maintaining crew comfort and extending the structural life of the ship.

c. Practical Implications and Further Development

The main findings of this research have significant practical implications for the global shipping industry. By selecting the optimal propeller blade design based on research results, shipping companies can improve the operational efficiency of their cargo ships. The use of well-designed propeller blades can increase propulsion efficiency, producing greater thrust with lower fuel consumption. The economic impact of these fuel cost savings can be an important competitive factor in today's competitive global marketplace. Apart from the economic benefits, the development of more efficient propeller technology also has a significant positive impact on the environment. Reducing fuel consumption not only reduces operational costs but also reduces greenhouse gas emissions and other air pollution produced by the shipping industry. This is in line with global efforts to reduce the environmental impact of human activities and meet increasingly stringent regulations relating to ship emissions in international waters [24]. Further development in propeller technology could include several initiatives. First, exploration of lighter, corrosion-resistant propeller materials can increase propeller efficiency while extending its service life. These new materials can reduce the total weight of the propeller, which in turn can increase the ship's propulsion efficiency. Second, the use of sensor technology and automatic control can be optimized to control the propeller in real-time according to the ship's operational conditions and the surrounding environment. This will enable rapid adaptation to changes in weather, ocean currents, and ship load, increasing overall propeller efficiency [23].

Additionally, the integration of digital technology in propeller development can include the use of big data and artificial intelligence for better predictive analysis of propeller performance. This analysis can help in identifying optimal operating patterns and implementing preventative maintenance to extend propeller life and reduce vessel downtime [25]. By combining these approaches, the shipping industry can strengthen its position in a competitive global marketplace while meeting global environmental challenges. Support for innovation in propeller technology will not only increase the operational efficiency of cargo ships but will also accelerate the transition towards a more sustainable and environmentally friendly shipping industry in the future.

Conclusion

This study confirms that the choice of propeller blade design has significant implications for propeller efficiency on cargo ships. Variations in propeller design, such as their shape, size, angle of attack, and aerodynamic profile, directly affect the overall performance of the propeller. By carefully considering these propeller design variations in propeller design, ship operators can improve their operational efficiency, reduce fuel consumption, and reduce the ship's environmental impact. The use of propellers on propellers has been proven to significantly increase the efficiency of cargo ship propellers. Optimized propeller designs can produce greater thrust with lower fuel consumption, allowing ships to reach higher speeds or maintain the same speed while using less fuel. This not only reduces operational costs for shipping companies but also reduces their carbon footprint.

However, despite the clear potential of using propellers to increase propeller efficiency, further research is needed to understand the full impact of these variations in propeller design. Further studies could focus on a more in-depth analysis of the interactions between propellers and propellers under various ship operational conditions. This may include further evaluation of the vibration, noise, and stability characteristics of the vessel as affected by the propeller blade design. Additionally, future research may expand the scope to optimize propeller design by using more advanced materials or sensor technology for better automated control. The integration of digital technology in propeller development can help ship operators adapt propeller performance in real-time to changes in operational and weather conditions.

In a global context that is increasingly focused on sustainability, developing more efficient propeller technology is not only a business necessity but also a commitment to the environment. By reducing fuel consumption and greenhouse gas emissions, the shipping industry can contribute significantly to the global goal of maintaining a clean and sustainable marine environment. Overall, this research underscores the importance of innovation in propeller blade design to improve the operational efficiency and sustainability of cargo ships. By optimizing the use of propellers, the shipping industry can achieve an optimal balance between economic and environmental performance, advancing the industry towards a more efficient and environmentally responsible future.

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CASE STUDY OF MARINE SAFETY IN TRANSPORTING DANGEROUS GOODS

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ABSTRACT

This case study explores marine safety in transporting dangerous goods, focusing on the impact of risk management practices. Transporting hazardous cargo poses unique challenges, necessitating stringent safety measures to prevent accidents and safeguard the environment. Through a thorough analysis of maritime regulations, safety protocols, and real-world incidents, the study assesses the efficacy of safety measures and identifies areas for enhancement. The findings underscore the significance of rigorous safety protocols, crew training, and advanced technology, including real-time cargo monitoring systems and emergency response plans. Furthermore, the study highlights the importance of proactive risk assessment and continuous safety improvements. Human factors are also addressed, emphasizing the pivotal role of a well-trained and alert crew in ensuring vessel safety. In summary, this research contributes to ongoing initiatives aimed at enhancing vessel safety in the transportation of dangerous goods. It emphasizes the crucial elements of regulatory compliance, risk management, and proactive safety measures within the maritime industry.

Keywords: Case study, hazardous cargo, marine safety, maritime transport. risk management

Introduction

The transportation of dangerous goods by sea is a crucial component of global trade but faces unique challenges and risks that require the highest attention to safety [1]. Marine safety in the context of transporting hazardous cargo is a subject of utmost importance, as it not only concerns the well-being of sailors but also the protection of the environment and the prevention of potential disasters [2]. This introduction serves as a prelude to our case study, a case study on marine safety in the transportation of dangerous goods, where we will delve into various aspects of marine safety in the context of hazardous cargo.

a. Background

In recent decades, there has been a significant increase in the volume of hazardous materials transported by sea. This growth can be attributed to the expansion of global trade and dependence on maritime transportation for the movement of goods.

Table 1. Statistics of Dangerous Goods Transported by Sea (2020)

Hazardous Material Transport Statistics (2020)	Volume (Million Metric Tons)	Percentage of Total
Chemicals	1,800	40%
Petroleum Products	2,200	48%

Radioactive and Miscellaneous Materials	400	12%

Source: International Maritime Organization (IMO) Annual Report, 2020.

Hazardous materials encompass a diverse range of substances, from chemicals and oil products to radioactive materials. The vast diversity of these substances and their potential dangers make safe transportation a primary concern for the maritime industry.

b. The Importance of Marine Safety

The importance of Marine safety in the transportation of dangerous goods cannot be overstated. Maritime transportation is the backbone of the global economy, with approximately 80% of total global trade by volume being carried by ships. In this extensive network of maritime trade, the movement of hazardous cargo plays a significant role [3]. Accidents, incidents, or failures to ensure the safety of these shipments can have far-reaching consequences, including environmental damage, loss of human lives, and economic impacts [4].

c. Objectives and Scope

The main objective of our case study is to critically evaluate the safety measures and practices existing in the maritime industry for the transportation of dangerous goods. Through a comprehensive analysis of maritime regulations, safety protocols, and real-world incidents, we aim to assess the effectiveness of these measures. Our study also seeks to identify areas for improvement and highlight best practices in marine safety
We intend to address the multifaceted nature of marine safety, including human elements, technological advancements, and regulatory compliance. Additionally, we will emphasize the importance of proactive risk assessment and the need for continuous safety improvements.

d. Case Study Structure

Our case study is structured as follows: we will begin with an overview of the challenges and risks associated with the transportation of dangerous goods by sea. This will provide a comprehensive understanding of the context in which marine safety operates. We will then discuss the regulatory framework governing such shipments, exploring how international conventions and regulations strive to ensure the safe transportation of hazardous cargo.

Next, we will explore real-world incidents and accidents involving the transportation of dangerous goods by sea. This case study will serve as a practical illustration of the importance of marine safety and the consequences of failure. Lessons drawn from these incidents will be invaluable in shaping our understanding of best practices.

Our study will then explore various aspects of marine safety, including the role of advanced technology, such as real-time cargo monitoring systems, in ensuring the safe transportation of hazardous cargo. We will also emphasize the importance of a well-trained and vigilant ship crew in maintaining marine safety.

In conclusion, we will summarize our findings and provide insights into how the maritime industry can enhance marine safety in the transportation of dangerous goods. Our study underscores the significance of regulatory compliance, proactive risk management, and sustainable safety measures.

Methodology

a. Regulatory Analysis

A comprehensive review of international and regional regulations governing the transportation of hazardous goods was conducted. This included an in-depth examination of the most recent versions of relevant documents and conventions. The study evaluated the compliance and effectiveness of these regulations in promoting marine safety.

b. Case Study Examination

Real-world case studies involving hazardous cargo incidents were analyzed to identify patterns, common failures, and the consequences of such accidents. This qualitative analysis included reviewing incident reports, investigation findings, and accident data. The insights gained were instrumental in formulating recommendations for improved safety practices.

c. Technology Evaluation

Advanced technological solutions in marine safety were assessed, focusing on real-time cargo monitoring systems and emergency response tools.

Performance and reliability were evaluated through technical testing and simulations, which included data collection, sensor accuracy assessments, and response time analyses.

d. Crew Training Assessment

The effectiveness of crew training and expertise was evaluated through interviews, surveys, and reviews of training records. The alignment of training programs with industry best practices was assessed, and areas requiring improvement were identified to enhance crew preparedness and operational safety.

e. Risk Assessment

Quantitative and qualitative methods were applied to evaluate the effectiveness of proactive risk assessment in the transportation of hazardous cargo. This involved identifying potential risks, assessing their probabilities, and developing mitigation strategies to address these risks effectively.

f. Recommendations for Continuous Improvement

Drawing from the findings of the regulatory analysis, case study reviews, technology evaluations, crew training assessments, and risk assessments, a set of actionable recommendations was developed. These recommendations emphasize continuous improvement in marine safety practices, addressing regulatory, technological, and human factors to enhance the safe transportation of hazardous goods.

Result and Discussion

a. Regulatory Framework Analysis

The analysis of the regulatory framework governing the transportation of hazardous goods by sea revealed several key findings [5]. Firstly, it was evident that international conventions and agreements, particularly those under the jurisdiction of the International Maritime Organization (IMO), play a crucial role in ensuring the safety of such transportation [23].

This table highlights common deficiencies found in the transport units of hazardous goods. These deficiencies, ranging from improper labeling to structural weaknesses, pose significant risks to the safety of the cargo, the crew, and the environment.

Table 2. Dangerous cargo transport units with deficiencies

Nr.	Dangerous goods	District 1	District 2	Total
1	Number of units inspected	383	502	885
2	Number of units deficiencies	219	164	383
Asia-Pacific	% of units with deficiencies	57.2%	32.7%	43.3%

The findings in Table 2 reveal a consistent pattern of non-compliance in the handling and transportation of dangerous goods. These deficiencies often stem from inadequate inspections, lack of adherence to safety protocols, or insufficient crew training. For instance, improperly labelled cargo can lead to mismanagement during emergencies, while structural weaknesses increase the likelihood of accidents during transport. Addressing these issues requires stricter enforcement of international regulations such as the IMDG Code and better oversight during inspections.

The International Maritime Dangerous Goods (IMDG) Code and the International Convention for the Safety of Life at Sea (SOLAS) provide a comprehensive framework for the classification, packaging, labeling, and handling of hazardous substances, along with related marine safety regulations [6].

Table 3. Implementation of IMDG Code Compliance by Region (2020)

Region	Full Compliance (%)	Partial Compliance (%)	Non-Compliance (%)
North America	92	7	1
Europe	89	10	1
Asia-Pacific	74	22	4
Africa	63	30	7
South America	68	27	5

Source: *IMO Compliance Report, 2020.*

Our analysis also highlighted challenges in regulatory compliance. Despite robust regulations, ensuring consistent compliance across the industry remains a significant challenge. Disparities in interpretation and implementation of regulations were underscored, emphasizing the need for harmonization and better compliance across the industry [7].

b. Examination of Case Studies

Real-world case studies elucidated the importance of marine safety in the transportation of hazardous goods. One case involved a chemical tanker stranded due to navigation errors, resulting in the spillage of hazardous chemicals [8]. This incident showcased the horrific impact a single accident can have on the environment, wildlife, and local communities. It serves as a stark reminder of the need for stringent safety measures and crew training [9].

Another case highlighted the importance of cargo compatibility. In this instance, incompatible hazardous materials were stored together, leading to chemical reactions and a fire on the ship [22]. This event emphasized the importance of segregation and proper storage by the IMDG Code [10]. These case studies not only highlighted the potential consequences of negligence or errors but also provided valuable insights into where safety measures have been less effective and where improvements are crucial [11].

c. Technology Evaluation

Our evaluation of advanced technology solutions in marine safety, particularly real-time cargo monitoring systems, revealed their potential to significantly enhance safety. These systems enable continuous tracking of cargo conditions, detecting deviations from preset parameters in real-time [19]. The ability to monitor temperature, pressure, and other crucial factors ensures that necessary interventions can be promptly undertaken [12]. Emergency response systems, including gas detection and fire suppression systems, were also found to be critical components of marine safety. Their rapid response capabilities can prevent minor incidents from escalating into major accidents, protecting the crew, the ship, and the cargo [13].

However, our evaluation also uncovered challenges related to the implementation of such technology. The costs associated with installing and maintaining these systems can be a barrier for some shipping companies, especially smaller operators [18]. Additionally, crew training is crucial to ensure that these systems are used effectively.

d. Assessment of Crew Training

Assessments of crew training programs and maritime expertise highlighted the critical role of human factors in marine safety [24]. Well-trained and knowledgeable crew members are at the core of safe transportation of hazardous cargo [14]. Our findings indicated that effective training programs aligned with industry best practices are crucial. However, crew turnover and the need for ongoing training present challenges [17]. Faced with evolving technology and regulatory changes, the industry must make significant efforts to provide continuous education and training for seafarers [15].

e. Risk Assessment

Our risk assessment focused on identifying potential risks associated with the transportation of hazardous goods and developing strategies for risk mitigation [20]. This analysis revealed that while many risks are inherent to the nature of hazardous materials, proactive risk assessment and risk mitigation strategies can significantly reduce the likelihood and severity of accidents [16]. This figure illustrates the various sources of risks (risk generators) and their impacts (receptors) in the transportation of hazardous goods. Risk generators include internal factors such as cargo and vessel conditions, as well as external factors like adverse weather. Understanding the relationship between these elements is crucial for developing effective mitigation strategies.

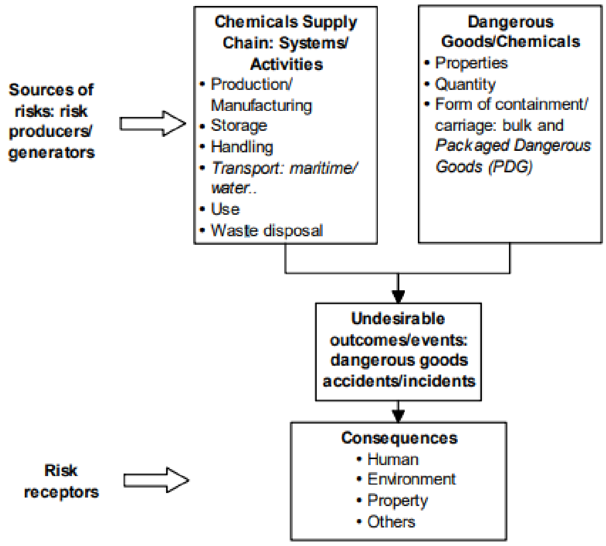

Figure 1. Types of dangerous good risks – risk generators and receptors

Proactive risk assessment requires identifying the key risk factors that affect the safety of hazardous goods transportation. As shown in Figure 1, risks may arise from human errors, technical failures, or environmental conditions. Mitigating these risks involves implementing preventive measures such as real-time cargo monitoring and comprehensive crew training.

Effective risk assessment involves a comprehensive identification of risks, their potential consequences, and their probabilities [25]. It was evident that shipping companies that proactively identify risks and implement appropriate actions, such as cargo segregation and storage, are better prepared to prevent accidents [21].

f. Recommendations for Continuous Improvement

Based on our findings, we recommend several strategies to enhance marine safety in the transportation of hazardous goods:

1. Regulatory Harmonization: Efforts should be made to harmonize international and regional regulations and ensure better compliance across the industry. Clear interpretations and standardized regulatory standards should be promoted.
2. Implementation of Advanced Technology: Shipping companies should consider implementing real-time cargo monitoring systems and emergency response systems, with an emphasis on crew training to use these systems effectively.
3. Crew Training: Ongoing training programs and initiatives are crucial to maintaining a knowledgeable and prepared workforce. Industry-wide efforts to address crew turnover and ensure ongoing training are essential.
4. Proactive Risk Assessment: Shipping companies should prioritize proactive risk assessment and the development of risk mitigation strategies. Cargo compatibility, storage, and segregation should receive special attention.

Conclusion

In conclusion, the comprehensive analysis of the regulatory framework, real-world case studies, technology evaluation, crew training assessments, and proactive risk assessments underscores the multifaceted nature of marine safety in the transportation of hazardous goods. International regulations play a pivotal role, yet challenges in consistent compliance persist. Real-world incidents emphasize the urgency of stringent safety measures. Advanced technologies exhibit significant potential but face implementation challenges. Crew training remains critical, particularly in a dynamic industry. Proactive risk assessment strategies prove effective in reducing the severity of accidents. Harmonizing regulations, embracing advanced technologies, prioritizing ongoing crew training, and maintaining proactive risk assessment practices are recommended for continuous improvement in enhancing marine safety.

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IMPACT ANALYSIS OF THE FUJI LESTARI PROGRAM ON FISH RESOURCE RECOVERY AND THE ADVANCEMENT OF SUSTAINABLE DEVELOPMENT GOAL 14 (LIFE BELOW WATER) IN THE JAVA SEA (FISHERIES MANAGEMENT AREA 712), INDONESIA

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ABSTRACT

The Fuji Lestari program, implemented regularly by the Ministry of Marine Affairs and Fisheries (KKP) through the Fishing Technology Center (BBPI), aims to restore fishery resources. The Java Sea (FMA-712), characterized by the highest population of fishers, has been categorized as fully exploited, necessitating the Fuji Lestari program to restore its condition. This study evaluates the program's impacts in Bangsring waters, Banyuwangi Regency (2011); Panjang Island, Jepara Regency (2021); and Karang Jeruk, Tegal Regency (2024). The methodology included field observations, underwater visual census (UVC), and interviews using purposive sampling targeting program beneficiaries. Data analysis assessed ecological and economic impacts. Ecological impacts included changes in coral cover in Bangsring and Panjang Island, as well as increases in fish abundance and diversity in Karang Jeruk. Economic impacts were analyzed by calculating the total economic valuation (TEV) for the three locations. Results show a significant increase in live coral cover of 2.4 hectares in Bangsring waters and 1 hectare in Panjang Island waters. In Karang Jeruk, reef-associated fish species increased from 6 to 12 species, with a diversity index rising from 1.49 to 1.71. The TEV from direct, indirect, existence, and option benefits in Bangsring, Banyuwangi Regency was IDR 11,856,378,385; Panjang Island, Jepara Regency was IDR 5,136,896,500; and Karang Jeruk, Tegal Regency was IDR 9,655,638,600. Variations in impact across regions depended on environmental damage levels and the characteristics of fisher beneficiaries. Furthermore, stakeholder collaboration is crucial in optimizing existing opportunities to ensure the program's future success.

Keywords: Bangsring, fish apartment, fuji lestari, karang jeruk. panjang island

Introduction

The FUJI LESTARI program (Fish-Apartment Untuk Jadikan Laut Sehat, Nelayan Hebat dan Mandiri or Fish-Apartment for Healthy Seascapes, Empowered and Independent Fishermen) is a community empowerment initiative designed to enhance marine resource sustainability through technical assistance, training, and support for Indonesian fishing communities. This program is anchored in the 14th Sustainable Development Goal (SDG 14: Life Below Water), which emphasizes marine conservation and the sustainable use of ocean resources. The program has been recognized by the Government of Indonesia as a national priority due to its potential to mitigate overfishing and support ecosystem restoration [1].

A key innovation of the program is the fish-apartment (FA), an artificial reef structure developed by the Fishing Technology Center (BBPI), Ministry of Maritime Affairs and Fisheries (KKP). These structures consist of vertical and horizontal partitions made from recycled polypropylene (PP), a material chosen for its strength, durability, and elasticity. Unlike traditional artificial reefs, FA modules can be mass-produced, facilitating broader adoption across Indonesia. When well-managed, FA structures function as spawning grounds, feeding areas, and nursery habitats—critical for enhancing fish populations and supporting biodiversity recovery [2].

Since its launch in 2011, the FUJI LESTARI program has deployed 10,950 FA modules across Indonesia, with one of its most intensive implementations occurring in the Java Sea, particularly in Fisheries Management Area (FMA) 712 (WPP 712) [3]. The Java Sea plays a vital role in Indonesia's fisheries sector, supporting highly productive but heavily exploited fish stocks. Official assessments indicate that FMA 712 has been under significant pressure, as evidenced by the utilization rate of large pelagic fish, which increased from 0.63 in 2017 to 1.3 in 2022, and demersal fish, which rose from 0.83 in 2017 to 1.1 in 2022 [4] [5]. This trend underscores the urgent need for sustainable fisheries management to restore declining fish stocks and ensure long-term economic viability for local fishermen.

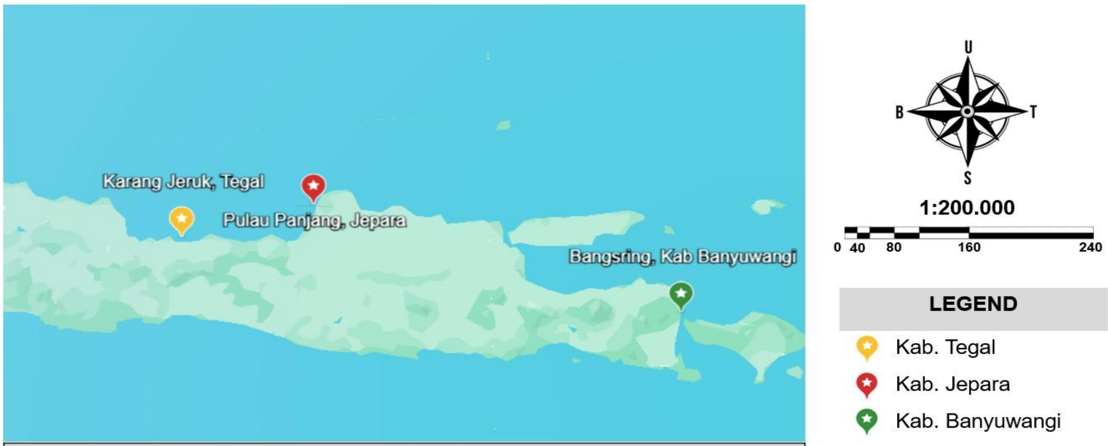
Within FMA 712, three key regions have received FA installations at different points in time, reflecting diverse ecological and socio-economic conditions:

a. Banyuwangi Regency (2011) – Among the earliest adopters, this area has seen significant changes in fish population dynamics and local fishing practices.
b. Jepara Regency (2021) – A relatively recent recipient, offering insights into mid-term ecological and economic impacts.
c. Tegal Regency (2024) – The latest implementation site, providing an opportunity to assess short-term effects and early adoption challenges.

This study aims to determine the impact of the Fuji Lestari program ecologically and economically in various regions and at different implementation times. By analyzing the merits of the program, the study will highlight how FA can serve as a model for balancing fisheries sustainability and economic resilience, aligning with the SDG 14 targets of reducing marine degradation, restoring fish stocks, and promoting responsible fishing practices in FMA 712.

Methodology

This research was conducted from November 2023 to November 2024 in three locations: Bangsring waters, Banyuwangi Regency, with 589 FA modules; Panjang Island waters, Jepara Regency, with 100 FA modules; and Karang Jeruk waters, Tegal Regency, with 40 FA modules (Figure 1).



Location Coordinate		
Tegal Regency	Jepara Regency	Banyuwangi Regency
109°12'39.91"E 06°48'56.55"S	110°37'59.37" E 6°34'51.41" S	114°25'54.10" E 8°03'11.10" S

Figure 1. Research Locations

The methods used include field observations, underwater visual census (UVC), and interviews. Data analysis was conducted descriptively by explaining the ecological and economic impacts. Ecological impacts observed included changes in coral cover in Bangsring and Panjang Island, as well as increases in fish abundance and the Shannon-Wiener diversity index in Karang Jeruk. Economic impact analysis was conducted by calculating the total economic value (TEV) for the three locations. (Figure 2).

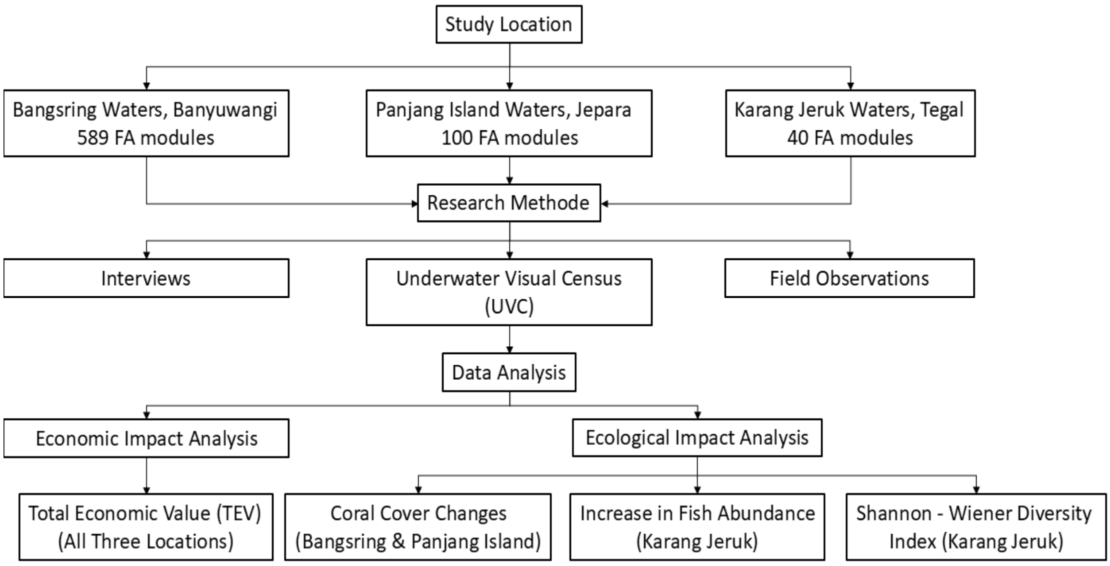


Figure 2. Flowchart Diagram Research

a. Coral Cover and Fish Diversity

Coral fish data were collected using the Underwater Visual Census method by [6] with modifications to the Stationary Visual Census (SVC) method by [7] and [8], as illustrated in Figure 3.

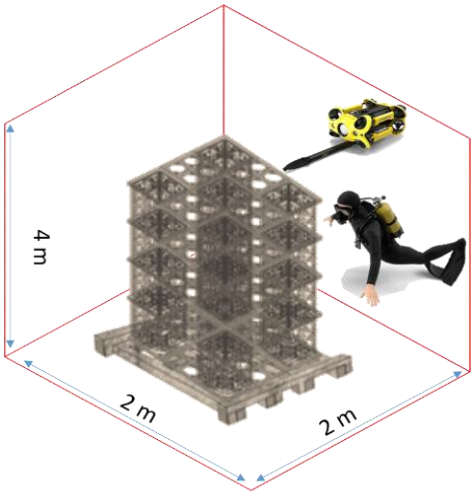


Figure 3. Illustration of Underwater Visual Census

The Shannon-Wiener diversity index (H') was used to calculate coral reef fish diversity.

$$H' = -\sum_{i=1}^{n} Pi . \ln Pi$$

Where:
H' = Diversity Index
Pi = ni/N
ni = Number of individuals of the first species
N = Total number of individuals

According to [9], diversity is categorized as:

Low diversity: H' < 2,30
Moderate diversity: 2,30 < H'< 3,50
High diversity: H' > 3,50

b. Total Economic Value

The number of beneficiary fishermen respondents was determined using the Slovin method. According to [10], the Slovin method is formulated as follows:

$$n = \frac{N}{N . e^2 + 1}$$

Where:
n = Number of respondents
N = Population size
e = Margin of error

Based on the Slovin calculation, the number of respondents in each location was 200 in Banyuwangi Regency, 100 in Jepara Regency, and 100 in Tegal Regency. These respondents represented artisanal fishermen using environmentally friendly fishing gear who benefited from the Fuji Lestari program.

The total economic valuation (TEV) of coral reefs in the FA deployment areas was calculated using the following formula by [11]:

$$TEV = UV + NUV$$
$$UV = DUV + IUV + OV$$
$$NUV = EV$$

Where:
TEV = Total Economic Value
UV = Use value
DUV = Direct use value

IUV = Indirect use value
OV = Option value
NUV = Non-use value
EV = Existence value

Result and Discussion

a. Increase in Live Coral Cover

The study results show an increase in live coral cover following the implementation of the Fuji Lestari program. Observations in Panjang Island and Bangsring waters, as reported [12] and [13] (Table 1), demonstrate the program's success several years after FA deployment. This increase is marked by a reduction in dead coral and sandy areas, as well as the growth of soft and hard corals on FA partitions. Although the FAs in Panjang Island waters have not yet formed a complex coral reef community, the presence of biofouling on some modules indicates the beginning of interactions between passive and active biota communities. In contrast, findings in Banyuwangi, where the program was implemented earlier (2011), show a more complex coral reef structure and ecosystem stability due to FA introduction.

Changes in live and dead coral cover in Panjang Island demonstrate the dynamics of restoration following the Fuji Lestari program. In 2010, live coral cover was recorded at 3.23 hectares, decreasing to 2.42 hectares in 2019, but increasing again to 3.51 hectares in 2023. This decline is likely related to local ecosystem pressures before the Fuji Lestari program, such as massive and unsustainable destructive fishing. The increase in live coral after 2019 indicates the success of FA deployment, which provided new substrates for coral colonization. From 2010 to 2019, live coral cover decreased by 0.81 hectares, while dead coral increased by 0.80 hectares. However, this trend reversed from 2019 to 2023, with live coral increasing by 1.09 hectares and dead coral increasing by only 0.09 hectares. The smaller increase in dead coral compared to live coral growth indicates the success of the restoration program, where additional substrates through FAs supported new coral colonization. This is consistent with findings that artificial reefs can provide additional substrates that support coral growth and mitigate ecological pressures [14].

Meanwhile, in Bangsring, the longer-running Fuji Lestari program has resulted in more stable coral ecosystem development. The restoration program, which began in 2011, has shown more significant results compared to Panjang Island. In 2011, live coral cover was recorded at 3.7 hectares, increasing significantly to 6.1 hectares by 2020. Live coral increased by 2.12 hectares from 2017 to 2020, far exceeding the growth in Panjang Island. In contrast, dead coral in Bangsring increased by 0.54 hectares during the same period, though at a relatively controlled rate compared to live coral growth. [15]. state that artificial reefs can strengthen physical structures and increase ecosystem heterogeneity. Additionally, Bangsring's initially better condition compared to Panjang Island may have facilitated biota adaptation to FA modules.

Table 1. Changes in Live Coral Cover in Bangsring and Panjang Island

Year	Coral Cover (Ha)		Changes (Ha)	
	Live	Dead	Live	Dead
PANJANG ISLAND - JEPARA				
2010	3,23	3,01	-	-
2019	2,42	3,81	0,81	0,80
2023	3,51	3,90	1,09	0,9
BANGSRING - BANYUWANGI				
2011	3,7	0,79	-	-
2017	3,98	0,7	0,28	0,09
2020	6,1	1,24	2,12	0,54

Source: Jepara Regency [12] and Banyuwangi Regency [13]

Although the coral reef structure associated with Panjang Island is not yet complex, the presence of biofouling and initial colonization indicates interactions between biota communities. Support this finding [16], stating that artificial reefs serve as transitional habitats that can improve local ecosystem dynamics. Bangsring, with its more complex ecosystem, exemplifies how artificial reefs can help achieve ecosystem stability through long-term planning and continuous monitoring. [17] state that artificial structures can provide substrates that support coral ecosystem restoration by increasing substrate diversity. For long-term restoration success, it is essential to set specific goals when designing artificial reefs, such as targeting biodiversity enhancement and ecosystem stability. These findings align with [18], which shows that restoration success depends on design, substrate materials, and project locations that support coral colonization and long-term ecosystem stability.

b. Fish Species Composition

Based on initial observations in Karang Jeruk waters, Tegal Regency, in August, six species from six families of associated fish were found, while in November, 12 species from 12 genera and nine families of associated fish were observed around the FAs. The fish species composition is presented in Table 2.

Reef-associated fish can be categorized based on their feeding habits into herbivores, carnivores, and corallivores. Herbivorous fish, such as those from the *Pomacentridae* family, feed on algae and help maintain coral ecosystem balance by preventing algal dominance. Carnivorous fish, such as those from the *Lutjanidae* family, prey on small fish or invertebrates and play a role in maintaining the food chain structure in coral reef ecosystems. Meanwhile, corallivorous fish, such as those from the *Chaetodontidae* family, feed on coral polyps, and their presence is often used as an indicator of coral reef health due to their dependence on healthy coral conditions [19].

Based on their role in the ecosystem, reef-associated fish can also be categorized into major fish, target fish, and indicator fish. Major fish play a significant role in the structure of coral fish communities, such as herbivorous fish from the *Scaridae* and *Acanthuridae* families. Target fish are species with high economic value and are frequently caught by fishermen, such as snappers (*Lutjanidae*) and groupers (*Serranidae*). Indicator fish are species whose presence reflects the health of the coral reef ecosystem, such as fish from the *Chaetodontidae* family, whose abundance correlates with the presence of live coral [20].

At the family level, the composition of all observed fish comes from different families. The August composition consisted of one major fish species with herbivorous feeding habits and five target fish species with carnivorous feeding habits. The November composition consisted of three major fish species with herbivorous feeding habits, seven target fish species with carnivorous feeding habits, and two indicator fish species with corallivorous feeding habits.

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Table 2. Coral Fish Composition in Karang Jeruk Waters - Tegal

NO	Family	Species	Type	Group
		Periode Agustus		
1	*Pomacentridae*	*Pomacentrus coelestis*	**Herbivore**	Major Fish
2	*Lutjanidae*	*Lutjanus lutjanus*		Target Fish
3	*Terapontidae*	*Terapon jarbua*		Target Fish
4	*Lethrinidae*	*Gymnocranius grandoculis*	**Carnivore**	Target Fish
5	*Carangidae*	*Alectis indica*		Target Fish
6	*Scatophagidae*	*Scatophagus argus*		Target Fish
		Periode November		
1	*Pomacentridae*	*Abudefduf vaigiensis*		Major Fish
		Pomacentrus coelestis	**Herbivore**	Major Fish
2	*Blenniidae*	*Cheilodipterus isostigma*		Major Fish
3	*Siganidae*	*Siganus javus*		Target Fish
4	*Lutjanidae*	*Lutjanus lutjanus*		Target Fish
5	*Nemiptridae*	*Scolopsis temporalis*	**Carnivore**	Target Fish
6	*Carangidae*	*Gnathanodon speciosus*		Target Fish
		Selaroides leptolepis		Target Fish

7	*Scatophagidae*	*Scatophagus argus*		Target Fish
8	*Ephippidae*	*Platax teira*		Target Fish
9	*Chaetodontidae*	*Chelmon rostratus*	**Corallivore**	Indicator Fish
		Chaetodon octofasciatus		Indicator Fish

The presence of species from the Pomacentridae family, albeit low, provides an initial indication of live coral growth around the FAs. The presence of species such as *Scatophagus argus* and *Gymnocranius grandoculis* also enriches the community, although their numbers are lower. Research by [21] shows that artificial structures with high complexity can serve as alternative habitats that support target species. With a total of six species found, these results demonstrate the potential of FAs to increase fish diversity

Indicator species such as *Chelmon rostratus* and *Chaetodon octofasciatus* indicate improving habitat quality. The presence of target species such as *Lutjanus lutjanus* further strengthens the potential of FAs to support local fishery sustainability. This aligns with previous studies, which show that the longer artificial reefs are deployed, the more algae attach to the attractors, ropes, and covers, indicating that artificial reefs provide food for coral fish [22]. Research by [23] adds that artificial reefs not only attract target fish but also support a broader diversity of fish species, from herbivores to carnivores. The data obtained show predation and competition among fish species, an important ecological process in maintaining a healthy fish community structure in artificial reef areas.

c. Coral Fish Diversity Index

Observations in August and November showed significant increases in dominance (C), evenness (E), and diversity (H') for fish associated with the FAs. The observation results are shown in Figure 4.

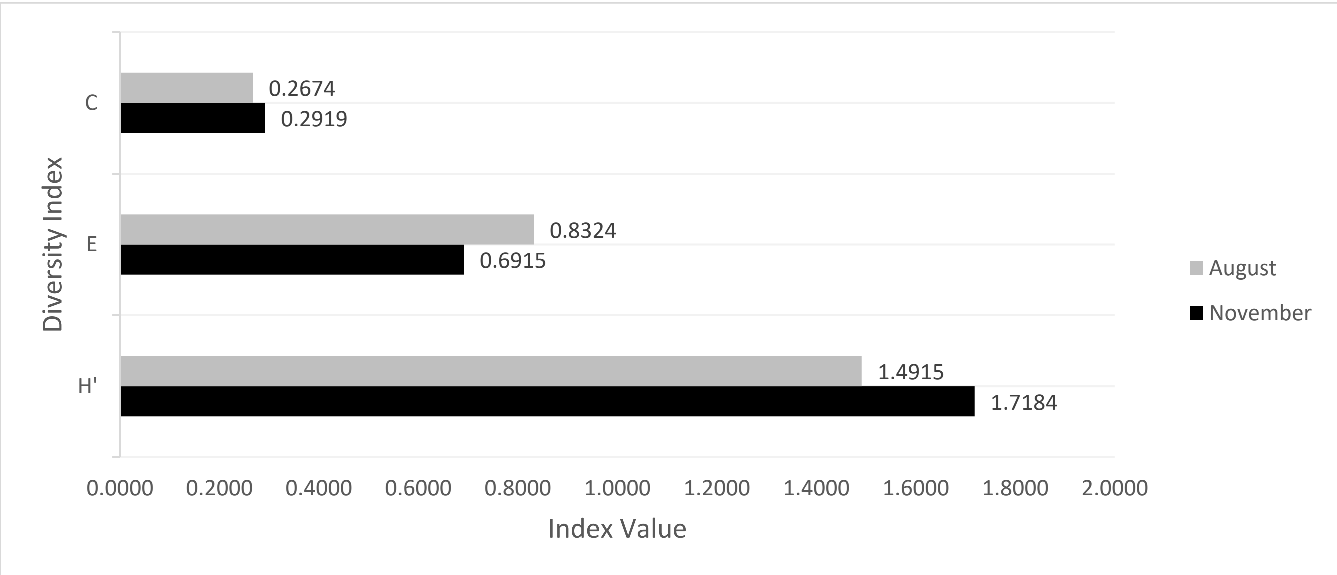

Figure 4. Diagram of Coral Fish Diversity Index in Karang Jeruk Waters, Tegal Regency

The dominance index (C) for this fish community was 0.2674, indicating that dominance by a single species is not overly strong. This is important because low dominance suggests that community diversity remains well-maintained. Although *Pomacentrus coelestis* show ed higher abundance, the low dominance index indicates that no single species significantly dominates the entire ecosystem. This suggests that the artificial reefs can provide a relatively balanced environment for various fish species. In contrast, the dominance index (C) in November was 0.2919, slightly higher than in August (0.2674). This increase in dominance reflects the role of dominant species, such as *Siganus javus*, which dominated the community. However, the relatively low dominance value indicates that the FAs can still maintain species diversity effectively. Data indicates that the FAs are beginning to function as effective alternative habitats for supporting both target and non-target species. Further increases in diversity are expected as the habitat develops. [24] highlight that the success of artificial habitats often requires time to reach optimal carrying capacity. [25] state that mature habitats can support greater biomass and ecosystem functions, as reflected in this study. Well-managed FAs demonstrate significant potential to support local fishery sustainability.

The evenness index (E) in August was 0.8324, indicating that although some species dominated, the distribution of individuals among species was relatively even. This suggests that while certain species were more abundant, the artificial reefs were able to maintain a balance among species overall. *Pomacentrus coelestis*, as the species with the highest individual abundance (41.51%), contributed significantly to the existing diversity. This evenness index value indicates that other species, such as *Terapon jarbua* (22.64%) and *Lutjanus lutjanus* (15.09%), played significant roles in maintaining community structure. In contrast, the evenness index (E) in November was 0.6915, lower than in August. This indicates that the distribution of individuals among species became less even, with greater dominance by *Siganus javus*. This decline in evenness is typical during the ecosystem adaptation phase, where dominant species tend to take advantage of new habitats. However, species such as *Scolopsis temporalis* and *Selaroide s leptolepis* still played important roles in maintai ning ecosystem balance. This is supported by [26], who state that well-designed artificial habitats can reduce pressure from dominant species and support the growth of fish communities.The presence of species with moderate contributions to community structure shows that the FAs can still support a fairly diverse species distribution despite the dominance of certain species.

In August 2024, observations showed a diversity index (H') of 1.4915, which is relatively low but reflects the initial formation of a coral fish community. The composition was dominated by *Pomacentrus coelestis* (41.51%), which stands out as an opportunistic species with high adaptability to artificial habitats. The presence of species such as *Terapon jarbua* (22.64%) and *Lutjanus stellatus* (15.09%) indicates that the FAs have begun to provide habitats for target fish groups. Although the diversity value is moderate, the dominance index (C) of 0.2674 suggests the presence of dominant species. This aligns with findings by [27], who state that new habitats tend to be dominated by adaptive species during the early stages.

In November 2024, observations showed a diversity index (H') of 1.7184, higher than in August. This value reflects a more stable and diverse coral fish community, indicating improved ecological function of the FAs. The fish community during this period was still dominated by *Siganus javus* (50.20%), which became a key species in the community structure due to its ability to utilize artificial habitats as a source of food and protection. The presence of species such as *Lutjanus lutjanus* (13.98%) and *Scolopsis temporalis* (10.10%) shows that the FAs are beginning to support target fish species with significant economic and ecological value. This aligns with findings by Bohnsack (1986), who state that artificial habitats can attract species with specific ecosystem preferences, particularly economically valuable fish species.

Ecologically, the presence of species such as *Gymnocranius grandoculis* and *Scatophagus argus* contributes to the balance of the fish community. The presence of species such as *Platax teira* (3.47%) and *Scatophagus argus* (1.02%) also indicates that the FAs can attract species with specific habitat preferences. The complex structure of artificial habitats allows these species to find optimal shelter, supporting overall community stability.

d. Total Economic Value

Total Economic Value (TEV) was used to measure the economic benefits of the artificial reef program by considering various types of values associated with the ecosystem. TEV includes direct use value (DUV), derived from the direct use of resources, such as fisheries, tourism, and marine recreation. This use contributes economically to coastal communities through increased income from the fisheries and marine tourism sectors [28].

Additionally, there is indirect use value (IUV), which includes the ecological role of artificial reefs in maintaining marine ecosystem balance, such as coastal protection from abrasion and providing habitats for various marine species. The presence of artificial reef structures can enhance marine biodiversity, contributing to the stability of the food chain and fishery productivity in the surrounding areas [29].

Direct use value was calculated based on income from the fisheries and tourism sectors affected by the Fuji Lestari program. Indirect use value was estimated based on coastal protection and carbon sequestration benefits experienced by program beneficiaries. Existence value was calculated based on the willingness to pay (WTP) of beneficiaries to sustain the program, and option value was derived from the conversion of biodiversity value based on the land area used in the Fuji Lestari program across the three regions. Based on quantitative analysis, the economic value of the fish apartment areas in each region is presented in Table 3. This comprehensive approach captures both the tangible and intangible benefits of the program, providing a holistic assessment of its economic impact. Furthermore, these findings offer a robust basis for policy recommendations and strategic planning to enhance sustainable marine resource management in the region.

Table 3. Total Economic Value (TEV)

Region	Types of Fish Apartment Values				Total (IDR)
	Direct Use Value (IDR)	Indirect Use Value (IDR)	Existence Value (IDR)	Option Value (IDR)	
Banyuwangi Regency	11,348,700,000	450,540,825	41,800,000	15,337,560	11,856,378,385
Tegal Regency	9,614,000,000	30,597,000	10,000,000	1,041,600	9,655,638,600
Jepara Regency	4,908,000,000	76,492,500	20,000,000	2,604,000	5,007,096,500
Total Economic Value of Fish Apartment (IDR)					26,519,113,485

Based on Table 3, the total economic valuation (TEV) of the fish apartments in Banyuwangi Regency, Jepara Regency, and Tegal Regency amounts to IDR 26,519,113,485. The highest TEV was recorded in Banyuwangi Regency at IDR 11,856,378,385, followed by Tegal Regency at IDR 9,655,638,600, and Jepara Regency at IDR 5,007,096,500. These results show that direct use value contributes the most to the TEV compared to other value types.

Banyuwangi Regency has the highest TEV due to the 13-year duration of the program, as explained earlier (Table 1). The high value of capture fisheries is due to the fact that all fishermen in Bangsring are ornamental fish exporters, and their high awareness of environmentally friendly fishing practices has resulted in sustainable economic impacts. The tourism sector also plays a significant role, as the area was not a tourist destination before 2011. The highest contributions came from capture fisheries and tourism. The fisheries sector contributed IDR 6,552,150,000, while the tourism sector contributed IDR 4,796,550,000. However, thanks to the efforts of the beneficiary groups, the annual tourism revenue now reaches IDR 12.6 billion, generating multiplier effects for the local economy in Banyuwangi [30].

Tegal Regency has the second-highest economic valuation potential, as the FA deployment area is a fishing ground that had previously suffered damage. Based on interviews, most fishermen have shifted their fishing practices from within the Karang Jeruk marine conservation area, even encroaching on the core zone, to areas around the FAs located outside the conservation area. The high value is due to the average annual income of beneficiary fishermen in this location reaching IDR 9,130,000,000. This aligns with data from [31], which states that the *payang jabur* fishing industry in Tegal Regency is a major economic driver for coastal communities and supplies raw materials for the processed anchovy industry in Pemalang and Kendal. The anchovy production in Karang Jeruk waters includes *nasi* anchovy and *jawa* anch ovy.

The results in Jepara Regency show the lowest value compared to the other two locations, despite having more FA modules deployed than Tegal Regency. This is because the FAs in Jepara function as artificial barriers against environmentally harmful fishing practices and as release areas for crab larvae. As a result, fishing activities are restricted to prevent damage to the area. Nevertheless, the capture fisheries sector still contributes IDR 3,610,000,000 annually, and tourism revenue from sport fishing amounts to IDR 1,298,000,000 per year.

e. Sustainable Development Goals (SDGs) - 14

The 14th sustainable development goal is to conserve and sustainably utilize marine and ocean resources for sustainable development. To achieve the national marine ecosystem targets by 2030, 10 targets have been set, measured through 15 indicators. These targets include sustainable marine spatial planning and management, Maximum Sustainable Yield (MSY), combating Illegal, Unreported, and Unregulated (IUU) fishing, expanding marine protected areas, and supporting small-scale fishermen. Efforts to achieve these targets are outlined in policies, programs, and activities.

The Fuji Lestari program positively correlates with SDG-14. The program supports 4 out of 10 targets, namely targets 2, 4, 5, 7, and 9. The program's implementation in Bangsring (Banyuwangi Regency), Panjang Island (Jepara Regency), and Karang Jeruk (Tegal Regency) has demonstrated positive impacts, as evidenced by the following: First, an increase in coral cover. Second, the number of fish species caught and associated with the reefs increased from 6 to 12 species in 2015 (**Target 14.2**), indicating success. The transition from destructive fishing practices to environmentally friendly methods (**Target 14.4**). The economic valuation of the program shows that local economies have also benefited (**Target 14.7**). Additionally, there are impacts outside SDG-14, such as a reduction in coastal erosion from 2 meters per year due to the wave-breaking benefits of FAs, stabilizing the coastline by 2050 (**Targets 13.1 and 13.b**). Finally, fish catch production has increased annually (**Targets 1.1 and 1.5**). Based on sampling in the three locations, the program has increased fishermen's income within one to two years (**Targets 1.1 and 1.5**).

Target 14.2 (Ecosystem Restoration): The increase in coral cover (Bangsring: 6.1 hectares) aligns with this indicator. However, it should be noted that this area is still less than 10% of the total WPP-712 area. To achieve the global target (restoring 20% of degraded marine ecosystems by 2030), replicating the program in other regions is key [32].

Target 14.4 (Sustainable Fishing): Although fish catches have increased, WPP-712 remains fully exploited. This indicates that FAs have not fully addressed overfishing pressures. Integration with effort reduction policies is necessary [33].

Target 14.7 (Economic Benefits for SIDS/LDCs): Although TEV has increased, benefit distribution in Jepara is uneven due to access restrictions. Fishermen's participation in program planning (*bottom-up approach*) can improve inclusivity [34].

Conclusion

The Fuji Lestari program has successfully increased live coral cover and fish diversity in the three study locations. Additionally, the program has generated significant economic impacts, particularly through the capture fisheries and tourism sectors. This study demonstrates that FAs can be an effective solution for restoring degraded marine ecosystems while improving fishermen's welfare. The program's success also contributes to achieving Sustainable Development Goal (SDG) 14, particularly in marine ecosystem restoration and coastal community empowerment.

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SHIP RESISTANCE ANALYSIS WATERJET REMOTELY OPERATED VEHICLE (ROV) USING COMPUTATIONAL FLUID DYNAMICS (CFD) METHOD

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ABSTRACT

The propulsion system is a system that supports the performance of high-speed ships. Waterjet ship propulsion systems have long been known and used as propulsion systems for various types of ships, but their widespread application is still subject to their relatively low propulsive efficiency when compared to ship propulsion systems that use propellers, especially during relatively low ship speeds. The usual problem with ROVs using conventional propellers when inspecting in low water in the river is the blockage of river impurities, such as water hyacinths and underwater roots, on the ROV propellers. But there is a limitation to the problem when this waterjet is installed on the ROV should be used on inspections that do not work on the seabed, and the ROV can only be in a hovering position because the waterjet is susceptible to dirt. The purpose of this study was to analyze the ship's resistance of the waterjet remotely operated vehicle (ROV) propulsion system with the results of simulating the effect of the Waterjet ROV design on the total resistance of the Waterjet ROV increased by 5.69 N using the CFD method and the difference in prisoner comparison using the maxsurf method was 1.75%. The thrust analysis of the ROV model with a waterjet propulsion system has a higher thrust increase of 9.21 N when compared to the ROV model with a conventional propeller propulsion system, with a thrust value of 6.94 N. From the analysis of the fluid velocity contour results of the two best ROV models, namely the Waterjet ROV because the placement of the waterjet position on the outer side of the ROV frame so that the placement of the original Propeller inside the inner frame of the ROV is released as a result it tends not to create more turbulence and friction in the water in the middle of the ROV but the surface of the ROV frame on the outside which is added waterjet propulsion components causes higher hydrodynamic pressure.

Keywords: Resistance, waterjet, propulsion system, thrust

Introduction

A propulsion system is a system that moves a ship forward and backward that has thrust [1]. An engine is a device that has the ability to convert heat energy owned by fuel into motion energy. Based on its function, the engine terminology is used as a source of power or prime power [2]. The propeller is the most common form of ship propulsion used in moving ships.

The propulsion system is a system that supports the performance of high-speed ships [3]. Ship propulsion systems with waterjets have long been known and used as propulsion systems for various types of ships [4]. However, widespread applications still hit their relatively low propulsive efficiency when compared to ship propulsion systems that use propellers, especially during times of relatively low ship speeds [5]. A common problem with ROVs using conventional propellers when inspecting low water in rivers is clogging cables and underwater roots in their propellers [6].

There are various types of ship propulsion systems, for example, waterjets. The manufacture of waterjet propulsion systems began in the seventeenth century, called waterjet, because this system utilizes the thrust of water to drive ships [7]. Harnessing this water boost will have an impact at an increasing rate [8]. Thrust waterjet propulsion systems are used on patrol boats. The patrol boat is one of the Indonesian Navy ships tasked with monitoring Indonesian territorial waters [9]. Thus, a ship with high speed is needed.

ROVs are tethered underwater vehicles, commonly used in the deep-water industry, such as offshore hydrocarbon extraction [10]. These vehicles are connected to surface vessels by buoyant moorings or, often when working in rough conditions or deeper water, load carrier umbilical cables are used in conjunction with a TMS mooring management system [11]. The ROV has evolved from its first introduction in 1953 by Dimitri Rubinoff, to now it has been used in a variety of activities [12]. Underwater intervention, repair, and use in maintenance operations are some of the capabilities of the ROV, which is the result of one of its features, being able to capture underwater images [13].

The purpose of this study was to analyze the effect of installing a WaterJet propulsion system on a Remotely Operated Vehicle (ROV) based on total resistance, thrust, and speed contours. This study used the Computational Fluid Dynamics (CFD) method. This research hypothesis is expected to provide innovations, replacing the waterjet propulsion system on the ROV with a More Responsive Thrust and reducing cable clogging and underwater roots compared to conventional propellers.

Methodology

a. Modeling ROV

The ROV data used is data obtained from Surovotic Indonesia in the field survey process, as shown in Table 1. Surovotic is the only ROV company and community in Indonesia. As seen in Figure 1. This ROV data will be used as a reference for WaterJet ROV modifications. Research into the WaterJet propulsion system on this ROV is needed to validate other research, such as simulation research. In this study, only the main dimensions of the ROV from Surovotic Indonesia were taken, which will be modified with the Waterjet propulsion system.

Table 1. Main Dimensions of ROV Surovotic.

Information	Unit	Dimension
Overall Length	Cm	45,7
Waterline Length (LWL)	Cm	44,32
Breadth ROV (B)	Cm	33,8
Depth ROV (H)	Cm	25,4
Draft ROV (T)	Cm	12,7
Displacement (Δ)	Kg	12
Speed ROV (Vs)	Knot	3

Figure1. Modeling ROV Surovotic Indonesia

b. Modification ROV WaterJet

Model creation and simulation using CAD Inventor, Maxsurf, and Rhinoceros 5.0 applications. and Computational Fluid Dynamics (CFD). WaterJet ROV modeling will be simulated to find the total resistance value, contours, speed, and thrust. In Figure 2 will be shown the model of the modified Waterjet ROV seen above, front and side using the CAD Inventor application

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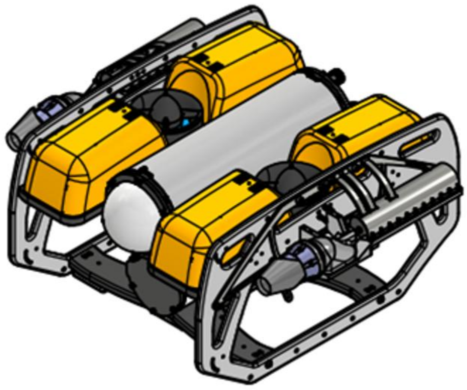

Figure 2. TOP View ROV WaterJet

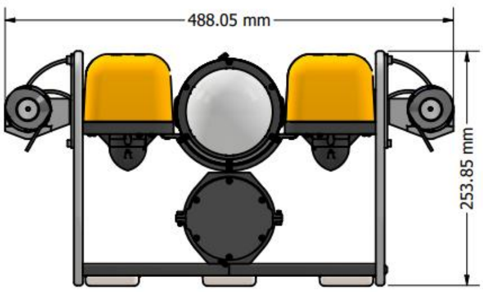

Figure 3. Front View ROV WaterJet

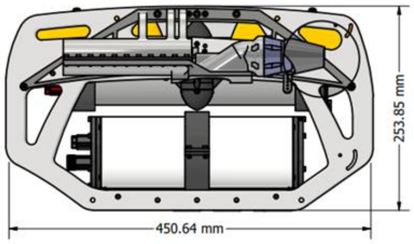

Figure 4. Side View ROV WaterJet

c. *Simulation Method*

The author uses Ansys Fluent Meshing because it provides more detailed meshing controls and is also easy to control. After the model creation process is complete and solid, the next step is to carry out the flow simulation process on the model using CFD simulation with software where anys. The purpose of this simulation is to determine the ship's resistance, flow pattern, speed contours, and thrust on the WaterJet ROV.

a. Geometry

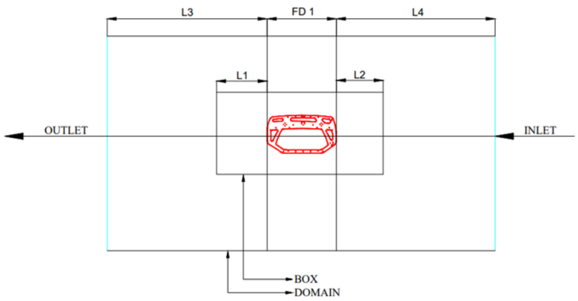

Figure 5. Geometry stage modelling ROV WaterJet speed 3 knots.

For pool dimensions used on ROV with WaterJet Propulsion System can be seen as follows (ITTC, 2011):

L1: length from stern to rear side of box
= 2,5 x ship length
= 2,5 x 45,7
= 114,25 cm = 1142,5 mm

L2: length from bow to front side of box
= 2,5 x ship length
= 2,5 x 45,7
= 1142,5 mm

L3: length from stern to the back side of the domain
= 3 x ship length
= 3 x 45,7
= 137,1 = 1371 mm

L4: Length from bow to front side of domain
= 4 x ship lenth
= 4 x 45,7
= 182,8 cm = 1828 mm

FD1: ROV length from stern to bow
= 1 x ship length
= 1 x 45,7
= 45,7 = 457 mm

b. Meshing

The meshing process is the arrangement of components into small elements to determine the character of a ship shape to be analyzed. At this meshing stage, restrictions such as inlets, outlets, walls, and non-hulls are also added. Inlet is defined as the direction of entry of fluid flow, outlet is defined as the direction in and out of fluid flow, wall is defined as the right and left side pool boundaries, and non-hull is defined as the frame of the ROV Waterjet ship that affects fluid flow.

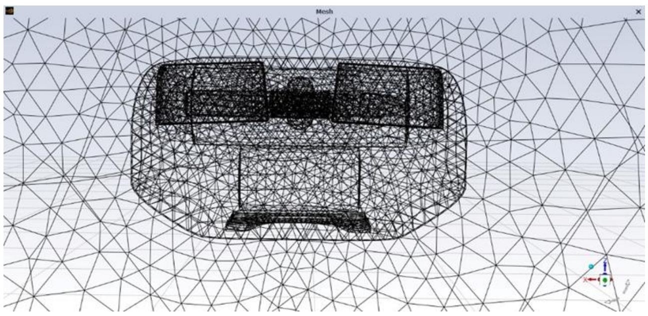

Figure 6. Meshing Stage modeling ROV WaterJet speed 3 knots.

Independent grid test to check the quality of mesh simulation is evaluated by cell slope. Table 2 show the result of the quality of skewness mesh obtained.

Table2. Meshing slope results

Information	Result
Body Sizing	0,1 m
Skewness Quality Sizing	0.55151257 mm
Element	1123912
Meshing type	Hexcore

c. Set Up

The set up process is one of the stages that must be passed in a computational fluid dynamic simulation. Where in the set up process is a setting of parameters that include success in simulation. Here are the set up parameters for the ROV with the waterjet propulsion system with speed 3 knot.

Table 3. Parameters seu up ROV system propulsion waterjet 3 Knot

GPU Type Gravity	none steady Pressure-Based Z = -9,81 m/s²
Models	
Viscous Multiphase Phase 1 Phase 2	k-epsilon (2 eqn), SST off air Water liquid
Boundary conditions	
Inlet Multiphase	
Bottom level Velocity magnitude	-0.91 1,543 m/s atau 3 knots
Outlet Multiphase	
Bottom level Monitor Initialization Open channel	-0.91 drag force, delta time, iterations per-timestep, flow time hybrid initialization none
Run calculation	
Timescale factor Number of iterations	0,1 1000

Here is a picture of the ROV set-up process with a Waterjet propulsion system with a speed of 3 knots.

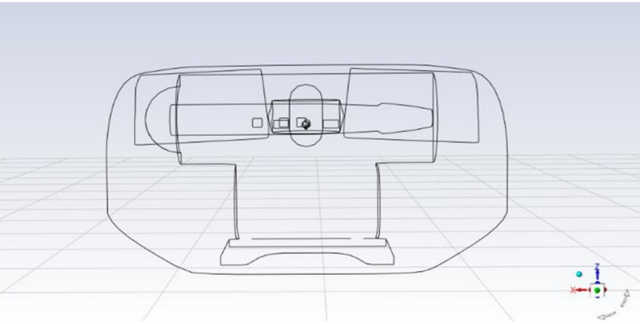

Figure 7. Set up the Stage ROV with a propulsion system waterjet.

d. Result

The solution process is a process after the setup process is complete. The result of the solution process can be seen in Figure 8, which is a graph with the x-axis showing iteration and the y-axis showing drag (n). From the results of the simulation graph shows 1000 iterations as follow

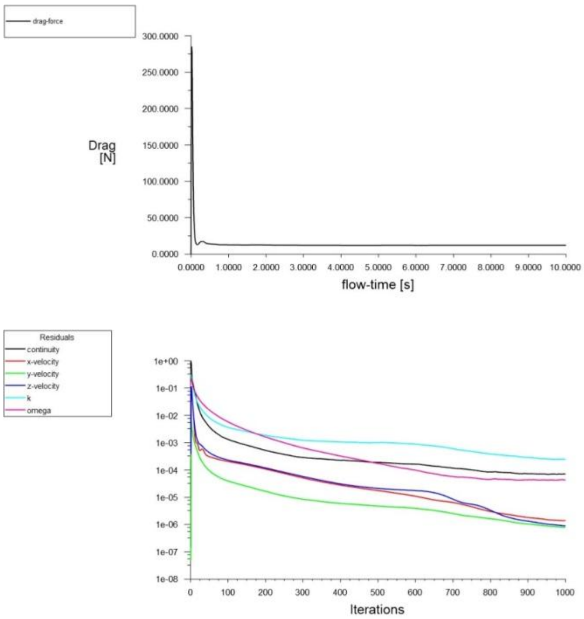

Figure 8. ROV Graphic result with waterjet propulsion system.

Result and Discussion

a. *Simulation Results*

The results of the simulation of the WaterJet ROV model based on the results of analysis using Computational Fluid Dynamic (CFD) software at a speed of 3 knots or 1.543 m/s get a total resistance value of 5.69 N. in this model the flow pattern shows laminar flow because the manual reynold number calculation value shows 7,715 x 10^5. The highest thrust yield with a service speed of 3 knots on the WaterJet ROV model is 9.21 N and the lowest thrust result with a service speed of 3 knots on the Conventional Propeller ROV model is 6.94 N.

Table 4. Simulation result of both ROV models using CFD

Kind	Calculation Result Resistance (N)	Calculation Result Thrust (N)
ROV Propeller Konvensional	4,29 N	6,94 N
ROV Waterjet	5,69 N	9,21 N

b. Flow *Patterns* ROV

The following is the result of the ROV flow pattern representing velocity using streamlined velocity flow in the water phase. In Figure 9 can be seen that the direction of fluid flow can be laminar, and that ROV undergoes laminar flow can be seen by the calculation of the Reynolds number (Rn) below.

For external flows in the ROV frame or hull, the magnitude of the Reynolds number is as follows (USNA, 2002):

- Flow laminar: $Rn < 5 \times 10^5$
- Flow turbulen: $Rn > 1 \times 10^6$
- Transition to laminar to flow turbulen: $5 \times 10^5 < Rn < 1 \times 10^6$

$$Rn = \frac{Lwl \ x \ Vs}{\nu} \quad (1)$$

Where:
LWL = Ship length
Vs = Speed ship (m^2/s)
ν = viscosity kinematik ($1{,}188 \times 10^{-6}$ m^2/s)

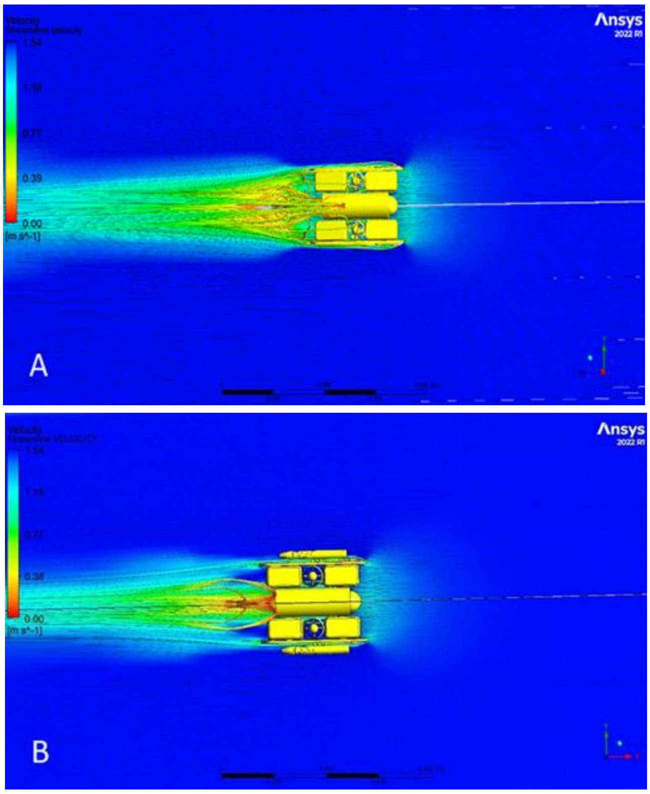

Figure 9. Flow patterns ROV Propeller (A) and Waterjet (B), speed 3 knots.

c. *Speed Contour ROV*

Visualization of the ROV speed of the conventional propeller propulsion system as shown in figure 10 shows the contour of the fluid flow velocity around the ROV at a speed of 1.54 m/s by showing blue and green colors in the outlet area. At the time of inflow, the flow velocity value ranges from 1.16 m/s to 1.54 m/s. It decreases in speed when it hits the ROV frame.

While on the contour of the fluid flow velocity around the ROV in the inlet area by showing green and yellow colors. At the time of inflow, the flow velocity value ranges from 0.77 m/s to 1.15 m/s. It decreases in velocity when it hits the ROV frame. As in Figure 10.

The results of the ROV Water jet analysis of the fluid velocity contour of the two best ROV models, namely the Waterjet ROV, are due to the placement of the waterjet position on the outer side of the ROV part frame. so that the original placement of the propeller inside the inner frame of the ROV is removed. tends not to create more turbulence and friction in the water in the center of the ROV, but the surface of the ROV frame on the outside, to which the waterjet propulsion component is added, causes higher hydrodynamic pressure and greater resistance to fluid flow. The rated speed at the front location of the bow of the ROV Waterjet is 1.15 m/s and 0.77 m/s, while in front of the bow of the ROV Propeller is 1.30 m/s and 1.46 m/s.

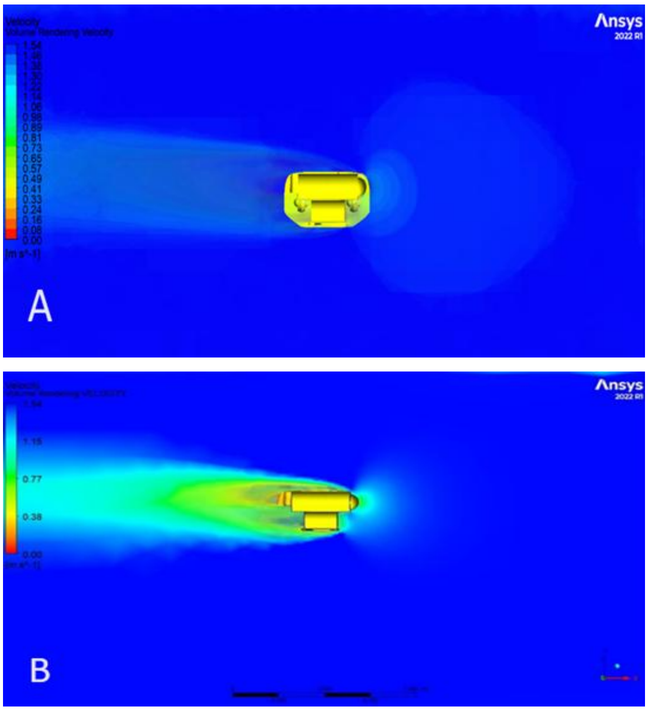

Figure 10. Speed Contour ROV Propeller (A) ROV WaterJet (B) speed 3 knots.

d. Manual Calculation Result

After conducting simulations, there are manual calculations that use algorithms from CFD (Fluent Meshing) to be used as reinforcement of simulation results in determining the total resistance value of the ROV, and there are deep validation results with a maximum error of less than 5% to show the accuracy results. Of course, this manual calculation uses the Harvald method as follows.

- Calculation coefficient of friction (Cf)
  $Cf = \frac{0.075}{(\log Rn - 2)^2}$ (2)
- Modeling Ship Correlation Allowance (C_A)
  For the ship with L≤100m, $10^3 C_A$ = 0,4
  So that C_A = 0,4 x 10^{-3} = 0,0004
- Calculation of Viscous Coefficient (C_V)
  $C_V = (1 - k) \text{ x } C_F + C_A$ (3)
- Calculation coefficient total resistance (C_T)
  $C_T = C_F + C_A + C_V$ (4)
- West surface area (S)
  S = 1,025 x Lwl (Cb x B + 1,7 x T) (5)
- Calculation resistance total (R_T)
  $$R_T = \frac{1}{2} \rho \; x \; C_T \; x \; S \; x \; V^2$$ (6)

Where:
ρ = density of seawater (1,025 kg/m3)
C_T = coefficient of total resistance
S = underwater fuselage (m^2)
V = speed flow (m/s)

e. Manual Calculation of Thrust

In manual calculations of thrust using the book of resistance and propulsion of the SV ships. Aa. Harvald 1989 Manual calculations determine the thrust generated by the Waterjet ROV model, including calculations such as advance speed (Va). And the calculation of thrust (T) is as follows:

- Advance Speed Calculation (Va)
  $V_a = V_s \text{ x } (1 - \text{w})$ (7)

Where:
V_a = *advance speed*
V_s = Ship Speed m/s
w = Wake fraction = 0.5 x Cb – 0.05

- Thrust (T)
  T = R_T/(1-t) (8)

Where:
T = *Thrust*
R_T = *Resistance*
t = *Thrust deduction factor* (k = 0,7–0,9)
= k x w

Conclusion

The effect of the Waterjet ROV design on the total resistance of the WaterJet ROV increased by 5.69 N, with the previous result of the ROV Propeller model of 4.29 N. The design of the Waterjet ROV on thrust increased by 9.21 N., and the previous result of the ROV Propeller model by 6.94 N; the difference in the thrust ratio of the two models was 32.7%. Therefore, Waterjets produce greater thrust compared to Propellers. In the design of the Waterjet against the contours of the fluid velocity of the two best models, namely the Waterjet, because of the placement of the position of the waterjet on the outer side of the ROV frame. so that the original placement of the propeller inside the inner frame of the ROV is removed. tends not to create more turbulence and friction in the water in the center of the ROV, but the surface of the ROV frame on the outside, to which the waterjet propulsion component is added, causes higher hydrodynamic pressure and greater resistance to fluid flow. The rated speed at the front location of the bow of the ROV Waterjet is 1.15 m/s and 0.77 m/s, while in front of the bow of the ROV Propeller is 1.30 m/s and 1.46 m/s.

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ANALYSIS OF PASSENGER EVACUATION ON FERRY KMP TRISNA DWITYA USING PATHFINDER

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ABSTRACT

The use of ships as a transportation is growing rapidly, of course, this is also related to transportation safety related including ship accidents. The National Transportation Accident Commission (KNKT) recorded 86 accidents in the sea transportation sector from 2010 to 2019. In 2018, the KMP Trisna Dwitya ferry ran aground, which resulted in 28 passengers having to be evacuated. Safety on ships must be optimized by minimizing casualties. The determining factor in evacuation is the time it takes for passengers to get out of the waiting room on the ship. Hence, it is necessary to calculate the time for the evacuation process. The purpose of this study is to obtain results in the form of evacuation time during a fire and evaluate the simulation of passenger evacuation in the fastest time. The method used is modeling and simulation, where modeling is used to simulate and analyze the time required for evacuation with the Pathfinder software. The results of the analysis and simulation yielded 3 different scenarios. Scenario 1: When the fire point is on the main deck where the motorized vehicle with evacuation time reaches 20 minutes 21 seconds. Scenario 2, when the fire point is in the left side engine room, reaches 20 minutes 57 seconds. Scenario 3, when the fire point is in the right-side engine room, the time obtained is 21 minutes 1 second. So that the 3 scenarios have met the requirements of the IMO, which is less than 60 minutes during the evacuation process on a passenger ship.

Keywords: Evacuation, IMO, KNKT, ship accident, pathfinder

Introduction

Sea transportation makes a significant contribution to the national and regional economies, as stated in Law No. 17 of 2008, that it is very strategic for national insight and is an important instrument in supporting the goal of national unity and integrity. The contribution of sea transportation is becoming important because the costs incurred by sea transportation are minimal compared to the costs of land and air transportation [1].

Ferries play an important role in several regions, so ferry activities are quite busy. The number of passengers and vehicles that must be transported, and the safety elements on the ship, must be prepared. Supporting equipment in case of fire, ranging from life jackets to emergency boats to evacuate passengers, must be prepared. Not only preparing the equipment, but it is also necessary to learn the evacuation route so that passengers can quickly and safely go to the designated muster point.

Transportation and public buildings generally require the relevant agencies to provide evacuation

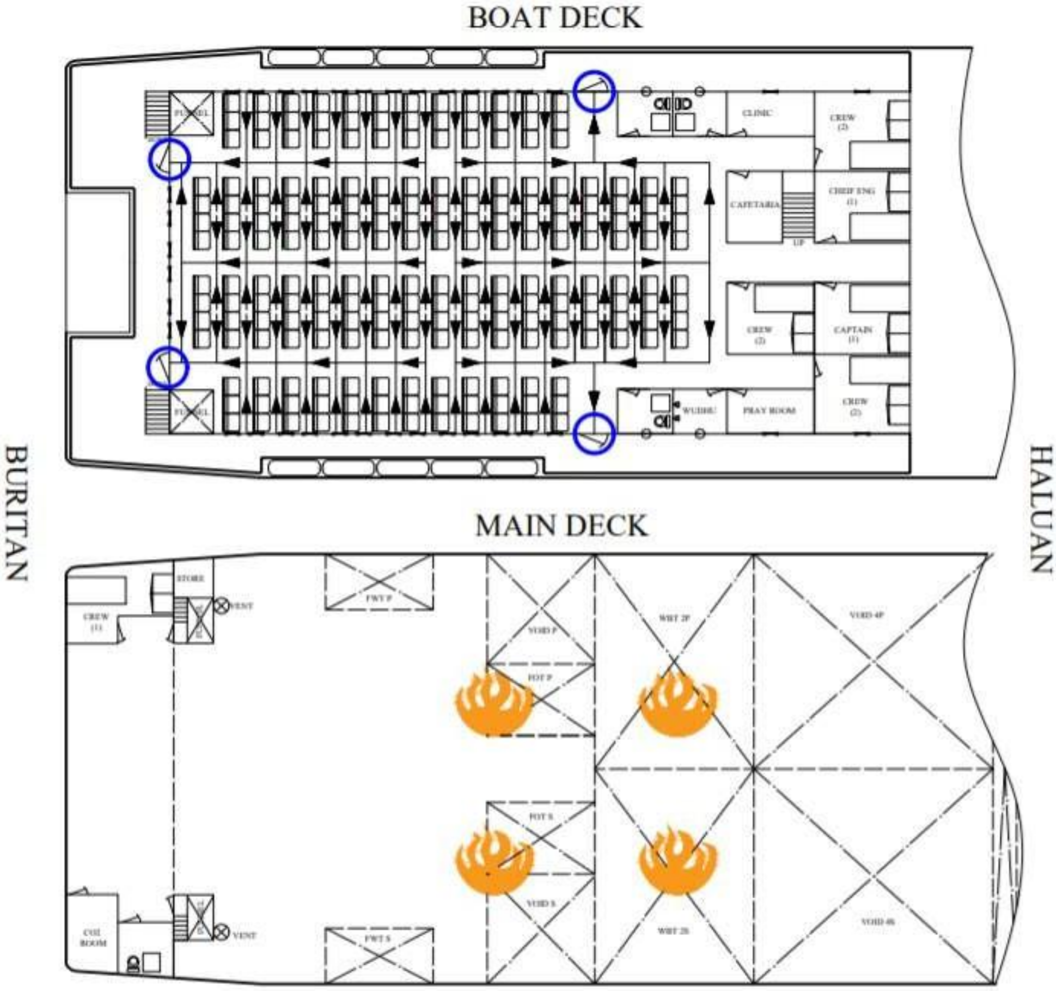

Figure 1. Evacuation route when the fire is on the main deck

plans during emergencies, and they must be followed by everyone in the environment. Based on the analysis of post-disaster events related to habitual human behavior, namely: 1) Most people do not start walking when the alarm sounds. In this case, there is a delay in reacting to the alarm, called the awareness time. 2) People often take the path they know rather than following the directions of

the symbols on the emergency exits. 3) People are generally influenced by the movements of people around them, which tend to be dominant. 4)

5) Physical and psychological conditions are very important, and each person has different circumstances. 6) People can go through smoky areas with limited visibility if someone acting as a leader leads them. 7) In crowded conditions, there is often panic [2].

Evacuation time under the International Maritime Organization (IMO) criteria is partial, i.e., evacuated passengers are considered to gather at a certain point, before moving together to the next point, so that the determination of passenger evacuation time is strongly influenced by changes in passenger density against movement speed. However, in reality, the movement of passengers during the evacuation process can be said to move simultaneously. One of the efforts made to reduce the density of the evacuation route is to unravel the pile of passengers on alternative routes that might speed up the evacuation [3].

The speed of walking in groups will reduce the speed by 20% compared to walking alone, with a distance of 3 m between groups. Furthermore, the walking speed of the group in front will be faster than the walking speed of the group behind it. However, individual walking speed in the opposite direction can be slower than group walking speed [4].

In 2018, KMP Trisa Dwitya had an accident, running aground while crossing on Saturday in July 2018. The ship was dragged by the current until it finally ran aground near the navigation lights. The ship carried 28 passengers. The evacuation process was carried out 3 times so that it could be evacuated safely [5]. Based on this, this research aims to

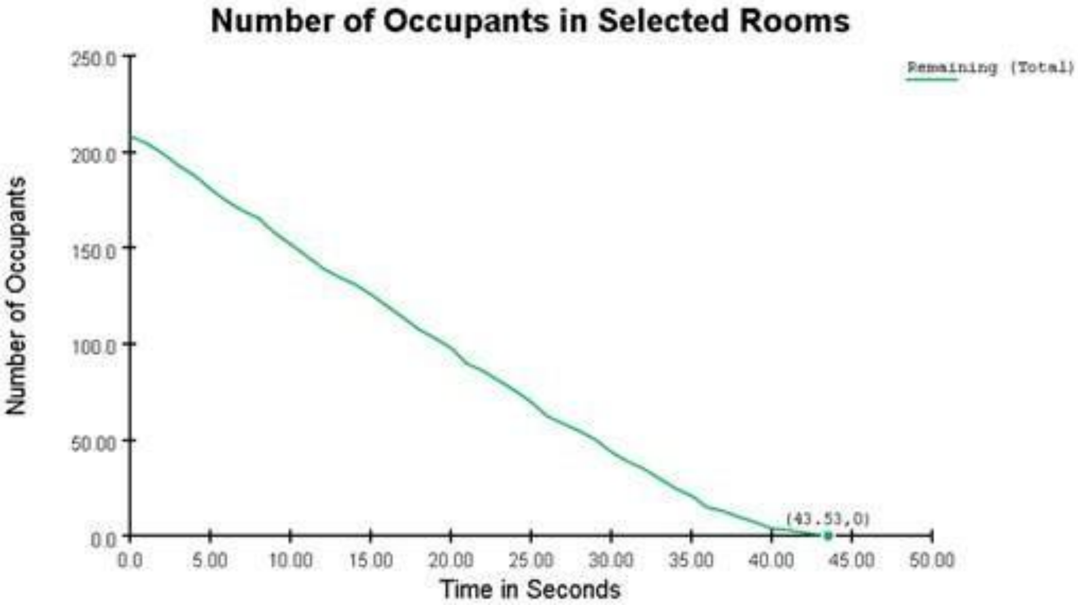

Figure 2. Graph of evacuation time leaving the waiting room (scenario 1)

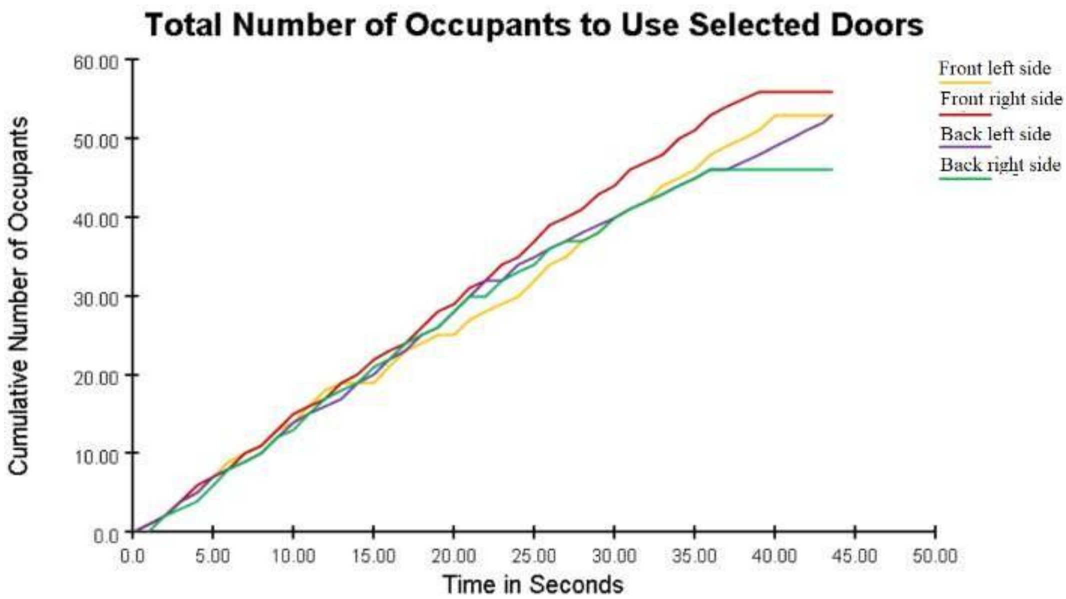

Figure 3. Graph of the number of exiting passengers at each door (Scenario 1)

determine how long it takes for the evacuation process and simulate the. evacuation process to get a fairly efficient time in the event of an accident.

Methodology

This research is a simulation, which is a form of research that aims to obtain an overview through a small-scale or simple system (model) in which the model will be manipulated or controlled to see the effect [6].

a. Literature Study

Literature study is carried out to study theories that can support existing problems. Literature studies are obtained from several theories and discussions on the flow during passenger evacuation from books, journals, theses, and the internet. Evacuation on the ship refers to the safety plan contained on the ship. Evacuation on the ship is carried out quickly so that there are no casualties. Evacuation simulations are carried out to find the time required when evacuate ship passengers during a fire. Evacuation simulations are analyzed using Pathfinder software (one of the evacuation path simulation software based on human simulator agents and movements) with several fire situations, to determine the time required during the evacuation process.

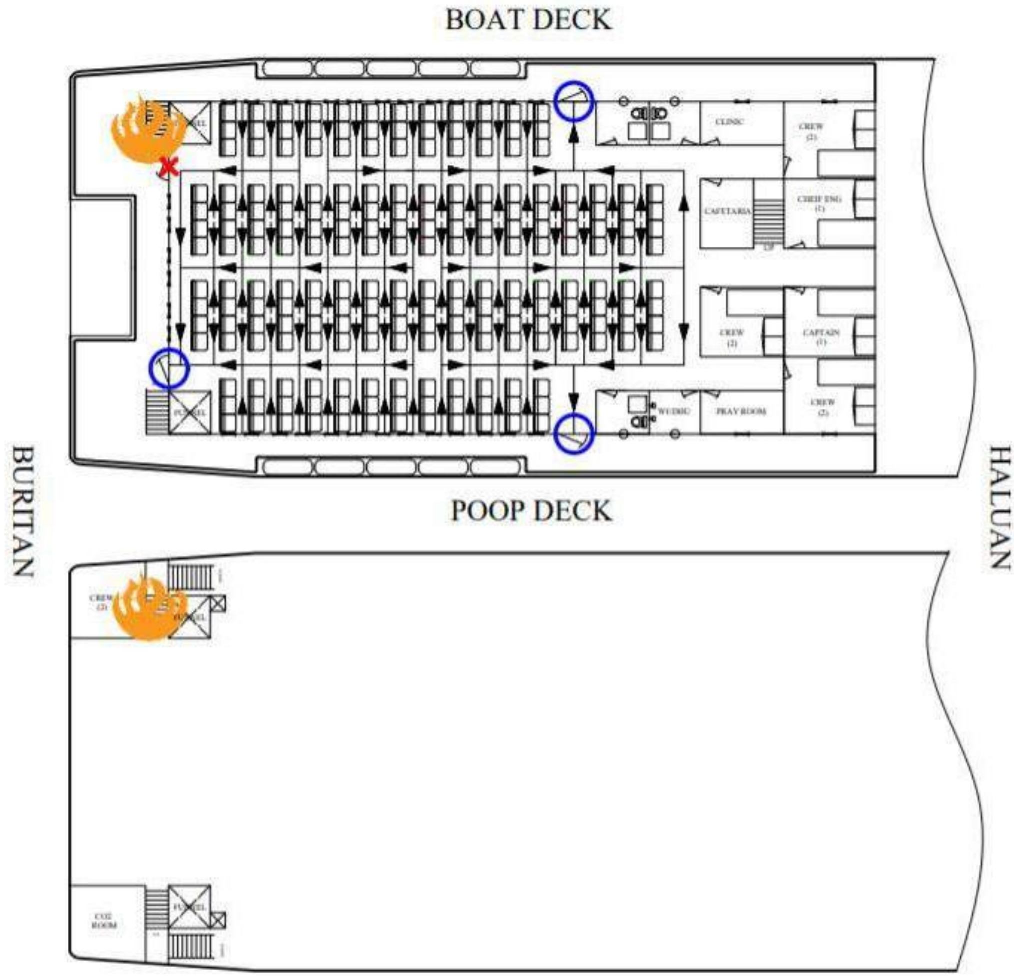

Figure 4. Evacuation route when the fire is in the left side engine room.

b. Data Collection

Data collection aims to clarify the subject to be raised in the thesis; the data required are: safety plan, general arrangement, and ship passenger capacity. At this stage, supporting data about matters that are per the methods used are collected for further analysis.

The data used is KMP Trisna Dwitya, using a general arrangement and safety plan with the following ship data:

Panjang total (LOA)	= 54,90 m
Lebar (B)	= 14,40 m
Tinggi kapal (D)	= 3,50 m
Sarat (T)	= 2,57 m
Crew	= 13 lives
Passengers	= 208 lives

c. Model Design and Simulation

Scenario Design and modeling are done using Autocad and Pathfinder software, by drawing the design of the waiting room on KMP Trisna Dwitya using Autocad as a background on the Pathfinder.

Placement of fire points in fire-prone places because in the section that is the point where fires easily occur. So that 3 scenarios are obtained that will be used in the simulation, like: scenario 1 when the fire point is on the main deck of the ship, scenario 2 when the fire point is in the left engine room, and scenario 3 when the fire is in the right side of the ship's engine room. The simulation process is carried out using Pathfinder software by entering data such as: the location of the exit, the area that can be passed by passengers, and the number of passengers in the room.

d. Data Analysis and Simulation Results

Data analysis is carried out by paying attention to several points such as the number of exits, the placement of passenger seats, access roads that will be through by passengers, and the placement of hotspots that have the potential for fire, such as the left side engine room, right side engine room, and main deck, where motorized vehicles.

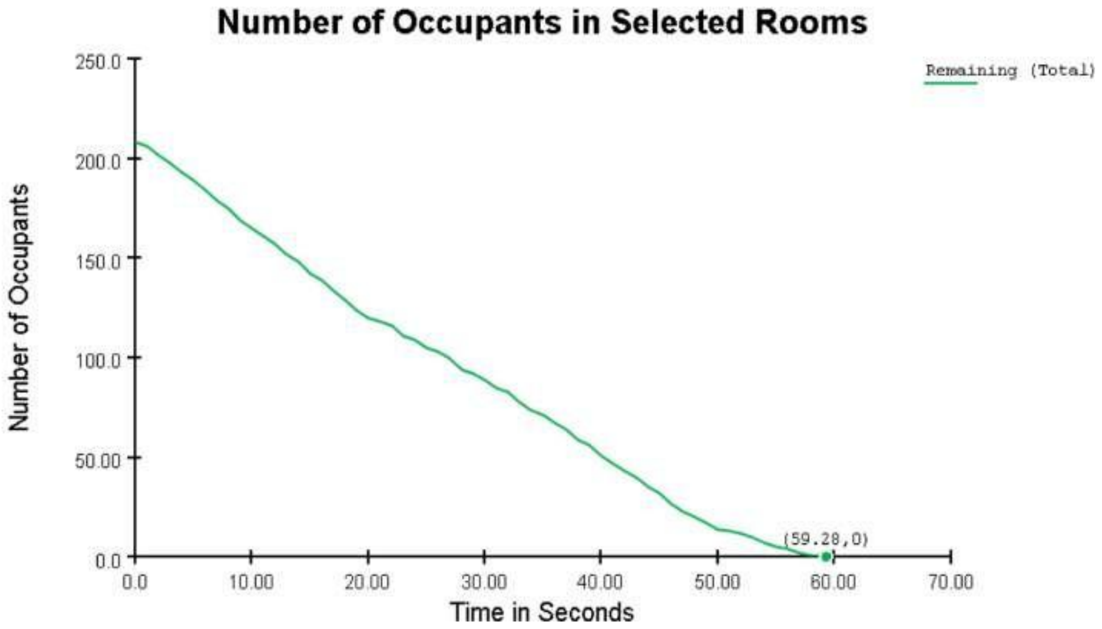

Figure 5. Graph of evacuation time leaving the waiting room (scenario 2).

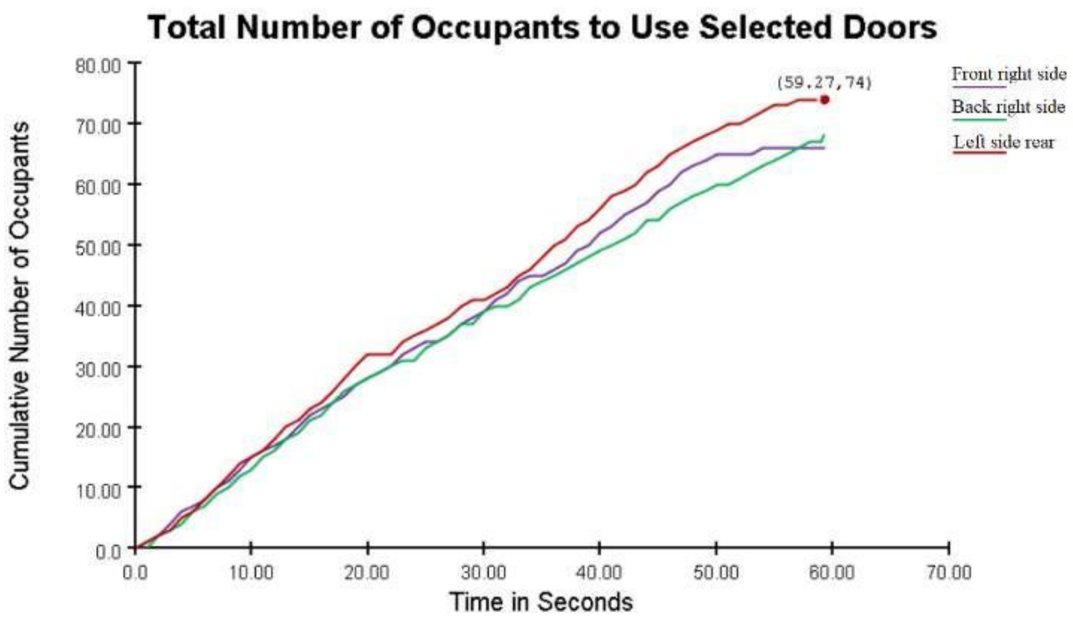

Figure 6. Graph of the number of passengers exiting each door (Scenario 2).

Simulation results using Pathfinder software in the form of graphs and time. In this case, the graph shows the value of the object's movement in choosing its evacuation path, while the time shows the time it takes to leave the passenger room on the KMP Trisna Dwitya ship.

The results obtained from the simulation must meet the standards set by IMO, which is no more than 60 minutes for the evacuation process on passenger ships [7], [8].

e. Evaluation of the Simulation Results

According to [8], after obtaining the results of the passenger evacuation simulation, the simulation results will be evaluated against the standards set by the IMO. If the results obtained meet the specified standards, it can proceed to the conclusion stage; if the simulation results do not meet the predetermined standards, the model design and simulation process must be repeated until the results are under safety requirements [7].

Result and Discussion

The evacuation process aims to save passengers or cabin crew. In this article, there are 3 scenarios

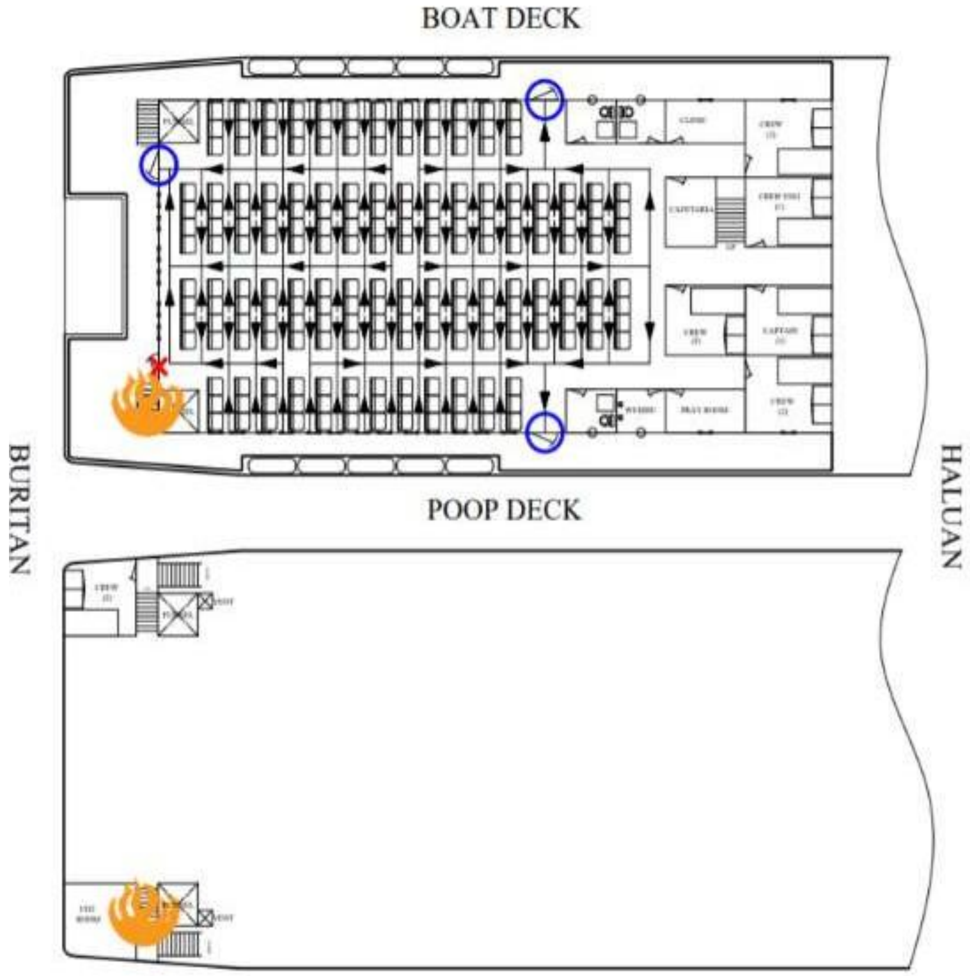

Figure 7. Evacuation route when the fire is on the right side of the engine room (Scenario 3).

used, namely when the fire point is on the main deck, left, and right-side engine rooms.

The placement of the fire point in scenario 1 is on the main deck. The placement of the fire point is based on the location of the vehicle on the main deck so that it can become a source of fire.
Based on the evacuation simulation in Figure 1, the results obtained are that 208 ship passengers need 43.53 seconds to evacuate out of the room. 43.53 seconds with the condition that all exits can be used.

Based on Figure 2, the right rear door is the door that is not chosen by many ship passengers, with 46 people. The right-side front door is the exit access chosen by many people, reaching 56 people. The left front door and the left rear door were passed by 53 people. The majority of passengers choose to exit through the front door of the ship, either the right front or the left front.

The simulation results show that the total time required for the evacuation process is 43 seconds (T). The response time is 5 minutes during the daytime (A). In this case, the overlap time uses 22 minutes 3.12 seconds (E+L), so that the time required for evacuation is as follows:

= 1.25(A+T) + 2/3(E+L)
= 1.25(5'+43") + 2/3(22'3.12")
= 20'21"

So, the simulation results of the evacuation process in scenario 1 took about 20 minutes and 21 seconds.

The fire point in scenario 2 is in the left side engine room. During the evacuation process, the door near the left staircase cannot be used because the position of the door is too close to the fire source, so there are only 3 doors that can be used. Therefore, the evacuation route simulated for the evacuation process only uses 3 exit accesses in the ship's waiting room, namely the right-side rear door, the left side front door, and the right-side front door (Figure 4).

The results of the evacuation simulation in scenario 2, out of 208 passengers on board, took 59.28 seconds to evacuate the room, with the condition that the left side rear exit door could not

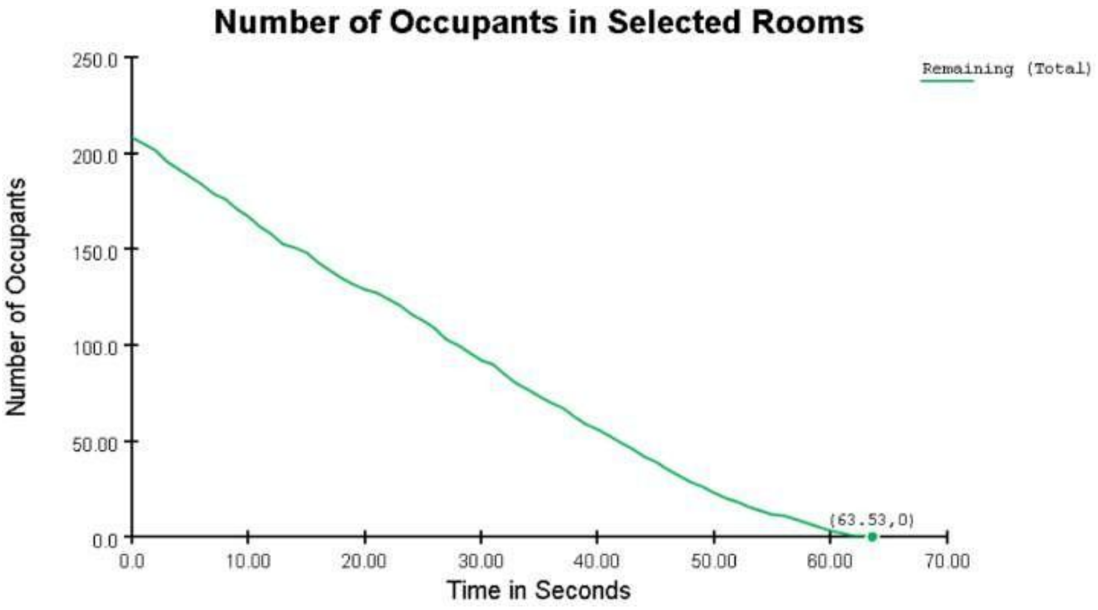

Figure 8. Graph of evacuation time leaving the waiting room (scenario 2).

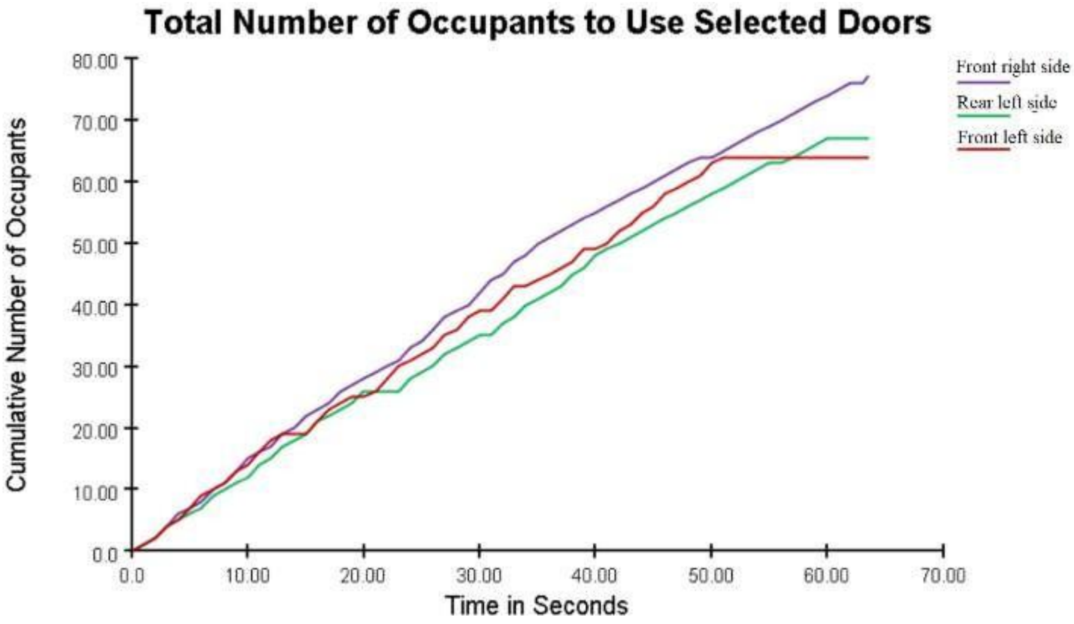

Figure 9. Graph of the number of passengers exiting each door (Scenario 2).

be used because it was too close to the fire source (Figure 5).

The number of passengers at each door, namely the right front door, is an access door that is not chosen by many ship passengers, with 66 people. The left front door of the ship became the exit access chosen by many people, as many as 74 people, and on the right side of the back door, the number of people reached 68 passengers (Figure 6).

Based on the simulation results in scenario 2, the total time required for the evacuation process is 59 seconds (T). The response time is 5 minutes during the daytime (A), and the overlap time uses 22 minutes 3.12 seconds (E+L), so that the time required for evacuation is as follows:

= 1.25(A+T) + 2/3(E+L)
= 1.25(5'+59") + 2/3(22'3.12")
= 20'57"

So, the simulation results in scenario 2 are about 20 minutes 57 seconds for the evacuation process.

In scenario 3, the fire point is in the right-side engine room, so that during the evacuation process, the door near the starboard staircase cannot be used because the position of the door is too close to the source of the fire, so there are only 3 doors that

Table 1. Results of the 3 scenarios

No	Scenario	Number of passengers on board	Number of usable doors	Evacuation time obtained	Evacuation time limit
1.	Scenario 1	208	4 doors	20 minutes 21 seconds	< 60 minutes
2.	Scenario 2	208	3 doors	20 minutes 57 seconds	< 60 minutes
3.	Scenario 3	208	3 doors	21 minutes 1 seconds	< 60 minutes

can be used. So that the evacuation route simulated for the evacuation process uses 3 exit access doors, namely the left side rear door, the left side front door, and the right side front door (Figure 7).

The evacuation simulation in scenario 3 obtained the results, namely from 208 ship passengers it takes time to be able to evacuate out of the room for 63.53 seconds with the condition that the exit door at the back of the right side cannot be used because it is too close to the fire source (Figure 8).

Based on Figure 9, the left front door is the door access that is not chosen by many ship passengers, with a total of 64 people. The most intended number is the right front, with a total of 77 people, and at the back of the left, totaling 67 people. The majority of passengers choose to exit through the door at the front of the ship.

Based on Figure 9, the left front door is the door access that is not chosen by many ship passengers, with a total of 64 people. The most intended number is the right front, with a total of 77 people, and at the back of the left, totaling 67 people. The majority of passengers choose to exit through the door at the front of the ship.

From the simulation results above, the total time required for the evacuation process is 1 minute 3 seconds (T). The response time is 5 minutes during the daytime (A), and the overlap time uses 22 minutes 3.12 seconds (E+L), so that the time required for evacuation is as follows:

= 1.25(A+T) + 2/3(E+L)
= 1.25(5'+1'03) + 2/3(22'3.12)
= 21'1"

So, the simulation results in scenario 3 are about 21 minutes and 1 second for the evacuation process.

Based on the 3 scenarios that have been carried out, the simulation results for KMP Trisna Dwitya have met the regulations set by MSC.1/Circ. 1238, which is less than 60 minutes, so that during the evacuation process in the future if there is a fire incident on the ship, passengers can evacuate quickly so that casualties occur a fire incident on the ship, passengers can evacuate quickly so that casualties can be minimized (Table 1).

Based on experiments from several simulations, it can be seen that there are differences and the evacuation time process. One example in terms of time, when the evacuation process in the scenario when the fire point is on the main deck is quite short because the exit access can be accessed maximally by using all available doors, namely 4 access doors.

In the scenario simulation when the fire point is in a certain place such as above the engine room which coincides under the up and down access to the passenger room, so that it can hamper the evacuation process. so that the time needed is slightly longer because the exit access cannot be accessed optimally because the exit can only be used 3 out of 4 doors.

The simulation process with Pathfinder software only has a predictive and simulation function based on the regulations that have been implemented. IMO calculation guidelines: there are several things in the calculation, including waiting time on each deck and estimation of the level of awareness in humans towards the environment, to cause an extension of time. While in the simulation, there is no waiting time and awareness, so that the simulation time can run simultaneously.

Conclusion

Based on the simulation results for scenario 1, where the fire point is located on the main deck of the ship, the evacuation time is 20 minutes 21 seconds. In scenario 2, where the fire point is located in the engine room on the left side of the ship, the evacuation time is 20 minutes 57 seconds. In scenario 3, where the fire point is located in the engine room on the starboard side of the ship, it takes 21 minutes and 1 second.

The evacuation results from scenarios 1 to 3 are already a fast evacuation and are by the provisions of the IMO, which is less than 60 minutes. So that KMP Trisna Dwitya has met the standards that have been determined.

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