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Analysis of Causes of Starting Failure on Auxiliary Engine MT Green Stars with HAZOP Method

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Abstract **- The air motor starter is a critical component used to rotate the auxiliary engine flywheel to initiate the first combustion process. This system utilizes high-pressure air from a compressor or air tank to power the starter motor, which is connected to the engine's crankshaft. The rotational movement generated by the air starter motor enables the auxiliary engine to start. This study aims to analyze the causes of starting failure in the auxiliary engine on MT Green Stars, particularly due to damage to the air motor starter bearing. The research employs a descriptive analysis method using the HAZOP (Hazard and Operability Study) approach, supported by data from observations, logbooks, technical manuals, journals, and interviews. The research was conducted on board MT Green Stars, a vessel equipped with three auxiliary engines, one of which experienced starting failure. The results indicate that starting failure is caused by several factors, including bearing rupture in the starter motor, clogged injectors, and dirty fuel filter and compressor. This failure leads to disruptions in the electrical system, hydraulic and pneumatic systems, and work efficiency, and poses a risk to the main engine and overall ship safety. Preventive and corrective maintenance is recommended, with emphasis on routine checks based on the Planned Maintenance System (PMS) and regular toolbox meetings.**

Keywords - Bearing, air motor starter, auxiliary engine, start failure

I. Introduction

Indonesia as the largest archipelagic country in the world, holds a strategic and vital position in global maritime affairs. Geographically, Indonesia is dominated by ocean territory, making it a maritime nation by nature and necessity. According to the Central Bureau of Statistics (BPS), the total territorial area of Indonesia is approximately 1,892,410.09 km², of which 77.14% consists of ocean[1]. With over 17,000 islands scattered across equatorial waters, Indonesia is inherently dependent on maritime transportation for inter-island connectivity, national economic integration, and participation in international trade routes. Given its geographical characteristics, sea transportation plays a critical role in supporting Indonesia's socio-economic development. One of the key infrastructures supporting maritime transport is the ship itself. The safe, efficient, and uninterrupted operation of ships is crucial not only for trade but also for national resilience and connectivity. In this context, ship performance and reliability become central concerns, especially for large commercial vessels such as tankers, cargo ships, and passenger ferries[2].

A ship's operational capability largely relies on two major engine systems: the main engine (ME) and the auxiliary engine (AE). While the main engine serves as the primary propulsion mechanism, auxiliary engines are equally vital as they provide electrical power for a wide range of essential onboard systems. These include navigational equipment, communication devices, control systems, cargo handling equipment, air conditioning, lighting, and safety mechanisms. Essentially, auxiliary engines serve as the heart of the ship's electrical power system, particularly when the vessel is not underway or during anchorage and port operations[3]. Auxiliary engine is categorized as an auxiliary machinery system that has a critical operational role on board. It converts mechanical energy, produced by a diesel engine (prime mover), into electrical energy through an alternator. This energy conversion process ensures that all electrical loads required by the ship are met, regardless of whether the vessel is in motion or stationary[4].

Due to their continuous and heavy-duty usage, auxiliary engines are susceptible to various operational risks, including mechanical failure, wear and tear, and more specifically, failure in the starting system. One of the most frequently encountered issues in ship operations is the failure to start the auxiliary engine, which can significantly hamper onboard electrical distribution and disrupt mission-critical operations such as loading, unloading, or vessel maneuvering. Onboard failures of this nature are especially problematic during transitional moments, such as unberthing or emergency readiness. The starting system of an auxiliary engine is generally divided into two types: electrical and pneumatic (air pressure-based)[5]. Each system has its own operational characteristics, advantages, and challenges. During the researcher's one-year onboard practice aboard MT Green

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Stars, an oil tanker vessel engaged in regional petroleum distribution, several operational challenges related to the auxiliary engine were encountered[6].

Notably, during an OHN (One Hour Notice) procedure a preparatory step to alert the engine room crew one hour before maneuvering it was observed that one of the auxiliary engines failed to start. This failure occurred at a critical time, just before unberthing from Balongan for a voyage to Balikpapan. According to standard operating procedures, two auxiliary engines must be operational prior to maneuvering. However, the failure to start one of them not only delayed the process but also posed a potential safety hazard. The start-up mechanism for auxiliary engines on MT Green Stars relies on a pneumatic system, which uses compressed air to turn over the diesel engine and initiate the combustion process. Pneumatic systems are favored in marine applications due to their lower risk of sparking and thermal buildup[7]. Despite these advantages, pneumatic starter systems are not immune to mechanical failure, particularly in complex components such as planetary gears and bearings. These components are subject to repeated high-stress cycles, which, without adequate maintenance or due to material fatigue, can lead to system breakdowns[8]

A. Auxiliary Engine Overview

The auxiliary engine, commonly referred to as the ship's diesel generator, plays a central role in ensuring the uninterrupted power supply to all electrical and electronic systems onboard. Auxiliary engines as essential machinery that ensures the operational readiness of ships at all times[9]. These engines operate on the principle of energy transformation from chemical energy in diesel fuel to mechanical energy in the combustion engine, and finally to electrical energy through an alternator. Considering their importance, auxiliary engines are subject to various types of maintenance, including preventive, corrective, and scheduled overhauls, to ensure their longevity and reliability[10].

B. Starting System Description

The starting system is the initial mechanism that brings the auxiliary engine to life. It is designed either in electric or pneumatic configuration. The latter, which is implemented on MT Green Stars, relies on high-pressure compressed air to rotate the flywheel, initiating the engine cycle. This system comprises several interdependent components such as the solenoid valve, air starter motor, pilot control valve, clutch, and planetary gear arrangement. The choice of a pneumatic starter, while advantageous in explosive or high-temperature environments, requires meticulous maintenance due to its mechanical complexity and sensitivity to pressure loss or component wear[11].

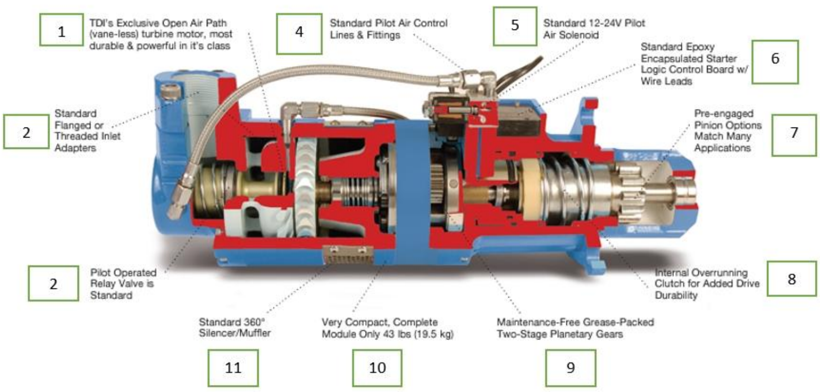

Figure. 1. Air Motor Starter Component

Based figure 1 following are the components of an air motor starter:

1. Open air path
2. Standard flanged
3. Pilot operated relay
4. Pilot air control
5. Solenoid water pilot
6. Starter control board
7. Pinion
8. Clutch
9. Planetary gear
10. Body
11. Silencer

C. Planetary Gear

The planetary gear system, also known as epicyclic gearing, is an integral part of the pneumatic starter mechanism. Planetary gears allow for high torque transmission in compact configurations[12]. The system comprises a central sun gear, orbiting planetary gears mounted on a carrier, and an external ring gear. This configuration enables efficient torque multiplication and smooth power transmission with minimal noise and vibration, making it suitable for marine starter systems.

D. Bearing

Bearings are machine elements that reduce friction and support the rotating shaft, ensuring smooth mechanical motion. Bearings play a critical role in minimizing resistance between moving parts by using rolling elements with low coefficients of friction[13]. In the context of pneumatic starters, bearing failure can lead to imbalance, vibration, and failure of the gear or clutch systems, directly affecting the ability to start the auxiliary engine.

Despite being widely used and mechanically robust, pneumatic starter systems are still susceptible to operational failure, particularly due to wear and fatigue in high-stress components such as bearings and planetary gears. Incidents of auxiliary engine starting failure, as experienced on the MT Green Stars, reveal potential weaknesses in current inspection, maintenance, and reliability assurance procedures. Such failures not only compromise the ship's readiness and safety but may also delay critical operations, leading to economic and operational losses[14].

This research presents a novel application of the HAZOP (Hazard and Operability Study) methodology in diagnosing and analyzing the causes of auxiliary engine starting failure in maritime contexts. While HAZOP has traditionally been used in process industries for risk assessment[15], its implementation in the marine auxiliary engine domain is still relatively limited. By applying HAZOP to a real-life failure case aboard MT Green Stars, this study contributes a structured and systematic approach to identifying component-level hazards especially in the pneumatic starter's bearing and planetary gear system[16]. The findings are expected to provide actionable insights into preventive maintenance, design optimization, and training protocols for engine room personnel, ultimately enhancing the reliability of auxiliary engine start-up systems on commercial vessels[17].

II. Method

The type of research that the researcher will present this time is qualitative based with a descriptive analytical research method. The definition of descriptive analytical according is a method that functions to describe or provide an overview of an object being studied through data or samples that have been collected as they are without conducting analysis to make conclusions that apply to the public[18].

A. Method of collecting data

This research in the data collection process uses various methods including observation, interviews, literature, documentation, and questionnaires.

B. Data analysis technique

This study uses the HAZOP (Hazard and Operability Study) method for the data processing process. HAZOP is a hazard identification method that can be carried out while a process is in progress, so that potential hazards can be identified early and evaluated while the process is still ongoing, so that improvements can be made immediately without stopping the process[19]. The likelihood table is used as a frequency indicator that states how many events occur. Danger occurs as a source of problems in the auxiliary engine. The consequences table is used as a description of the level of repair/maintenance for damage that occurs to the hazard[20]. After processing the data using the likelihood table and consequences table, the next table needed is the risk matrix table. According to the Risk Management Procedure Policy published by UNSW Safety and Sustainability[21]

TABLE 1.
LIKELIHOOD

Level	Criteria	Description
1	Rarely happening	Occurs once a year
2	Small possibility	Occurs 2-3 times
3	Possible	Occurs 4-5 times
4	Most likely	Occurs 6-7 times
5	Almost Certain	More than 7x

TABLE 2.
CONSEQUENCES

Level	Criteria	Description
1	Not Significant	Regular maintenance
2	Small	Advanced maintenance
3	Medium	Requires O/H on components, short time
4	Heavy	Requires O/H on components, long time
5	Extreme	Requires O/H throughout

		CONSEQUENCES				
		1	2	3	4	5
LIKELIHOOD	A	M	H	H	VH	VH
	B	M	M	H	H	VH
	C	L	M	H	H	VH
	D	L	L	M	M	H
	E	L	L	M	M	M

FIGURE. 2. UNSW MATRIX

III. Results and Discussion

This research was conducted during a sea practice program that lasted approximately 12 months, spanning from August 10, 2023, to August 13, 2024, aboard the MT Green Stars. The MT Green Stars is a tanker-class vessel owned and operated by PT Waruna Nusa Sentana, a company engaged in the national shipping industry. Throughout the research period, the researcher was actively involved in observing and participating in various engine room operations, with full support and guidance from the ship’s engine department crew, including the chief engineer, second engineer, third engineer, fourth engineer, fifth engineer, and oiler.

Their collective assistance and practical insights significantly contributed to the successful documentation and analysis of technical incidents, particularly those related to auxiliary engine failure[22]. The central focus of this study is the persistent issue surrounding the starting failure of the auxiliary engine, specifically due to problems in the air starter motor system. One critical incident occurred on June 24, 2024, when the MT Green Stars was scheduled to depart for Balikpapan after completing loading and unloading activities at the Balongan terminal [23].

As per standard operational procedures, the engine department initiated preparations by executing an OHN (One Hour Notice), which includes, among other tasks, the startup of at least two auxiliary engines to support maneuvering and navigation systems. However, during this routine procedure, the engineering crew encountered a significant anomaly despite several attempts, one of the auxiliary engines failed to start[24]. Engineer along with the oiler, attempted multiple restarts using the standard protocol but were unsuccessful. Recognizing the criticality of the situation, they immediately reported the issue to the chief engineer. Responding promptly, the chief engineer carried out an initial inspection and concluded that the fault likely originated in the air starter system.

He then issued a directive to remove the air motor starter unit from the affected auxiliary engine for a more thorough examination. The air motor starter was subsequently disassembled in the ship’s workshop, where detailed diagnostics were conducted[25]. This disassembly process aimed to identify mechanical or pneumatic faults that could hinder the start-up mechanism, such as damage to internal gear components, valve malfunctions, or contamination in the air lines. The hands-on investigation and fault isolation that took place became a pivotal moment in this research, forming the basis for hazard identification and subsequent risk analysis[26].

This incident not only underscored the critical role of air starter systems in ensuring the operational readiness of auxiliary engines but also highlighted the real-world implications of mechanical failures aboard a commercial vessel[27]. It served as a key case study that enabled the researcher to apply systematic methods, such as the HAZOP analysis, to evaluate risk levels, determine causative factors, and propose maintenance strategies aimed at preventing similar failures in the future[26].

HAZOP

The HAZOP research method focuses on the process of identifying a problem systematically. In the process, HAZOP explains each stage of the process in an effort to identify the source of the problem. Therefore, a sequential analysis is needed to facilitate the identification process and the process of subsequent improvement steps. Steps in identifying hazards using the HAZOP method include[28].

TABLE 3.
FINAL HAZARD CLASSIFICATION

No	Hazard
1	Compressor
2	Air motor starter
3	Fuel filter
4	Injectors

TABLE 4.
DEVIATION

No	Hazard	Deviation
1	Compressor	Less flow
2	Air motor starter	No flow
3	Fuel filter	Less flow
4	Injectors	No flow

TABLE 5.
CAUSE

No	Hazard	Cause
1	Compressor	Dirty air filter
2	Air Motor Starter	Component damage
3	Fuel filter	Dirty filter
4	Injectors	Nozzle clogged

TABLE 6.
CONSEQUENCES

No	Hazard	Consequences
1	Compressor	Dirty air coming in
2	Air motor starter	The start process is not optimal
3	Fuel filter	Low fuel pressure to the nozzle
4	Injectors	Fuel atomization

TABLE 7.
FREQUENCY

No	Hazard	Frequency
1	Compressor	2
2	Air Motor Starter	6
3	Fuel filter	2
4	Injectors	3

TABLE 8.
RISK MATRIX

No	Hazard	Frequence	L	C	L*C	Color	Risk Level
1	Air motor starter	6	4	3	12	Red	Very High
2	Injectors	3	2	4	8	Yellow	High
3	Compressor	2	2	3	6	Green	Medium
4	Fuel filter	2	2	2	4	Blue	Low

Identifying

Identifying hazards found in the research area MT Green Stars has experienced auxiliary engine start failure with various hazard sources including injectors, compressors, air motor starter, fuel filters, and panels

b. Classify the hazards found.

Based on Table. 3, the classification of auxiliary engine start failure hazards is determined from the top four ranks that have experienced MT Green Stars auxiliary engine start failures. Air motor starter hazards have the highest number of experiences by MT Green Stars engine crews. This is followed by injector, compressor, and fuel filter hazards. Panel hazards are ranked last or in the sense that only a few crews experience them. Therefore, it is determined that the writing of this scientific paper will focus only on four hazards, namely air motor starter, compressor, injector, and fuel filter.

c. Describe the deviation that occurs

Deviation in HAZOP is a deviation from normal operational conditions in a process[29]. The deviation in each hazard can be described as follows: a compressor that should channel pressurized air, but is lacking in its flow. Table. 4 explain that an air starter motor that should drive the gear, but does not drive the gear. A fuel filter that should deliver fuel, but is lacking because it is dirty. An injector that should spray fuel, but cannot spray.

d. Describing the causes of deviation

The causes according to Table. 5 of each hazard include compressors caused by dirty air filters, air motor starter caused by damaged components, fuel filters caused by dirty filters, and injectors caused by clogged nozzles

e. Describing what arises from the deviation (consequences)

The consequences of each hazard include a compressor that causes the incoming air to become dirty, an air motor starter that causes the starting process to be less than optimal, a fuel filter that causes the fuel pressure to be low to the nozzle, and an injector that

a.

causes the fuel atomization to be hampered based on Table. 6

f. Assess risk by determining the frequency of occurrence (likelihood) and the consequences (consequences).

Each hazard has a number/frequency of occurrence and has consequences of severity based on Table. 7. As for the frequency of the number of hazard events can be determined based on the incident on board[30]. The frequency on the ship refers to Table. 1 to determine the frequency level. The severity level shows how severe the maintenance/repair process is also referring to Table. 2.

g. Multiply and sort the likelihood multiplication by consequences according to the risk matrix

According to Table. 8, the likelihood and consequence values of each hazard source can be seen. The next step is to multiply the likelihood value and the consequence value to obtain the level of danger (risk level) in the risk matrix which will later be used in ranking potential hazard sources.

h. Designing improvements for risks “very high” level

From Table. 8, it is found that the fuel filter has a value of 4 where the risk level is low. Then at the medium risk level, the compressor hazard gets a value of 6. The high risk level is obtained by the injector which has a value of 8. The highest risk level with a fairly large value compared to the other three hazards with a value of 12 is obtained by the air motor starter. Based on the results of these data, it is concluded that the air motor starter is a hazard with the highest risk level value. The air motor starter causes a failure to start the auxiliary engine because the components inside are damaged.

Based on the results of the matrix table, the result are

a. Factor causing failure to start the auxiliary engine

1) Component factor

Based on the ranking, the air motor starter is ranked first in the risk matrix. This is due to the multiplication of the likelihood and consequence tables which are very high. The air motor starter gets a score of 12 where the risk matrix indicator shows an very high level with a red level color. .

The main factor that causes the air motor starter to not function properly is a broken bearing. This bearing is located on the planetary gear which functions to reduce the rotation of the turbine motor. The rotation of the turbine is reduced so that the rotation is slower but still has a large torque to rotate the flywheel at the start of the engine. A broken bearing can certainly inhibit the working process of the planetary gear which will certainly cause the planetary gear rotation process to be continued to the shaft to be slow. The cause of the broken bearing can occur due to several factors, namely the quality of the bearing used has low specifications and corrosion of the bearing. Failure to start due to the broken bearing of the air motor starter on the MT Green Stars was experienced 6 times. As for the repair process of the air motor starter, it requires dismantling or O / H components with a short time. Of course, considering the frequency and severity, the air motor starter deserves to be called the main cause of the failure to start on the auxiliary engine of the MT Green Stars ship.

2) Maintenance factor

Maintenance is one of the most important factors in keeping the engine in top performance. If maintenance is ignored, it is certain that in the future there will be unwanted damage. Based on the results of the interview with third engineer as the person in charge of the auxiliary engine, the answer was obtained regarding the damaged air motor starter, one of which was due to lack of maintenance. The air motor starter is only used every time you want to start the auxiliary engine. Of course, this results in a lack of focus on maintenance on the components in the air motor starter

3) Spare part factor

Based on the statement of the chief engineer who handled the spare part request process, it was concluded that for the air motor starter component, the company often did not send spare parts. As for the process of replacing damaged bearings, they were not replaced using new bearings but used bearings found in the auxiliary engine spare part storage workshop with the status of used/reconditioned spare parts.

b. Impact of failure to start the auxiliary engine

1) Disturbance in the ship electrical system

Auxiliary enginevery necessary on ships because it drives the electric generator. Disturbances such as failure to start the auxiliary engine can cause disruption to the electrical system and can cause blackouts of lighting, navigation, and other control systems

2) Pump system failure

Auxiliary engine functions to drive the pumps on the ship. Examples of pumps are cooling pumps, fuel pumps, and ballast pumps.

3) Disturbances in hydraulic and pneumatic system

Many ship systems such as winches, cranes, and steering systems rely on power from auxiliary engines. If they fail, cargo loading and unloading operations and ship maneuvering can be disrupted.

4) Operational delays and ship efficiency

Failure to start the auxiliary engine can cause disruption to ship operations, especially during the process of leaving/entering the port where the ship requires a maneuvering process that requires more than one auxiliary engine to operate.

5) Risk damage to the main engine

Auxiliary engine often used as a support for the ship's main engine. If it fails to operate, then the supporting systems such as the cooling system and lubrication system can be disrupted

6) Safety and regulatory breaches

The rules regarding world maritime safety are regulated in SOLAS, which explains that every ship is required to have a backup power source. Backup power sources are used in emergencies, therefore it can increase the risk of accidents if there is no backup power source.

c. Handling auxiliary engine start failure

1) Preventive maintenance

Preventive maintenance is a type of maintenance that is carried out periodically to prevent damage before it occurs.

a) Daily maintenance
- Checking fluid levels such as fuel tank, oil level, and coolant
- Visual inspection of components to ensure nothing is loose
- Visual inspection of components to ensure nothing is loose

b) Weekly Maintenance
- Air filter cleaning.
- Checking the fuel and lubrication pump
- Check generator voltage and frequency fluctuations

c) Monthly maintenance
- Check fuel injectors
- Daily tank cleaning to avoid blockages
- Filter inspection and replacemet

d) Annual maintenance
- Overhaul on auxiliary engine components that have passed their running hours
- Calibration of protection system such as overcurrent relays and AVR

2) Breakdown maintenance

Breakdown maintenance is a treatment carried out after the component is damaged and cannot operate. Here the researcher will share the breakdown maintenance process on the auxiliary engine air motor starter component. The steps are as follows:

a) Make sure the auxiliary engine panel is in the off position.
b) Remove the air motor starter attached to the auxiliary engine using a wrench and torque wrench.
c) Make sure the pinion gear and flywheel are removed
d) Take the air motor starter to the workshop.
e) Prepare an L key, screwdriver, and hammer to open the air motor starter.
f) Disassemble and remove the components one by one

g) Remove broken/damaged bearings in planetary gears
h) Replace the new bearing then reinstall it on the planetary gear and add sufficient grease.
i) Reinstall the removed components
j) Tighten the cover bolts with the correct torque using an L key.
k) Test the air motor starer using air, if the pinion gear moves then the bearings on the planetary gear rotate properly.
l) Bring the air motor starter to the auxiliary engine
m) Reinstall the assembled air motor starter into the auxiliary engine.
n) Auxiliary engine start test
o) Auxiliary engine can be start

IV. Conclusion

This study has investigated the root causes of the failure to start the auxiliary engine aboard MT Green Stars, with a focus on analyzing hazards through the HAZOP (Hazard and Operability Study) method. The primary objective, as outlined in the abstract, was to identify the most critical hazard that inhibits the successful operation of the auxiliary engine and to determine its impact on ship performance and operational safety. The findings reveal that the failure to start the auxiliary engine was caused by several interrelated technical issues: (1) broken or damaged bearings within the planetary gear system of the air motor starter, (2) clogged injector nozzles, (3) dirty air filters on the air compressor unit, and (4) contaminated fuel filters. Among these, the most critical factor, as identified through HAZOP risk matrix analysis, was the failure of the air motor starter bearing system, which demonstrated the highest severity and likelihood rating in terms of risk impact. This critical failure in the starter system directly hindered the activation of the auxiliary engine, leading to a cascade of functional disruptions across the vessel. The inability to start the auxiliary engine meant that the ship's electrical generation was compromised, which further affected key systems such as ballast and bilge pumps, hydraulic and pneumatic controls, navigation and communication systems, and other operational equipment.

The novelty of this research lies in its application of the HAZOP methodology to marine auxiliary engine start-up failures, specifically within the pneumatic starting system a domain where such structured hazard identification approaches are still underutilized. Unlike conventional maintenance logs or observational diagnostics, the HAZOP approach allowed for a systematic identification, categorization, and ranking of operational risks, providing a quantitative foundation for maintenance prioritization and decision-making. Furthermore, the study contributes practically to marine engineering by offering a replicable diagnostic framework for ship operators, shipyards, and classification bodies to adopt in improving engine room reliability. The integration of HAZOP with real-world engine failure scenarios presents a new paradigm in marine risk management, emphasizing proactive safety assurance rather than reactive troubleshooting. The insights generated can inform Standard Operating Procedures (SOPs), engineer training modules, and risk-based maintenance planning in similar vessel classes. In conclusion, by understanding the most significant risk contributors to auxiliary engine failure and implementing targeted maintenance strategies guided by structured hazard analysis, ship operators can greatly enhance the reliability of critical onboard systems, ensure operational safety, and improve overall fleet efficiency.

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References

[1] BPS. Indonesian Statistic 2024. Central Bureau of Statistic; 2024
[2 Regulation of Minister of Transportation of Indonesia; 2022

[3] Reddy, B. K. "Generators. In Electrical Equipment" (pp. 73–111). Wiley. https://doi.org/10.1002/9781119771708.ch3

[4] Syahputra, D. W., & Wahyuningsih, S. (2023). Analysis of Disturbance and Maintenance on Diesel Engine Generator at KM. Egon. In Journal of Business Technology and Economics (Vol. 1, Issue 1).

[5] Jastrzębski, G. Description of the Pneumatic Work Cycle of the Starting Unit of the UAV Launcher. Journal of KONES Powertrain and Transport, 24(4). https://doi.org/10.5604/01.3001.0010.3150

[6] Taylor, D. A. “An Introduction to Marine Engineering”. 1st ed, 2021, pp. 28-30.

[7] Chybowski, L., Myśków, J., & Kowalak, P. (2023). Analysis of fuel properties in the context of the causes of three marine auxiliary engines failure – A case study. Engineering Failure Analysis, 150. https://doi.org/10.1016/j.engfailanal.2023.107362

[8] McGeorge, H.D. “Marine Auxiliary Machinery. 7th ed, 1995, pp. 41-50.

[9] Aries, D. "Analysis of Electricity and Fuel Needs in MV Ship Operations. Srikandi Indonesia with Load Analysis Method" (Vol. 1, Issue 1).

[10] William G, et al. “Marine Engineering”. 1st ed, 1992, pp. 355-356

[11] Novian, A. Tri. "HND MWM TBD 234 V8 Auxiliary Engine Information System Using Visual Basic on KM Ship. Meratus Benoa." 2015,

[12] Anekar, N., Karad, V., Deshmukh, S., & Nimbalkar, S. "Planetary Helical Gear System" (Vol. 1). https://www.researchgate.net/publication/273755713

[13] Jastrzębski, G. Description of the Pneumatic Work Cycle of the Starting Unit of the UAV Launcher. Journal of KONES Powertrain and Transport, 24(4). https://doi.org/10.5604/01.3001.0010.3150

[14] Reddy, B. K. "Generators. In Electrical Equipment" (pp. 73–111). Wiley. https://doi.org/10.1002/9781119771708.ch3

[15] Anekar, N., Karad, V., Deshmukh, S., & Nimbalkar, S.. "Planetary Helical Gear System" (Vol. 1). https://www.researchgate.net/publication/273755713

[16] M. Julian Sugianto, R. Alexander Reggy, H. Aulia Fadhilah, D. Benedict, and P. Sukapto, “Proposed Improvements to Reduce the Risk Work Accidents on CV HB with FMEA and HAZOP Method,” J. Improsci, vol. 1, no. 5, pp. 227–235, 2024, doi: 10.62885/improsci.v1i5.233.

[17] N. Amelia Novitrie, A. Nadia Rachmat, M. Rohma Dhani, Y. Novrita Devi, , “Implementation of the Hazard and Operability Study (HAZOPS) Method in the Sedimentation Unit of the Gas Industry Wastewater Treatment Plant,” *Sediment. Unit Gas Ind. Wastewater Treat. Plant. J. Res. Technol.*, vol. 9, no. 2, pp. 201–209, 2023.

[18] Fenita Purnama Sari Indah, Junaida Rahmi, Ribka Milenia Elsaday Manurung, Tri Okta Ratnaningtyas, and Syaiful Bahri, “Analysis Of Occupational Safety And Health Risk Using The Hazard And Operational Study (Hazops) Method For Repairman,” *Texas J. Med. Sci.*, vol. 27, pp. 143–147, 2023, doi: 10.62480/tjms.2023.vol27.pp143-147.

[19] C. Study, N. S. Reflux, and D. Lpg, “Risk Analysis Using HAZOP -Fault Tree - Event Tree Methodology,” vol. 5, no. 2, pp. 98–105, 2020.

[20] C. Oktaviananda and R. Margareta, “Safety Risk Analysis Using Hazop Method At Pt. Asa,” *Food Agroindustry*, vol. 3, no. 1, pp. 29–45, 2022.

[21] E. Elhosary and O. Moselhi, “Automation for Hazop Study: a

State-of-the-Art Review and Future Research Directions," *J. Inf. Technol. Constr.*, vol. 29, no. July, pp. 750–777, 2024, doi: 10.36680/j.itcon.2024.033.

[22] A. N. Nuriah and E. Rudyarti, "OSH risk analysis with hazard identification risk assessment and control (HIRARC) method at NPK Fertilizer Production Department of PT X," *Period. Occup. Saf. Heal.*, vol. 2, no. 2, pp. 113–129, 2024, doi: 10.12928/posh.v2i2.9202.

[23] R. H. Majethiya and S. Dharaskar, "Hazop Study of Nano DAP Plant," pp. 753–769.

[24] S. Sari *et al.*, "Analysis of occupational health and safety at skin cracker factory using Hazard and Operability Study (HAZOP)," *J. Ind. Serv.*, vol. 8, no. 2, pp. 164–169, 2022, doi: 10.36055/jiss.v8i2.15537.

[25] A. Suhra, "Analysis of Occupational Safety and Health using The HAZOP Method on PT . ABC 3 Kg LPG Gas Cylinder Maintenance Workshop Employees," vol. 08, no. 01, 2023.

[26] A. Suryadi, M. Cattleya, P. A. Islami, and G. Ramadhan, "Safety Assessment Approach of Hazard and Operability (HAZOP) In A Power Plant Sector," vol. 2023, pp. 245–251, 2023, doi: 10.11594/nstp.2023.3635.

[27] A. Zakaria, J. Arifin, and B. Nugraha, "Analisis [19] S. Oktavianus, A. Waruwu, and A. C. Sembiring, "Minimizing Work Accidents in the Shipyarding Industry Using JSA and HAZOP Methods," *JKIE (Journal Knowl. Ind. Eng.*, vol. 9, no. 2, pp. 82–88, 2022, doi: 10.35891/jkie.v9i2.3287.

[28] S. Liandar, A. B. Putra, and E. Prahara, "Hazard and Risk Analysis of Driven Pile Foundation Works Using HIRARC Method," *E3S Web Conf.*, vol. 388, pp. 0–6, 2023, doi: 10.1051/e3sconf/202338801004.

[29] R. Lauri *et al.*, "Hazop Analysis of a Bioprocess for Polyhydroxyalkanoate (PHA) Production from Organic Waste: Part A," *Fermentation*, vol. 9, no. 2, pp. 1–14, 2023, doi: 10.3390/fermentation9020099.

[30] S. Jung, H. Kim, and C. Kang, "Efficiency Analysis of the Integrated Application of Hazard Operability (HAZOP) and Job Safety Analysis (JSA) Compared to HAZOP Alone for Preventing Fire and Explosions in Chemical Plants," Processes, vol. 13, no. 1, 2025, doi: 10.3390/pr13010088.