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Article

Analysis Of The Causes Of Suboptimal Steering Gear Performance Based On Maintenance Factors And The Quality Of Spare Parts On MV. Mulianim

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A B S T R A C T

The operational reliability of a ship's steering gear system is vital for navigation safety and vessel maneuverability, as regulated by International Maritime Standards (SOLAS). However, performance degradation often occurs due to inadequate maintenance practices and spare part constraints. This study aims to analyze the plausible root causes associated with suboptimal steering gear performance on the MV. Mulianim using a qualitative single-vessel case study approach. Data were gathered over a 12-month period through direct field observations, semi-structured interviews with three purposefully selected engineering officers, and documentation audits of the Engine Log Book and PMS records. Data validity was verified through an evidence-triangulation matrix and analyzed using Miles and Huberman's interactive model, combined with an Ishikawa (Fishbone) Root Cause Analysis. The findings indicate that the steering gear hydraulic pressure fluctuated between 85–90 bar against the manufacturer's 100 bar operational baseline, accompanied by high observable fluid turbidity and minor pipe leaks. These physical conditions were found to be associated with procedural and logistical constraints; specifically, 4 out of 15 scheduled Planned Maintenance System (PMS) tasks (26.7%) were overdue, and 2 out of 8 critical spare part categories were completely out of stock due to procurement delays. While direct mechanical causality cannot be definitively established without further experimental testing, the study suggests a strong relationship between logistical deficits and maintenance delays. To prevent potential navigational hazards, strict adherence to PMS schedules and the optimization of the shore-to-ship spare part procurement pipeline are recommended.

1. Introduction

In the current era of globalization, rapid technological advancements have established a highly competitive and borderless environment, compelling industries to rigorously enhance their efficiency and operational standards. The shipping sector, serving as the backbone of international trade, plays a critical role in this economic framework by providing cost-effective and large-scale transportation solutions that connect diverse geographic regions.

Indonesia is geographically defined as a massive archipelagic state, comprising over 17,000 islands, which structurally necessitates a highly reliable and expansive maritime transportation network (Hermawan & Sutanto, 2022). Within this strategic geopolitical and demographic framework, the maritime sector serves as the primary artery for national economic stability and logistical distribution. To guarantee that sea transportation remains safe, fast, and economically efficient, vessels must be equipped with superior mechanical systems that comply with strict maritime safety regulations, including those established by the International Maritime Organization (IMO) (Syibli & Nuryaman, 2021). Among the diverse array of auxiliary machinery installed on commercial vessels, the steering gear system stands out as a fundamentally critical component. The steering gear governs the directional trajectory of the ship, directly dictating its maneuverability, service performance, and the overarching safety of its navigational operations (Pangestu, Narto, & Amrullah, 2024).

The operational integrity of modern maritime vessels relies predominantly on electro-hydraulic steering gears, which convert mechanical and electrical energy into immense hydraulic pressure to manipulate the rudder (Edi et al., 2025). However, the mechanical endurance of the steering gear inevitably deteriorates over time due to continuous friction, thermal stress, and high-pressure fluid dynamics. This natural degradation must be systematically countered through rigorous maintenance protocols. Inadequate maintenance execution severely diminishes the system's efficiency, manifesting in pressure drops, delayed rudder responses, and in extreme cases, total directional control failure (Firdana, 2022; Rusdi, 2021).

Equally vital to maintenance execution is the continuous availability of spare parts (Alif, 2021). Deficits in spare parts within the high-pressure hydraulic environment often force crews to extend the lifecycle of degrading components, thereby accelerating structural wear and compromising the entire system's reliability (Premadi & Magdalena, 2022; Purba, 2022). Empirical field observations conducted aboard the MV. Mulianim—a commercial vessel engaged in high-frequency domestic logistics—revealed persistent anomalies within its steering gear operations. The vessel frequently experienced sluggish rudder responses and hydraulic pressure instability during critical port maneuvering phases. Preliminary investigations suggested that these technical malfunctions were heavily intertwined with delayed maintenance schedules and significant delays in spare part procurement. Consequently, this research provides an in-depth analysis of how maintenance execution factors and spare part availability mutually associate with the decline of steering gear performance, ultimately proposing strategic interventions for maritime engineering practices.

2. Literature Riview

2.1 Review of Previous Studies

The mechanical vulnerabilities of steering gear systems have been extensively documented in prior maritime engineering literature. Firdana (2022) investigated the low hydraulic pressure of steering gear pumps on the KM. Kelud, concluding that pressure degradation is directly triggered by neglected internal components. Similarly, Purba (2022) identified that mechanical neglect on the MT. Medelin Expo led to catastrophic failures of shaft seals and ball bearings, culminating in severe fluid leaks. Furthermore, Pangestu, Narto, and Amrullah (2024) emphasized that any deviation from optimal steering gear parameters immediately compromises the vessel's maneuvering capability. While these previous studies provide a robust descriptive foundation for understanding mechanical failures, much of the literature treats mechanical degradation in isolation. This present study aims to extend earlier findings by systematically investigating how shore-based logistical delays (spare part procurement) directly interact with onboard procedural compliance, utilizing a structured Root Cause Analysis to bridge the gap between technical failures and supply chain constraints.

2.2 Steering Gear Mechanics and International Regulations

The steering gear is explicitly designed to convert command signals from the vessel's bridge into precise rudder angles, enabling the ship to counter external environmental loads such as ocean currents and wind shear. Given its critical safety function, the system is strictly governed by international safety frameworks, specifically the SOLAS 1974 Convention, Regulation II-1/29 (IMO, 2014), which outlines explicit standards for steering gear arrangements. Under these regulations, vessels are mandated to operate with both a main and an auxiliary steering gear. Furthermore, operational and maintenance protocols must align with the International Safety Management (ISM) Code (IMO, 2018.

2.3 Hydraulic Principles and Planned Maintenance Systems (PMS)

Most commercial steering gears operate on electro-hydraulic principles rooted in Pascal's Law. To sustain immense hydraulic pressure, vessels implement a Planned Maintenance System (PMS). The PMS is a scheduled, preventive maintenance architecture designed to eliminate the need for reactive breakdown maintenance (Arief et al., 2024; Oktiani, Rakka, & Irawan, 2025). Indicators of PMS failure in hydraulic systems include the emergence of abnormal mechanical vibrations, acoustic humming, and accelerated wear of contact surfaces (Segara, Sunusi, & Purnomo, 2021).

2.4 Spare Parts Management

The integrity of a hydraulic steering gear is heavily reliant on the material strength of its constituent spare parts (Alif, 2021). Deficiencies in spare parts management and logistical availability force the engineering crew to utilize components beyond their safe operational lifespan, leading to inevitable seal ruptures and catastrophic fluid loss (Rusdi, 2021).

3. Research Methodology

3.1 Research Design and Location

This study employs a Qualitative Single-Vessel Case Study design to perform an in-depth investigation into the operational degradation of the electro-hydraulic steering gear system aboard MV. Mulianim (Rusandi & Rusli, 2021). A qualitative approach was deliberately selected to capture complex mechanical failure dynamics, maintenance behaviors, and supply-chain constraints within their natural operational environment. The research was conducted over a continuous 12-month sea practice (Prala) deployment.

3.2 Data Sources & Collection Techniques

To ensure methodological transparency and reproducibility, primary and secondary data were gathered using three systematic techniques:

1. Direct Observation: Non-participant observations were conducted during active maneuvering phases (entering and leaving ports). The measurement protocol involved visually recording the hydraulic system pressure gauges, visually inspecting oil clarity/turbidity from sampling valves, and observing external pipe joints for leaks. *Note: Fluid assessments were strictly visual; no laboratory viscosity or particle analyses were conducted.*
2. Semi-Structured Interviews: Participants were selected using purposive sampling based on their direct responsibility for the steering gear. The sample (n=3) consisted of the Chief Engineer, Second Engineer, and Oiler. Interviews explored PMS implementation barriers, daily inspection routines, and spare part procurement lead times.
3. Documentary Audit: A retrospective audit was performed on historical operational logs over the 12-month period. Documents reviewed included the Instruction Manual Book (to establish operational baselines), the Engine Log Book, PMS Maintenance Records, and Spare Part Inventory Lists.

3.3 Data Analysis and Validity

Data were analyzed using the interactive data analysis model proposed by Miles, Huberman, and Saldaña (2014):

1. Data Reduction: Filtering, categorizing, and coding raw observations, interview transcripts, and logbook entries related to system pressure drops and maintenance delays.
2. Data Display: Structuring synthesized evidence into visual matrix tables (Evidence-Triangulation Matrix) and an Ishikawa (Fishbone) Root-Cause

Analysis diagram.

3. Conclusion Drawing & Verification: Deriving plausible causal relationships between maintenance variables and steering system performance. To ensure analytical rigor and evaluate converging or conflicting evidence, triangulation of sources was applied by explicitly cross-referencing interview claims against physical pressure gauge readings and official vessel maintenance documentation.

4. Results and Discussion

4.1. General Profile of the Subject

MV. Mulianim is an Indonesian-flagged semi-container vessel registering 3,258 Gross Tonnage (GT) and equipped with a 2,037 PS Niigata 8-cylinder main engine. Operating on high-density domestic routes, the vessel undergoes frequent port-to-port transitions. This intense operational tempo places continuous mechanical stress on the steering gear system, demanding absolute precision to ensure safe navigational transitions.

Figure 1. MV. Mulianim

4.2. Analysis of Maintenance Factors

The empirical data explicitly revealed that the execution of the Planned Maintenance System (PMS) on MV. Mulianim was highly inconsistent. During the interviews, the Chief Engineer admitted that while the PMS serves as the primary maintenance doctrine, the extreme density of the vessel's operational schedule frequently forces the engineering crew to postpone routine steering gear maintenance in favor of urgent main engine repairs. The Second Engineer corroborated this, noting that tasks such as hydraulic fluid replacement and filter cleaning were often executed well past their scheduled intervals. A quantitative review of the PMS logs confirmed this, establishing that 4 out of 15 scheduled maintenance tasks (26.7%) were overdue during the observation period.

Field observations provided physical evidence supporting this maintenance deficit. Inspections of the steering gear room revealed micro-leaks (oil seepage) at several high-pressure hydraulic pipe joints. The hydraulic fluid extracted for visual inspection exhibited severe turbidity, indicating advanced contamination, though definitive claims regarding viscosity degradation cannot be established without diagnostic testing. Furthermore, during active maneuvering, the system's pressure gauge registered fluctuating pressures between 85 to 90 bar, failing to maintain the 100 bar operational baseline explicitly stated in the manufacturer's instruction manual.

Figure 2. Steering Gear Hydraulic Pressure Condition

4.3. Analysis of Spare Parts Quality and Availability

The operational disruptions associated with delayed maintenance were severely exacerbated by a fragmented spare parts supply chain. The Spare Part Inventory List and Damage Reports indicated a chronic shortage of critical replacement components. Specifically, 2 out of 8 categorized critical spare parts for the steering gear (including specific hydraulic seals) were entirely depleted from the ship's inventory. The Oiler reported that due to procurement delays from the shipping company's shore management, essential replacements were stalled, forcing the continued use of wearing components.

Figure 3. Hydraulic Steering Gear System Piping

4.4. Root Cause Analysis (Fishbone Mapping)

To systematically evaluate the empirical findings and map the plausible causal relationships behind the suboptimal steering gear performance, an Ishikawa (Fishbone) Diagram framework was employed. The analysis categorized the findings into four primary elements:

Table 1. cause-and-effect analysis Matrix

Cause Category	Specific Findings On Mv. Mulianim	Impact On Steering Gear
Man (Procedure)	Delay of routine maintenance due to the crew prioritizing urgent main engine repairs.	4 out of 15 (26.7%) of scheduled PMS tasks are left overdue.
Method (Procedure)	Neglect of hydraulic oil replacement intervals and filter cleaning schedules according to running hours.	Severe visual hydraulic oil contamination (turbidity) and unmonitored particulate accumulation.
Material (Spare Parts)	Procurement delays from shore management; 2 out of 8 critical spare part categories are entirely out of stock.	Degraded hydraulic seals are not immediately replaced, contributing to persistent oil seepage/leakage.
Machine (Condition)	Hydraulic pressure gauge registers drops to 85–90 bar against the 100 bar manual standard.	Associated with sluggish responses and delayed steering execution during critical maneuvering.

4.4. Discussion and Evidence Triangulation

To ensure the findings were robust, an Evidence-Triangulation Matrix was developed to evaluate the converging data points (Table 2).

Table 2. Data Validity Test Results

Problem Area	Interview Data	Observation Data	Documentation Audit	Synthesized Conclusion
Hydraulic Pressure Drop	Chief Engineer stated hydraulic pressure often drops during maneuvers.	Pressure gauge fluctuated between 85–90 bar (Manual baseline: 100 bar).	Engine Log Book recorded 6 occurrences of pressure drops during the period.	Converging evidence indicates a consistent decline in hydraulic system performance during operations.
PMS Delays	Chief Engineer stated hydraulic pressure often drops during maneuvers.	Visual checks found components (e.g., filters) lacking recent servicing.	PMS logs showed 4 out of 15 tasks (26.7%) were overdue.	Onboard execution of PMS is not optimal, increasing the risk of mechanical degradation.
Spare Parts Limitation	Chief Engineer stated hydraulic pressure often drops during maneuvers.	Visibly worn hydraulic seals remained in use without replacement.	Spare Part Inventory showed 2 out of 8 critical spares were out of stock.	Supply chain constraints force the prolonged use of degraded components, delaying repairs.
Spare Parts Limitation	Chief Engineer stated hydraulic pressure often drops during maneuvers.	Oil seepage observed on pipe joints; extracted oil exhibited severe visual turbidity.	Damage Reports recorded oil leak disturbances.	Oil contamination and leakage are persistent, observable symptoms of system strain.

The triangulation of the collected data establishes a highly plausible relationship between managerial maintenance negligence, spare part deficits, and the observed mechanical degradation of the steering gear. The failure to adhere to the PMS schedules allowed minor mechanical anomalies, such as particulate accumulation, to persist. Because the hydraulic pressure is the singular force manipulating the rudder, the observed 10–15% pressure deficit (85–90 bar) is strongly associated with the sluggish rudder response noted by the crew, thereby critically narrowing the vessel's safety margins during port entries (Herlambang, 2021; Sugiarto, 2023).

However, it must be acknowledged that a single-vessel qualitative case study cannot establish definitive mechanical causality. While the observed pressure drops and fluid turbidity correlate with overdue maintenance and spare part shortages, alternative explanatory variables—such as internal pump wear, relief-valve setting deviations, or air ingress—were not systematically isolated or tested through diagnostic tools. Therefore, the logistical and procedural failures identified in this study should be viewed as primary contributing conditions rather than sole mechanical causes.

5. Conclusion

The suboptimal performance of the steering gear on the MV. Mulianim is fundamentally associated with severe procedural and logistical deficiencies. Primarily, the chronic delay in executing the Planned Maintenance System (PMS)—driven by high operational tempos—prevented the timely diagnosis and rectification of potential hydraulic degradation, resulting in 26.7% of tasks being overdue. Secondarily, the acute shortage of critical spare parts (with 2 out of 8 categories unavailable) forced the prolonged utilization of compromised components. Based on the Root Cause Analysis, failures across Man, Machine, Method, and Material physically manifested as observable hydraulic pipe leaks, high fluid turbidity, and significant pressure fluctuations (dropping to 85–90 bar).

To decisively mitigate these vulnerabilities, targeted interventions are required at both the operational and managerial levels:

a. For the Ship's Engineering Crew: The execution of the Planned Maintenance System (PMS) must be strictly enforced. Daily visual inspections must be intensified to monitor hydraulic fluid clarity, detect micro-leaks, and accurately record pressure gauge stability.
b. For the Shipping Company Management: The procurement pipeline must be thoroughly audited and optimized to ensure that critical, OEM-compliant spare parts are permanently stocked aboard the vessel, thereby allowing the crew to perform immediate replacements of worn components before they induce systemic failures.

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