Analysis of Internal and External Inhibiting Factors on Maneuverability on the Kmp. Trisakti Adinda Ship

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Abstract:
The Bali Strait is a busy shipping lane with heavy traffic, where external factors such as strong winds and currents often hinder the maneuverability of Ro-Ro vessels like the KMP Trisakti Adinda, interacting with internal factors such as hull fouling. This study aims to identify the internal and external factors hindering maneuverability as well as mitigation efforts. Using a descriptive qualitative approach, the population consisted of the entire crew (22–28 people) on the Ketapang–Gilimanuk route, with a purposive sample of five key informants (Captain, First Mate, Engineer). Instruments included semi-structured interviews, observation, and documentation; analysis followed the Miles–Huberman method (reduction, display, verification). Results indicated that wind (20–30 knots), drift currents, low visibility (<0.5 miles), flat-bottomed hulls vulnerable to side forces, and fouling increased resistance by 5–10%. Conclusion: Effective mitigation through adherence to COLREGs, radar use, routine fouling maintenance, and enhanced safety measures.
Keywords: *Ocean Currents, Hull Fouling, Ship Maneuvering, Ro-Ro Ferry and Bali Strait.*

I. INTRODUCTION

The Bali Strait is a busy shipping lane connecting Java and Bali, with high vessel traffic, including Ro-Ro vessels like the KMP Trisakti Adinda. This high level of activity demands optimal ship maneuverability to maintain navigational safety and efficiency, with environmental factors often a key factor. Adverse weather conditions in the Bali Strait, such as strong winds and high waves, often cause vessels to deviate from their maneuvering paths, especially at low speeds where external forces dominate. Strong currents and reduced visibility due to rain or fog further exacerbate the situation, increasing the risk of collisions or grounding in the narrow waters.

External factors such as wind and current not only affect the ship's course but also interact with internal factors, such as the boxy hull shape of the Ro-Ro vessel on the KMP Trisakti Adinda, causing low stability during maneuvers [Sutryani et al., 2022][Devita, 2024]. Observations during sea practice show that during bad weather, ships have difficulty maintaining course, similar to the case of the sinking of the MV Wicly Jaya Sakti due to 3-meter waves and strong winds [KNKT, 2021].

Internal factors include hull fouling by barnacles that increases frictional drag, reducing propulsion response by up to 5% per 10-20 μm increase in roughness, as well as suboptimal engine conditions and crew coordination. [Murdiyanto et al., 2018] In the Bali Strait, this combination often hampers berthing, such as on MT Gandini where wind and currents caused a near collision [Djamaan & Muhayyang, 2020]

Previous studies have largely discussed single factors, but rarely analyzed internal-external interactions specifically on Ro-Ro vessels in the Bali Strait, leaving gaps in local mitigation strategies [Sutryani et al., 2022].

This study aims to identify internal and external factors inhibiting the maneuvering of KMP Trisakti Adinda and their mitigation efforts to improve navigational safety. The urgency is high given the high number of accidents in the Bali Strait due to weather and heavy traffic, which threaten the lives of crew, passengers, and the Indonesian maritime economy [KNKT, 2021]. Its novelty lies in the observation-based qualitative analysis of specific Ro-Ro vessel maritime practices, complementing previous studies with contextual mitigation recommendations such as routine fouling cleaning and intensive crew coordination [Djamaan & Muhayyang, 2020][Devita, 2024].

II. METHODS

This study uses a descriptive qualitative approach to analyze internal and external inhibiting factors affecting the maneuvering of the KMP Trisakti Adinda, in accordance with the background in Chapter I, which highlights the challenges of navigation in the Bali Strait and the objectives of identifying obstacles and mitigation efforts. This type of qualitative research is exploratory and interpretive, allowing for an in-depth understanding of phenomena through non-numerical data such as interviews and observations, as explained by Sugiyono in Qualitative Research Methods (2021). The descriptive approach aims to systematically describe actual conditions without broad generalizations, in line with the literature review framework in Chapter II, which discusses ship obstacles and maneuvering.

The main instruments included semi-structured interview guidelines for officers and crew, field observation sheets, and ship documents such as ships' particulars and crew lists, which supported triangulation of primary and secondary data. Data collection techniques included in-depth interviews with the captain, officers, and crew, direct observation during sea practice, and photographic documentation of weather conditions and the ship's hull to validate facts. Qualitative data analysis followed the Miles and Huberman model with data reduction (selection of relevant themes), data presentation (matrix and narrative), and drawing conclusions through iterative verification, as recommended by Creswell in Qualitative Inquiry and Research Design, fifth edition (2022). Emzir emphasized this interactive analysis to uncover the contextual meaning of verbal and visual data.

The study population consisted of the entire crew of the KMP Trisakti Adinda (approximately 22-28 people) involved in maneuver operations during sea practice on the Ketapang-Gilimanuk route, including navigational officers, engineers, and deck crew. The sample was selected purposively with the criteria of having direct experience of maneuvering in the Bali Strait, resulting in five key informants, namely the First Officer, Second Officer, and crew, to represent internal and external perspectives. This purposive sampling technique is in accordance with Sugiyono (2021) for qualitative research that emphasizes key informants with in-depth knowledge, ensuring data saturation without the need for a large sample.

The procedure begins with preparation (sea practice permit and instrument design), followed by 12 months of data collection on the KMP Trisakti Adinda vessel through interviews, observations of bad weather/strong currents, and documentation of hull fouling. Data is processed iteratively with reduction to focus on factors such as strong winds and hull construction, followed by presentation in triangulation tables and mitigation conclusions. Sudaryono supports this descriptive procedure to logically describe phenomena from the field to interpretation, with validation through member checking of informants. All stages comply with research ethics, such as respondent confidentiality, ensuring reliability according to the initial bibliography including Sugiyono (2017) and Suryabrata (2006).

III. RESULTS AND DISCUSSION

Overview of Research Results

KMP. Trisakti Adinda is a Ro-Ro passenger ferry where the researchers conducted their research, managed by PT. Trisakti Lautan Mas, operating the Ketapang-Gilimanuk route in the Bali Strait. Built in 2005, the ship can carry up to 132 passengers, 14 trucks, and wheeled vehicles via ramp doors without cranes, operated by a crew of 22-28 for efficient maneuvering in heavy traffic, supporting interprovincial transportation in Indonesia.

Fig.1KMP. Trisakti Adinda Ship

Data Presentation

1. Observation and Documentation Results

   a. External Factors

Fig. 2 Bad Weather Documentation

The main external factor identified through observation was the adverse weather conditions during the KMP Trisakti Adinda's maneuvers in the Bali Strait, such as the thunderstorms recorded in Figure 4.2 (researcher documentation, 2024). This unfavorable weather included strong winds, high waves, heavy rain, and limited visibility, significantly hampering the safety and smooth operation of Ro-Ro ferries, such as when sailing, anchoring, or docking at ports.

In such situations, ships experience difficulty maneuvering due to unstable rolling and pitching, causing delays in their journey, delays in departures, or delays in docking, prioritizing the safety of crew, passengers, and ship assets. This reduces operational efficiency and increases risks on busy routes like Ketapang-Gilimanuk.

1) Strong winds

Fig. 3 Documentation of Ship Wind Speed in Normal Weather

Under normal weather conditions, as seen in Figure 3, wind speeds in the Bali Strait range from 6 to 15 knots, which is relatively stable and does not significantly impact the KMP Trisakti Adinda's maneuverability, whether during sailing, changing course, or berthing/unberthing at the port. This range allows the Ro-Ro ferry to maintain its course and stability without significant obstacles.

However, when weather conditions worsen with winds exceeding 20 knots (even reaching 20-30 knots), the wind's thrust creates side forces that cause course deviations, accompanied by high waves that exacerbate rolling and pitching. This reduces stability, complicates directional control during low-speed maneuvers or in narrow waters, and hinders operational efficiency on the busy Ketapang-Gilimanuk route.

Fig. 4 Documentation of Ship Wind Speed During a Storm

Strong winds significantly impact Ro-Ro ferries like the KMP Trisakti Adinda due to their large windage area, which generates strong lateral thrust that can cause the vessel to deviate from its navigational course. Steering corrections and increased engine power are required to maintain stability. Regulations in

Law No. 17 of 2008 concerning Shipping place full responsibility on the captain for safety in all weather conditions, so anticipation through careful maneuver planning and high vigilance is mandatory.

2) Strong Current

Fig. 5 Flow Documentation

In addition to strong winds, strong ocean currents, as seen in Figure 5, were a significant external factor hampering the KMP Trisakti Adinda's maneuvering in the Bali Strait. Cross currents caused drift, making directional control difficult, especially at low speeds when rudders were less effective, influenced by tidal dynamics, seasonal winds, and the morphology of the seabed in the narrow Java-Bali waterway.

Under normal conditions, current speeds can be anticipated, but during tidal transitions they increase significantly, causing course deviations that require constant steering and speed adjustments. The interaction of currents with wind/waves creates turbulence, complicating berthing/unberthing maneuvers and causing drift, requiring the officer of the watch to monitor current patterns and bridge-engine coordination to maintain stability.

This is in line with the COLREGs precautionary principle for ship control in environmental conditions that limit maneuvering, emphasizing the understanding of oceanographic patterns for navigation safety on busy routes such as Ketapang-Gilimanuk.

3) Limited Vision

Fig. 6 Documentation of Limited Vision

Fig.7 Documentation of Normal Visible Power Conditions

Based on observations as seen in Figure 6 (limited visibility due to bad weather) in contrast to Figure 7 (normal conditions with clear visibility to see surrounding vessels and the harbor), visibility is a crucial external factor for KMP. Trisakti Adinda's navigation in the Bali Strait. In normal weather, visibility of ~3 nautical miles allows easy visual observation of land, harbors, other vessels, and navigation signs, supporting safe and efficient maneuvering on routine crossing routes.

During bad weather (heavy rain, fog, thick water vapor), visibility drops drastically to <3 miles or even 0.5 miles, limiting object identification in the dense traffic of the Bali Strait and increasing the risk of maneuvering errors. Crews are required to increase vigilance, use radar/navigation equipment, maintain a safe speed, and adjust careful controls according to COLREGs to minimize obstacles and maintain safe navigation.

b. Internal Factors

1) Hull Shape Construction

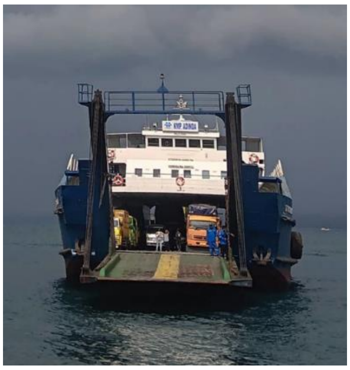

Fig. 8 Construction Documentation of the Trisakti Adinda Ship

Observations indicate that the flat-bottom hull of the KMP Trisakti Adinda is commonly used on ferry vessels in the Bali Strait due to its suitability for the harbor's shallow waters and the operational requirements for vehicle entry and exit. During normal sailing, this design provides initial stability when transporting passengers or trucks, supporting efficient maneuvering without significant constraints.

However, during bad weather with strong winds, the wide lateral surface of a flat-bottom hull increases its vulnerability to wind thrust, making it more prone to shearing, especially during low-speed maneuvers. Steering requires extra caution, careful planning, and adherence to SOLAS regulations and Shipping Law No. 17/2008 to ensure safety on busy routes.

2) Barnacles on the Hull of a Ship

Figure 9 Documentation of the Condition of the Ship's Rudder Leaf

Figure 9 shows the rudder of the KMP Trisakti Adinda covered in barnacles during its annual docking, increasing the hull's frictional resistance according to ship resistance theory, causing the engines to work harder for the same thrust. The ship's response to engine commands slowed, hampering overall maneuverability. Law No. 17 of 2008 concerning Shipping requires regular maintenance for seaworthiness, making this condition a technical management priority for navigational safety.

2. Interview

a. Informant 1 (Captain)

Based on the interview with Informant 1, the captain, it was revealed that external factors were one of the main obstacles in carrying out ship maneuvers. Weather conditions, particularly strong winds and currents, significantly affected the ship's ability to maneuver according to plan. In certain situations, even though maneuver commands had been given correctly, the ship could still experience deviations due to these environmental influences. This indicates that natural factors play a significant role in determining the success of ship maneuvers.

In addition to external factors, Informant 1 also explained that internal factors hampered the ship's maneuverability. These obstacles included delayed engine response and a lack of responsiveness on the part of the crew in carrying out commands from the bridge. Informant 1 provided an example of an incident when the ship was about to dock, where strong ocean currents combined with suboptimal engine response made the ship difficult to control. This situation required more intensive coordination between the captain and the deck crew to ensure the ship's maneuverability could continue safely.

b. (Informant 2 (Mualim I / Chief Officer)

Interviews with Informant 2 revealed that human resources, particularly the role of the ship's crew, significantly influence the smooth operation of a ship. Informant 2 emphasized that every command from the bridge must be understood and executed quickly and accurately. Delays or errors in receiving commands increase the risk of disruption to the ship's operation, particularly when maneuvering in crowded harbor areas.

Furthermore, Informant 2 explained that the lack of crew experience, especially among new crew members, is one of the internal factors that can hinder ship maneuvering. To anticipate this, a briefing is usually held before the maneuver to ensure the entire crew understands their respective duties and responsibilities. However, the human factor still has the potential for error, so direct supervision and correction in the field are necessary to minimize obstacles in the ship's maneuvering process.

c. Informant 3 (Second Class Officer)

According to Informant 3, the technical aspects of a ship's equipment significantly influence the smoothness of its maneuvers. Auxiliary equipment, such as the bow thruster, is a crucial component in ship maneuvers, particularly when docking or undocking. If this equipment is not functioning properly, the ship's ability to maneuver under control will be severely limited, increasing the difficulty of maneuvering.

Informant 3 also explained that there had been situations where the bow thruster could not be used, requiring manual maneuvering with the assistance of a tugboat. This situation required more intensive communication and enhanced crew skills. Therefore, Informant 3 emphasized the importance of inspecting and checking equipment before maneuvering as a preventative measure to avoid technical issues that could jeopardize navigational safety.

d. Informant 4 (Deck Guard Crew)

Interviews with Informant 4 revealed that from the perspective of deck crew, ship maneuvering often presents a stressful situation, particularly during busy harbor conditions. Informant 4 stated that speed and accuracy in carrying out tasks, such as rigging, are crucial to the success of the ship's maneuver. Even the slightest delay can pose a safety risk to both the ship and the crew.

Informant 4 also revealed that frequent obstacles stem from unclear communication between the bridge and deck, as well as interference with deck equipment. Unclear commands can cause confusion among the crew, while jammed or unusable equipment can slow down maneuvering. This indicates that coordination and readiness of deck equipment are internal factors that significantly influence the smooth operation of a ship.

e. Informant 5 (Machinist II)

Based on an interview with Informant 5, the second engineer, engine factors are one of the internal factors that significantly determine the success of a ship's maneuvering. Informant 5 explained that overheating of the engine can cause a slow response. This delayed response, even for a short time, can significantly impact the ship's maneuverability, especially when the ship requires rapid changes in speed or direction.

To overcome these obstacles, Informant 5 emphasized the importance of preparedness and close communication between the engine room and the bridge. Any problems that arise must be reported immediately so that they can be addressed together. Good coordination between the engine and navigation departments is considered key to minimizing internal obstacles, allowing the ship to maneuver safely and efficiently in accordance with existing operational conditions.

Data analysis

Table 1 Source Triangulation

No	Focus	Informant 1	Informant 2	Informant 3	Informant 4	Informant 5	Interpretation
1	Internal and external factors	Weather, wind, strong currents;	Crew readiness and	Equipment condition (bow	Communication and deck	Engine response and	Obstacles to maneuvering are influenced

No	Focus	Informant 1	Informant 2	Informant 3	Informant 4	Informant 5	Interpretation
	inhibiting ship maneuvering	slow engine response	experience	thruster)	equipment	overheating	by a combination of natural factors, ship technical factors, and human resources.
2	How to overcome motor obstacles	Intense coordination and high alertness	Crew briefing and supervision	Equipment check before maneuver	Clarity of communication and readiness of equipment	Engine standby and bridge–engine communications	Response efforts emphasize coordination, technical readiness, and communication.

Table 2 Triangulation Techniques

No	Aspect	Observation & Documentation	Interview	Conclusion
1	Internal and external factors inhibiting motor activity	Bad weather, box-shaped Ro-Ro hull, lots of barnacles	Informants mentioned the weather, shape of the ship, engine, human resources	Observation and interview data mutually reinforce the existence of internal and external barriers.
2	How to overcome motor obstacles	Crew readiness, equipment and ship condition are required.	Emphasis on coordination, checking and communication	Effective mitigation through operational and technical management of the ship

1. Internal and External Factors that Inhibit Ship Maneuverability

a. External Factors

Observations in the Bali Strait indicate that the dominant external factors hampering the KMP Trisakti Adinda's maneuvering are strong winds (6-15 knots normally, up to 30 knots during bad weather) and dynamic currents from the tides and seasonal winds (westerly in August, southeasterly at the end of the year). This interaction causes lateral forces, drift, and course deviation, requiring steering corrections and intensive engine settings, consistent with interviews with Informants 1-2.

Limited visibility (down to 0.5 nautical miles during rain/storms or after storms due to fog/water vapor) makes it difficult to identify other vessels, signs, and the shoreline on the busy Java-Bali ferry route. This increases the risk of collisions, especially during low-speed maneuvers.

Handling requires high vigilance of the officer of the watch via radar, safe speed reduction, and the COLREGS precautionary principle to maintain overall navigational stability.

b. Internal Factors

Observations confirmed that internal factors hampered the KMP Trisakti Adinda's maneuverability, in addition to external factors, primarily its flat-bottom hull construction and barnacle fouling.

Flat Bottom Hull: This design is optimal for stability when loading and unloading vehicles/passengers in the shallow waters of the Bali Strait, supporting low maneuvers when berthing. However, the large side area is vulnerable to strong winds (side force), demanding intensive steering/engine corrections in bad weather, although it is overcome with good control according to SOLAS/Shipping Law No. 17/2008.

Barnacle Fouling: As Figure 4.9 (annual docking), barnacles on the rudder/propulsion system increase frictional resistance (ship resistance theory), force the engine to work harder, slow the rudder/engine response, and reduce efficiency, especially at low maneuvers. In line with informant interviews 3/5; solution: periodic cleaning/anti-fouling paint for seaworthiness.

c. Efforts to Overcome Obstacles to Ship Maneuverability

Based on observations, interviews, and documentation of maritime practices, the obstacles to KMP Trisakti Adinda's maneuvering stemmed from external factors (bad weather, strong winds, strong currents, limited visibility) and internal factors (flat-bottom hull construction, barnacle fouling), so integrated mitigation efforts are needed to maintain the safety and efficiency of navigation in the Bali Strait.

Primary Response Efforts:

a) Crew Vigilance: The officer on duty monitors the weather, wind, and currents intensively to make appropriate navigation decisions during maneuvers (changing course, docking/undocking), in accordance with COLREGs and Shipping Law No. 17/2008.

b) Navigation Optimization: Use radar/AIS during low visibility (<0.5-3 miles) for detection of other vessels, beacons, ports in heavy traffic.

c) Maneuver Adjustment: Correct the rudder/engine against the side force of the wind/current (drift), set a low safe speed in narrow waters.

Technical Maintenance: Annual docking barnacle cleaning + anti-fouling paint to reduce frictional resistance, improve propulsion/steering response

IV. DISCUSSION

1. The Influence of Internal and External Factors that Inhibit Ship Maneuverability

 a. External Factors

1) Strong winds

Research findings indicate that ship maneuverability constraints cannot be determined by a single factor, but rather are the result of a complex interaction between environmental conditions and ship characteristics. One of the most dominant external factors is strong winds. In operational practice, wind has a direct impact on ship stability and control, particularly when maneuvering in confined waters such as shipping lanes and harbor areas.

Technically, strong winds blowing from the side (beam wind) will produce lateral thrust against the ship's hull. This impact will be greater on Ro-Ro type vessels that have a fairly large windage area due to the shape of their hull and superstructure. The wide wind catching area makes the ship more easily pushed off the planned course. At low speed conditions, such as when docking or undocking, this effect is even more significant because the thrust from the propeller and the effectiveness of the rudder are not working optimally. Strong wind conditions in the waters of the Bali Strait are one of the weather factors that can affect the smooth sailing activities and ship maneuvers. If the wind speed has reached more than 25 knots, the condition is considered quite dangerous for navigation safety. In situations like this, the Harbor Master will usually issue an appeal to operating vessels to temporarily halt sailing activities until the weather conditions improve. This step is taken as a form of preventative measure to minimize the risk of accidents at sea.

Furthermore, strong winds also directly impact a ship's ability to maneuver, particularly when entering a shipping lane or approaching a dock to dock. Strong gusts of wind can put pressure on the ship's hull, making it more difficult to control. Under these conditions, the ship cannot be forced to maneuver, as the pushing force of the wind and currents can cause it to deviate from its intended course. If maneuvers are attempted, there is a risk that the ship will be pushed by the current and wind, making it difficult to control and potentially posing a danger to the ship and port facilities.

As a result of these conditions, ship maneuvering becomes slower and requires greater caution from the captain and officers on watch. Ships typically must wait until the wind strength decreases before safely resuming maneuvers. Consequently, the time it takes for ships to reach their berths is longer than under normal weather conditions. This delay then impacts ship operational hours at the port, as some of the time normally used for loading and unloading activities is used to wait for safer weather conditions. Thus, strong winds impact not only the safety of shipping but also the time efficiency and smoothness of ship operations at the port.

This finding aligns with the results of interviews with the captain and first officer, who stated that strong winds are a major factor that must be anticipated in every maneuver. In such conditions, the officer on watch must make steering corrections and regulate engine power more intensively to maintain the ship's heading according to the maneuver plan. Within the national regulatory framework, Law Number 17 of 2008 concerning Shipping emphasizes that the captain is fully responsible for the safety of the ship, passengers, cargo, and voyage in all weather conditions. This means that the influence of wind is not only a technical challenge, but also a legal and professional responsibility that must be anticipated through the implementation of strict navigational safety standards and operational discipline on board.

2) Strong Current

Besides strong winds, strong ocean currents are also an external factor that significantly impacts the effectiveness of a ship's maneuverability. Currents moving transversely to the ship's bow can cause the ship to drift, making it difficult to control its direction and position in the shipping lane.

At low speeds, such as during berthing and undocking, the effects of currents are more pronounced because the ship's propulsion is not yet at its maximum. The officer on watch must continuously adjust course and speed to ensure the ship remains on a safe course. Rudder corrections must be accompanied by good coordination with the engine room to ensure that propulsion can offset the current forces acting on the ship's hull. The interaction between strong currents and the ship's characteristics can increase the difficulty of maneuvering. If the ship faces additional resistance due to hull conditions or specific design, the effects of currents are even more significant. Therefore, ocean currents are inseparable from the ship's overall technical and operational readiness.

In international practice, the principle of caution in dealing with the influence of currents and environmental conditions is in line with the provisions of the International Regulations for Preventing Collisions at Sea, particularly regarding the obligation to maintain proper observation and control the vessel at a safe speed according to water conditions.

3) Limited Vision

Another external factor that hinders ship maneuvering is limited visibility due to adverse weather conditions. Cloudy skies, rain, or fog can reduce visibility, making visual observation of navigation signs, other vessels, and channel boundaries less than optimal.

In conditions of limited visibility, the risk of misinterpreting the navigational situation increases. The officer on the watch must not only rely on visual observations but also maximize the use of radar and other navigational aids. Every change in the ship's course and speed must be carefully calculated to avoid potential collisions or grounding.

Regulatory obligations to maintain proper lookout and set a safe speed in conditions of limited visibility are stipulated in the International Regulations for Preventing Collisions at Sea. Thus, limited visibility is not only a technical constraint but also relates to compliance with international maritime safety standards.

b. Internal Factors

1) Hull Shape Construction

Based on an analysis of ship characteristics, one of the internal factors influencing a ship's maneuverability is the hull design. The KMP Trisakti Adinda uses a flat-bottom hull design. This design offers several advantages in ferry operations, particularly in terms of initial stability and ease of loading and unloading vehicles.

Based on analysis of ship operational data in the Bali Strait, the flat-bottom hull design demonstrates satisfactory performance under normal water conditions. The vessel's initial stability is relatively good, enabling it to maintain balance while carrying vehicles and passengers. Furthermore, the flat hull design also facilitates operation in waters with limited depths, a common characteristic of ferry ports in the Bali Strait.

However, analysis also shows that in adverse weather conditions, particularly when wind speeds increase significantly, this hull shape can be a factor affecting the ship's maneuverability. A flat-bottomed hull has a relatively larger surface area exposed to wind and wave action, making the ship more susceptible to these external forces. This can cause the ship to deviate or require more frequent rudder corrections to maintain the desired course.

Thus, it can be concluded that from the perspective of the ship's internal factors, the flat bottom hull design provides advantages under normal operational conditions, but in bad weather conditions in the waters of the Bali Strait, this design can affect the ship's maneuverability so that higher control and vigilance are required from the ship's crew.

These design characteristics are closely related to the ship's stability and hydrodynamics. Although it meets construction safety standards stipulated in SOLAS and the provisions of Law No. 17 of 2008 concerning Shipping, operationally, the design still requires more careful control and thorough maneuver planning.

2) Barnacles on the Stomach

Another internal factor contributing to maneuverability is the presence of barnacles and fouling on a ship's hull. An imperfectly clean hull surface increases surface roughness, increasing frictional resistance between the hull and seawater.

Theoretically, increased frictional resistance will reduce propulsion efficiency because some of the engine's power is used to overcome the additional resistance. Consequently, the engines must work harder to produce the same thrust. Consequently, the ship's response to engine commands from the bridge will be slower than under clean hull conditions.

This condition supports the second engineer's statement regarding the influence of engine performance on the effectiveness of the ship's maneuvers. If the thrust response is not optimal, corrections for wind and current influences will be less effective, increasing the risk of course deviation.

In the context of ship seaworthiness, hull and propulsion system maintenance is part of the obligation to fulfill technical requirements to maintain seaworthiness, as mandated by Law No. 17 of 2008 concerning Shipping. Therefore, hull maintenance is not merely a routine activity, but part of professional responsibility and compliance with shipping safety regulations.

2. Efforts to Overcome Obstacles to Ship Maneuverability

a. External Factors

Mitigating external factors such as bad weather requires a systematic approach. In strong winds and high waves, ships must reduce speed according to the safe speed principle stipulated in the International Regulations for Preventing Collisions at Sea (COLREG) to allow sufficient time and space to correct course.

Controlled increases in engine power to counter currents, maintaining heading relative to waves (heading adjustments), and increased visual and radar monitoring are essential steps to maintain ship stability and control. The captain's professional responsibility for making maneuvering decisions under adverse weather conditions is also emphasized in Law No. 17 of 2008 concerning Shipping.

b. Internal Factors

Addressing ship maneuverability issues requires a comprehensive and integrated approach. From a technical perspective, routine maintenance and inspections of engines, maneuvering aids, and hull cleanliness are crucial for maintaining ship performance. This is part of the obligation to maintain seaworthy vessels, as stipulated in Law No. 17 of 2008 concerning Shipping and the construction safety standards stipulated in SOLAS.

The relatively rectangular construction of Ro-Ro vessels impacts the vessel's hydrodynamic characteristics. To mitigate the resistance created by this shape, a sound operational strategy is required. The captain and officer on watch must consider the effects of wind and currents from the passage planning and port approach planning stages. Using a more proactive rudder angle, gradually increasing or decreasing engine power (engine adjustment), and utilizing tugboat assistance in extreme weather conditions are effective mitigation measures. Furthermore, proper ballast management to increase stability and reduce the effects of wind on the vessel's hull can also help maintain control during maneuvers.

The presence of barnacles (marine fouling) on a ship's hull increases frictional resistance, slowing the ship's response to engine commands. Fouling mitigation efforts include regular hull maintenance, including cleaning barnacles during docking and using standard anti-fouling paint. Companies should implement a routine underwater hull inspection schedule to ensure the hull surface remains in optimal condition. A clean hull can reduce ship resistance, resulting in more responsive and efficient maneuvering.

From an operational perspective, intensive coordination between the bridge, engine room, and crew is key. Pre-maneuver briefings, clear division of duties, rapid communication, and increased vigilance and sound decision-making by the officer on watch are essential to minimize accidents during maneuvers.

V. CONCLUSION

This study found that the maneuvering of the KMP. Trisakti Adinda in the Bali Strait was hampered by the interaction of external factors such as strong winds (up to 30 knots), dynamic tidal currents, and limited visibility (down to 0.5 nautical miles) with internal factors such as a flat-bottom hull susceptible to side force and barnacle fouling that increased frictional resistance by 5-10%. This combination caused drift, course deviation, and slow propulsion response at low maneuvers, confirmed by observations, crew interviews, and data triangulation, in line with Indonesian biofouling and Ro-Ro maneuver studies. Effective mitigation efforts include radar/COLREGs awareness, steering-engine corrections, and routine docking maintenance for efficiency and safety.

Limitations of this study include the qualitative focus on a single Ro-Ro vessel without quantitative measurements such as CFD drag simulations or real-time anemometer data, and the observation period being limited to a specific season, thus limiting generalization to other vessels or extreme conditions. Suggestions for further research include the integration of numerical models (such as FLUENT for hull roughness) and multi-vessel longitudinal analysis in the Bali Strait for quantitative validation and the development of maneuver prediction AI. Practically, these findings imply recommendations for the operator PT. Trisakti Lautan Mas and the Harbormaster: mandatory pre-maneuver crew briefings, a strict anti-fouling schedule, and a weather waiting protocol >25 knots to minimize accidents and improve efficiency on the Ketapang-Gilimanuk route.

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