Efforts to Prevent Oil Spills in Accordance with Annex I Implementation on the MT Capella Ship

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Abstract.
Oil spills from tanker operations threaten marine ecosystems, especially in busy lanes such as the Malacca Strait, where operational failures in manifold connections during cargo handling are a major contributor to incidents. This study analyzes oil spill prevention efforts in accordance with MARPOL Annex I on the MT. Capella and identifies the causal factors through a descriptive qualitative case study. Data were collected from purposive sampling of key informants (Master, Chief Officer, Boatswain), semi-structured interviews, participant observation during 12 months of sailing practice, and analysis of ship documents, processed through thematic reduction, source triangulation, and interpretive verification. The findings indicate the systematic implementation of preventive measures including pre-operation toolbox meetings, visual inspections of reducers/gaskets/flange, installation of drip trays, and recording in the Oil Record Book, which successfully controlled a minor leak on February 17, 2025, without significant marine pollution. The main causes included technical factors (gasket wear, uneven bolt tightening, pressure surges) and human factors (lack of strict supervision, weak communication), confirmed through triangulation. The conclusions confirm that procedural compliance is effective but hampered by a lack of scheduled maintenance and scalable emergency response. Recommendations include standardizing torque wrenches, routine gasket stocking, intensive drilling, and regulatory audits to optimize Annex I compliance in Indonesian tanker operations.
Keywords: *Cargo Operation, Manifold Leakage, MARPOL Annex I, Oil Spill Prevention and Tanker Safety.*

I. INTRODUCTION

Oil pollution due to *oil spills* poses a serious threat to the global marine ecosystem, with an increasing trend in incidents alongside intensive shipping activities. According to the International Tanker Owners Pollution Federation (ITOPF) report, there were more than 150 significant *oil spill* cases in 2022–2024, causing environmental damage worth billions of dollars and disrupting the livelihoods of coastal communities (ITOPF, 2024). Nationally, Indonesia, as an archipelagic country with high tanker traffic, recorded a 20% increase in *oil spill* incidents in 2023, particularly in the waters of the Malacca Strait and Natuna Sea (Bambang & Sari, 2023). The relevance of this topic is not only scientific—in the context of maritime sustainability—but also practical, as the MARPOL Annex I Convention serves as the primary prevention framework, although its implementation is still tested by operational factors (Romualdo et al., 2022).

This phenomenon is increasingly acute in Southeast Asia, where *oil spill* incidents from tankers often cross jurisdictional boundaries. A real example is the bunker ship accident at Pasir Panjang Terminal, Singapore, on June 14, 2024, which spilled around 400 tons of oil reaching the waters of Sentosa Island and potentially spreading to Indonesian waters, triggering coordination by Bakamla and TNI AL along with the installation of *oil booms* (CNN Indonesia, 2024). Empirical studies show that 70% of *oil spills* in this region originate from *cargo handling* operations on tankers, with long-term ecological impacts such as a 40% decline in biodiversity in affected zones (Monteiro et al., 2023); this aligns with findings by Widyaningsih and Nisa' Lestari (2019), who highlighted the importance of watchkeeping duties during loading and unloading operations on tankers like MT. Transko Arafura to prevent operational leaks. This issue demands in-depth analysis of onboard prevention practices, particularly in the manifold area during *cargo operations*.

Previous research has explored *oil spill* prevention through the lens of MARPOL Annex I regulations, with key findings that procedural compliance such as *sludge* management and *oily water separators* can reduce risks by up to 60% (Ameer et al., 2021). Studies in the Mediterranean emphasize the role of ship crew training in minimizing operational leaks, while research in Norway highlights the effectiveness of *double hull* designs compliant with Annex I (Knapp et al., 2022). Nevertheless, this literature tends to focus on general technological and regulatory aspects, with less emphasis on specific operational dynamics on tankers.

Comparisons across studies reveal inconsistencies: while Ameer et al. (2021) reported significant *oil spill* reductions post-Annex I implementation in the Middle East, Monteiro et al. (2023) found contradictions in Southeast Asia, where human factors like manifold handling errors caused 45% of incidents despite strict regulations. Methodological limitations in these studies include aggregate quantitative approaches without specific tanker case analyses, as well as a lack of regional context such as traffic density in the Malacca Strait (Romualdo et al., 2022; Bambang & Sari, 2023). Additionally, operational variables like *cargo operations* are rarely integrated in depth.

The clearly identified *research gap* is the lack of case-specific analysis on tankers like MT. Capella, which integrates operational causal factors with Annex I implementation in the Indonesian context. This *problem statement* is formulated as: efforts to prevent *oil spills* in accordance with Annex I in the manifold area of MT. Capella, along with their causal factors, have not been comprehensively explored to address regional implementation inconsistencies.

This research aims to analyze *oil spill* prevention efforts in accordance with Annex I on MT. Capella and identify their causal factors, with high urgency given the 2024 incident trends threatening Indonesian waters. Its novelty lies in a specific operational case approach that fills literature gaps through integration of field data and regulations, providing theoretical contributions in the form of a contextual prevention model and practical ones such as guidelines for ship crews and maritime polytechnics to minimize risks in *cargo operations*.

II. METHODS

This study uses a consistent methodological approach with the aim of analyzing oil spill prevention efforts in accordance with Annex I of MARPOL and its causal factors on board the MT. Capella tanker as a single case study object. Departing from the exploratory and interpretative nature of the research, the type of research chosen is a descriptive qualitative method with a case study approach, because this method allows for an in-depth understanding of social phenomena and operational practices in the ship's environment (Sugiyono, 2021; Emzir, 2022). The case study approach was chosen as the research design because it can describe the real context of the cargo operation process in the manifold area, including the dynamics of interactions between regulations, procedures, and crew practices (Yin, 2021; Baxter & Jack, 2022).

The study population included all crew members of the MT. Capella involved in operational activities, particularly cargo handling and oil spill prevention. The sample was selected using a purposive sampling technique from key informants who have strategic roles in the implementation of Annex I MARPOL. Key informants consisted of the Master, Chief Officer, and Boatswain, who met the inclusion criteria as officials directly responsible for oil spill prevention and handling in the manifold area, and had practical experience during the 12-month period of the researcher's on-board practice (Creswell & Creswell, 2023; Sutrisno et al., 2022). The researcher did not include crew members who were not directly involved in cargo operations as an exclusion criterion, in order to maintain the focus on perspectives relevant to the research objectives.

The research instrument consists of three main components, namely semi-annual interview guidelines.-structured questionnaire, observation guide, and ship document and archive guide. The interview guide was designed based on research domains, including (1) operational risks in the manifold area, (2) compliance with MARPOL Annex I, (3) implementation of standard operating procedures (SOPs) for oil spill prevention, and (4) occupational safety aspects related to oil spills, with indicators developed iteratively through a review of the latest literature on oil pollution prevention on ships (Bakker & van der Meulen, 2021;

Monteiro et al., 2023). The validity of the interview and observation instruments was strengthened through member checking and peer debriefing with maritime college instructors and other officers not included in the sample, as recommended by qualitative methodology (Lincoln & Guba, 1985; Creswell & Poth, 2023).

The research procedures were carried out chronologically over 12 months of sailing practice on the MT. Capella, starting from the preparation phase, field data collection, and analysis phase, in the following order. First, the preparation phase included formulating the research focus, adjusting the interview and observation guide, and obtaining initial permits from academics and the ship operator. Second, the data collection phase consisted of participatory observation during cargo operations in the manifold area, semi-structured interviews, and data collection.-structured with the Master, Chief Officer, and Boatswain, as well as the collection of ship documents and archives related to oil spill prevention SOPs, oil record books, and incident reports (if any). Third, the final stage of the procedure includes taking field notes, transcribing interviews, and categorizing documents to ensure data integrity and compliance with MARPOL Annex I regulations.

The data analysis technique used a descriptive qualitative analysis model with three main stages, according to a framework often used in qualitative research: data reduction, data presentation, and conclusion drawing (Sugiyono, 2021; Emzir, 2022). Interview, observation, and document data were reduced through thematic identification relevant to oil spill prevention efforts and their causal factors, by selecting quotes that represent recurring patterns and removing information irrelevant to the problem formulation. Next, the data were presented in a descriptive narrative form that illustrates the chronology and operational context, as well as in source triangulation tables (interviews–observations–documents) and technical triangulation to increase the credibility of the findings (Creswell & Creswell, 2023; Sutrisno et al., 2022). Conclusions were drawn interactively during and after data collection, by comparing field findings with theoretical concepts on oil pollution prevention and the implementation of MARPOL Annex I, thus enabling interpretive generalizations that remain grounded in empirical evidence.

Ethically, this study adhered to the principles of research ethics in the maritime industry and vocational education. The researcher obtained written permission from the ship operator and relevant educational institutions, and obtained verbal consent from all informants prior to the interviews, explaining the purpose of the study, its benefits, and their right to discontinue participation at any time. All information obtained was kept confidential, individual names were not explicitly mentioned in the manuscript, and the data were used solely for academic analysis and scientific writing purposes, without being diverted for commercial purposes or other publications without consent. This approach aligns with the ethical principles of qualitative research and international journal standards, which emphasize participant safety and the integrity of the research process (Bryman, 2022; Lincoln & Guba, 1985).

III. RESULTS AND DISCUSSION

Data presentation

1. Observation results

Based on observations made during sea practice on the MT. Capella, researchers obtained field data regarding the condition of the manifold area, cargo operations, and the potential for leaks that could lead to oil spills.

Fig. 1. Tool box meeting activity

On Thursday, January 2, 2025, at 09:00 LT (GMT+8), before the cargo operation began, all deck crew members attended a toolbox meeting led by the Chief Officer in the main deck area. The meeting discussed the work plan, cargo type, loading and unloading sequence, estimated pump pressure and flow rate, and the division of supervisory duties in the manifold area, tank sounding, communication with the terminal, and standby in the pump room. In addition, potential hazards such as leaks in the manifold, gasket damage, overpressure, tank overfilling, and the risk of slippery decks due to oil spills were identified. Researchers' observations indicate that this activity serves as an initial preparedness step in preventing oil pollution.

In general, the contents of the toolbox meeting before cargo operations include the following aspects:

1) Explanation of Work Plan or Job Planning
a) The type of cargo to be unloaded or loaded
b) Number and capacity of tanks involved
c) Sequence of loading/discharging activities
d) Estimated pump pressure and flow rate
e) Duration of activity
2) Division of Tasks and Responsibilities
a) Manifold supervisor
b) Tank sounding officer
c) Communication officer with terminal
d) Officers on standby in the pump room
3) Hazard Identification
a) Leaks in the manifold or flange
b) Gasket failure
c) *Overpressure*on the system
d) *Overfilling*tank
e) Slippery deck due to oil spill
f) Danger of toxic gases or vapors in the cargo

Fig. 2 Manifolds 2 and 3

Furthermore, on the same day, Thursday, January 2, 2025, at 1:00 PM LT (GMT +8), the research documented the physical condition of the cargo manifold area while the ship was sailing from Advario Port, Singapore to Bintulu Port, Malaysia. The observation results showed that the manifold is the central point of the cargo piping system that works under certain operational pressures. At the reducer connection, the use of flanges and gaskets as sealing elements is visible to maintain the forward flow of the system. In general, the visual condition looks normal, and a drip tray has been installed under the manifold connection as a preventive measure in case of oil seepage.

Fig. 3. Cargo operation

On Monday, February 17, 2025, at 10:00 PM LT (GMT+8), during cargo operations and the cargo pumps operating at operating pressure, researchers observed oil seepage at the reducer flange connection. The seepage was classified as minor leaking and was collected in the provided drip tray. Visually, the gasket at the connection appeared to have worn out, characterized by hardening and loss of elasticity. This condition causes a decrease in sealing capacity when the system is under operating pressure.

Fig. 4. Indications of a leak

At 3:00 PM LT on the same day, researchers conducted further observations of the leak's impact. They observed a thin layer of oil around the flange, causing the deck surface to become slippery and potentially posing a slip hazard to the crew. However, no marine pollution occurred as the leaking oil was properly contained and promptly handled by the crew on duty.

Fig. 5. Sopep store MT ship. Cappella

On Tuesday, February 18, 2025, at 10:00 LT (GMT+8), researchers observed the readiness of oil spill prevention equipment in the manifold area and found that drip trays, scupper plugs, and oil absorbents were available and ready for use. Observations showed that the manifold area is a critical point with a high potential for oil leaks due to technical factors such as gasket wear and suboptimal preventive maintenance. Although the leaks were still minor and did not pollute the waters, this condition emphasizes the importance of strict supervision, regular maintenance, and readiness of prevention equipment in accordance with the principles of pollution prevention regulated in MARPOL Annex I.

Fig. 6. Gasket

On January 2, 2025, at 1:00 PM LT (GMT+8), the vessel sailed from Advario Port, Singapore to Bintulu Port, Malaysia. Researchers documented the boatswain gasket at the reducer connection of the cargo pump manifold—a sealing component that maintains the tightness of the cargo pipe at different diameter flanges. The reducer adjusts the pipe size under operational pressure and pump vibration; the gasket works via compression (filling micro-gaps when bolts are tightened to the appropriate torque), and is made of oil-resistant material that can withstand pressure and temperature. Critical condition: Wear, deformation, cracking, or loss of elasticity (due to age/stress) lead to potential leaks and oil spills. Therefore, the gasket requires regular inspection and preventive maintenance.

2. Interview results

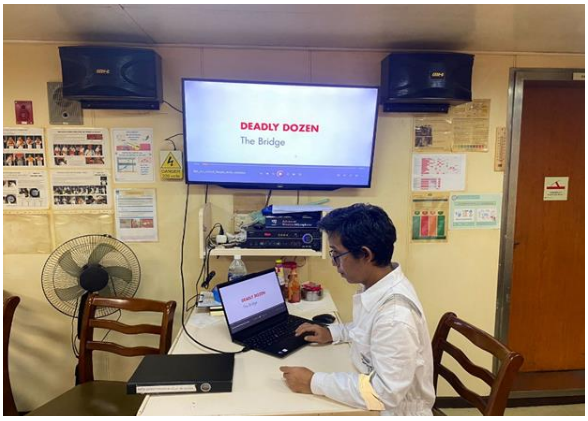


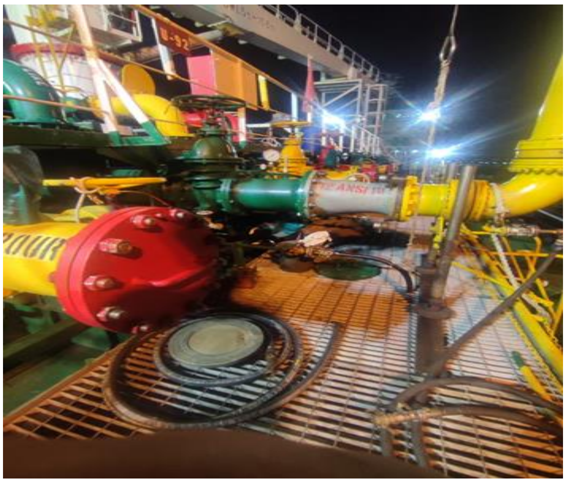
Fig. 7. captain interview

Based on the interview, the Captain highlighted the main risks of reducer/gasket leaks in the manifold as oil spills (marine pollution), fire hazards, crew safety, and international regulatory sanctions, because spilled oil spreads quickly if left untreated. The Chief Officer mentioned the causes as worn gaskets, loose bolts, and high pressure during loading/discharging, with prevention via pre-operation inspection of flanges/gaskets/drip trays, pump monitoring, and terminal communication. The Boatswain explained the emergency response: report to the Chief Officer, install scupper plugs, absorb oil using absorbent pads/booms, clean the deck, and drill oil spills regularly for crew coordination.

3. Data analysis

On January 2, 2025 at 09.00 LT (GMT+8) at Advario Port, Singapore, the Chief Officer led a toolbox meeting on the main deck before the cargo pump operation: discussing the work plan, cargo type, loading and unloading sequence, pressure/flow rate estimation, monitoring tasks (manifold, sounding tank, terminal communication), and identifying risks such as manifold/gasket leaks, overpressure, overfilling, and slippery deck—as primary prevention.

At 13:00 LT while sailing to Bintulu, Malaysia, visual observation showed normal manifold with drip tray installed on the flange to catch seepage; reducer/gasket as a critical point under operational pressure appeared to be sound but potentially worn without regular replacement, indicating the need for optimal preventive maintenance even though there were no active leaks.



Pig. 1. Cargo operation activities in the manifold area

On February 17, 2025, at 10:00 PM LT (GMT+8), during cargo operations at MT. Capella, investigators observed minor leaks at the manifold reducer flange connection; the leak was contained in a drip tray, preventing it from polluting the sea. Visual inspection revealed that the gaskets had decreased elasticity and hardened due to operational stress and age, indicating wear and tear that reduced sealing performance.

Pig. 2. Cargo operation activities in the manifold area

15:00 LT, 17 February 2025: Minor leaking at the reducer flange caused a thin oil film on the deck around the manifold, making the surface slippery and a slip hazard for the crew; the leak was controlled without marine pollution, but confirmed the manifold as a high-risk point requiring close monitoring/maintenance.

10:00 AM LT, February 18, 2025: Observation of oil spill equipment readiness on the manifold shows drip trays, scupper plugs, and oil absorbent ready for use; however, emergency response is not optimal for sudden large leaks, potentially delaying handling.

a. Source triangulation

Tab. 1 Source Triangulation

No	Indicator	Observation	Interview	Inference
1	Reducer and gasket leaks	Potential for seepage at high pressure was found	There was a small leak incident	Preventive maintenance and availability of spare gaskets are required.
2	Implementation of toolbox meeting	Toolbox is done before cargo operation	*Chief Officer*as the person in charge of leading the Toolbox meeting activities	The implementation of primary prevention is already under-

				way
3	Slip hazard risk on deck	The deck surface has the potential to be slippery when seepage occurs.	There was a near miss, the deck crew almost slipped	Small leaks still pose a risk to workplace safety.
4	Implementation of checklist and permit system	*Checklist*available before loading or discharging	*System permit to work*implemented	Administrative requirements are met, technical supervision needs to be increased
5	Use of drip tray	*Drip tray*mounted under the manifold	The crew provided a drip tray to accommodate seepage	The initial leak control system has been implemented
6	Availability of oil absorbent and scupper plug	Oil absorbent and scupper plug available	Master and Chief Officer stated that the equipment is always on standby during cargo operations.	Secondary prevention equipment in ready condition
7	Implementation of oil spill drilling	Drilling is carried out according to a monthly schedule.	Crew follows training according to procedures	Compliance with the Training obligations is underway
8	Pressure monitoring during transfer	Pump pressure monitoring is performed during operation.	*Chief Officer*states that high pressure increases the risk of leakage	Monitoring is running but attention is needed at the critical point of the reducer.
9	Availability of spare gaskets	Ready-to-use spare gaskets are not always available	*Boatswain*sometimes make manual gaskets	Lack of spare parts increases the potential risk of repeated leaks.
10	Implementation of bolt tightening standards on manifold flanges before cargo transfer	No use of torque wrench was found when tightening the manifold flange bolts.	*Chief Officer*stated that tightening was done manually based on experience	Technical standards for tightening do not fully refer to measured tightening methods, thus potentially causing leaks due to uneven pressure.

Discussion

1. What are the efforts and measures to prevent oil spills in accordance with Annex I?

Based on the results of research conducted during 12 months of sailing practice on the MT. Capella, data was obtained through direct observation, interviews with the Master, Chief Officer, and Boatswain, as well as documentation in the form of photographs and cargo operation checklist archives. The collected data was then reduced and analyzed to answer the first problem formulation, namely how to prevent oil spills in accordance with Annex I.

Observation results show that before the implementation of loading and discharging activities, operational preparations were carried out in the form of a toolbox meeting led by the Chief Officer. In this activity, the division of tasks, identification of leak risks in the manifold area, and anticipatory steps were discussed, especially if oil seepage occurs. Next, a visual inspection was carried out on the condition of the reducer, gasket, flange, and manifold bolts. This inspection aims to ensure there is no wear, cracks or imperfections in the installation that can cause leaks when pressure increases. In addition, a drip tray was installed under the manifold connection as an initial precaution in case of small seepage.

In an interview, the Chief Officer stated that before the pressure was increased to normal capacity, an initial loading rate was carried out at low pressure to ensure no leaks occurred. The Master also stated that every cargo transfer activity is recorded in the Oil Record Book as a form of administrative compliance with international regulations.

The obtained documentation, in the form of a cargo operation checklist, shows that the ship's procedural operational control system complies with company standards and regulations. Based on data reduction and interpretation, it can be analyzed that efforts to prevent oil spills on board the ship were implemented through preventive and administrative approaches. The preventive approach is evident in:

a. Implementation of toolbox meetings before operations
1) Inspection of gasket and flange condition
2) Pressure monitoring during initial loading
3) Installation of drip tray in the manifold area
b. The administrative approach is seen from:
1) Use of checklist before surgery
2) Recording activities in the oil record book
3) Supervision by deck officers during cargo transfer.

The analysis results also show that the inspections carried out are still visual and not all use structured technical methods, such as tightening bolts with certain torque standards or replacing gaskets based on a consistent planned maintenance system schedule. It was concluded that the implementation of MARPOL Annex I provisions has been carried out systematically, but there is still room for improvement in the aspect of strengthening technical controls to minimize the risk of leaks in the manifold area.

2. Factors causing oil spills on ships

Based on field observations, it was found that potential leaks in the manifold area generally occur at the reducer and gasket joints, especially when the pump pressure increases gradually towards maximum capacity. On several occasions, small leaks were found which were immediately addressed before they developed into larger spills. The results of interviews with boatswains stated that the condition of gaskets that have been used for a long time can experience a decrease in elasticity, so they are unable to withstand pressure optimally. The Chief Officer also explained that unstable pressure or too rapid a pressure increase can increase the risk of leaks. In addition to technical factors, human factors were also found, such as a lack of accuracy during final checks before operations began, as well as ineffective communication between deck officers and pump operators.

The documentation obtained shows that although procedures are in place, not all potential risks are detailed in the checklist, particularly regarding re-evaluation after the manifold connection is completed. Based on the reduced data analysis, the factors causing the oil spill can be grouped into two main categories: technical factors and human factors.

too fast can increase the risk of leaks. In addition to technical factors,

a. Technical factors
1) Gasket and reducer wear
2) Uneven flange surface
3) Uneven bolt tightening
4) Pressure surge during load transfer
b. Human factors
1) Lack of thoroughness in final inspection

2) Insufficient supervision during increased pressure
3) Ineffective communication during cargo operations

These technical factors and human error are the potential causes of leaks in the manifold area. Small leaks that are not immediately identified can develop into larger spills, impacting environmental pollution and crew safety. This analysis shows that oil spill prevention depends not only on the availability of procedures but also on consistent implementation, strict technical supervision, and increased crew awareness and discipline.

Overall, the research results indicate that MT Capella implemented an oil spill prevention system in accordance with MARPOL Annex I through operational and administrative approaches. However, the effectiveness of prevention is still greatly influenced by the technical condition of the equipment and the quality of human supervision.

IV. CONCLUSION

This study found that oil spill prevention efforts in accordance with Annex I MARPOL at MT. Capella have been systematically implemented through pre-operation toolbox meetings, visual inspections of manifolds and gaskets, installation of drip trays, and recording of the Oil Record Book, which successfully controlled minor leaks on February 17, 2025 without significant marine pollution. The main causes of reducer/gasket leaks include material wear due to pressure and service life, manual bolt tightening without a torque wrench, and human error such as insufficient supervision, which was confirmed through observation triangulation, Captain/Chief Officer/Boatswain interviews, and SOP documents. Although equipment readiness such as scupper plugs and oil absorbents was adequate, overall effectiveness was still hampered by the lack of scheduled preventive maintenance and optimal emergency response to major incidents.

Limitations of the study include a single focus on a single tanker (MT. Capella) for 12 months of practice, thus limiting generalization to similar operational conditions in the Strait of Malacca; a lack of quantitative data such as pump pressure measurements or gasket material analysis; and reliance on visual observation without laboratory testing. Suggestions for further research include the integration of IoT sensors for real-time monitoring, and a cost-benefit analysis of PMS maintenance. Practically, these findings recommend that maritime polytechnics such as the Surabaya Shipping Polytechnic strengthen oil spill drill simulations, ship operators implement standard torque wrenches and routine gasket stocks, and regulators improve Annex I audits to minimize risks in Indonesian cargo operations.

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