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Analysis of Tank Cleaning Implementation Using Crude Oil Washing on MT Swordfish

Iskandar[1*], Pranyoto[2], Rafael Mahesha Bintang Adhi Pratama[3], Cindy Cahyaning Astuti[4]

[1,2,3]*Politeknik Ilmu Pelayaran Semarang, Semarang, Indonesia*
[4]*Universitas Muhammadiyah Sidoarjo, Sidoarjo, Indonesia*
*iskandar801010@gmail.com

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Corresponding Author
Iskandar
Politeknik Ilmu Pelayaran Semarang, Jl. Singosari Raya No. 2A, Semarang 50242, Indonesia
Email: iskandar801010@gmail.com

ABSTRACT

Crude oil washing (COW) is used to remove oil residues from cargo tanks while limiting the production of oily wash water, but its performance depends on equipment integrity and crew readiness. This study examines operational obstacles to COW on MT Swordfish and evaluates the responses taken before the vessel's scheduled dry docking. A qualitative descriptive case-study approach was applied to observations, interviews with five categories of deck personnel, and shipboard documents collected during November 2023–November 2024. Data were analysed by reducing and comparing evidence across sources. Three equipment-related problems were identified: corrosion-related leakage in starboard COW line No. 4, which interrupted operations for approximately eight hours; malfunctioning fixed tank-washing machines caused by corroded gears; and seized manhole and purging-valve threads that delayed gas-freeing preparations. The reported response involved isolating the affected system, containing the spill, applying a temporary pipe repair, lubricating or manually moving impaired components, and planning permanent replacement during dry docking. Interviews also identified uneven procedural familiarity and workload pressures among the crew. The findings indicate that temporary corrective action enabled operations to continue but did not remove the underlying risks associated with ageing equipment and inconsistent preventive maintenance. A documented inspection programme, prompt replacement of defective components, task-specific training, and strict adherence to inert-gas and hot-work safety controls are recommended.

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1. INTRODUCTION

Crude oil tankers depend on effective cargo-tank cleaning to maintain cargo quality, prepare for inspection and dry docking, and control the risk of marine pollution. Residual crude oil and sludge may accumulate on tank walls and bottoms after cargo discharge, reduce usable capacity, obstruct suction arrangements, and complicate subsequent maintenance (Adigwe et al., 2022; Hasan et al., 2024). Because these deposits can contain flammable and hazardous components, tank cleaning is also a safety-critical operation that requires appropriate isolation, atmospheric control, and competent supervision (Altun & Arslan, 2013; Maljković et al., 2022).

Crude oil washing (COW) is an established method in which the crude oil cargo is circulated through fixed washing machines to remove deposits from cargo tanks. The solvent action of the crude oil enables more effective removal of adhered oil residues while reducing the volume of oily wash water generated when compared with a water-based cleaning approach (International Maritime Organization [IMO], 2000; Altun & Arslan, 2013). Regulation 33 of MARPOL Annex I requires COW systems on qualifying new crude oil tankers, and the approved COW Operations and Equipment Manual provides the governing operational framework (IMO, 2000, 2017).

Effective COW depends on an intact piping network, adequate washing pressure and machine movement, properly functioning cargo and stripping systems, and an operational inert-gas system. The COW operation must take place under the prescribed inert atmosphere and in accordance with vessel-specific procedures; gas freeing for tank entry is a separate activity that follows the relevant isolation, cleaning, and atmosphere-verification steps (IMO, 2000; International Chamber of Shipping et al., 2020). Operational planning must also account for cargo handling, crew allocation, contamination control, and the condition of machinery that may not be used regularly (Maljković et al., 2022).

Studies of industrial oil-tank cleaning discuss manual, mechanical, chemical, and automated techniques (Chrysalidis & Kyzas, 2020). Work on sludge removal and oil recovery also demonstrates the usefulness of alternative solvents, surfactants, heat, and separation technologies in appropriate settings (Bao et al., 2022; Gao et al., 2021; Su et al., 2023; Tian et al., 2024). However, results obtained from refinery tanks, catalysts, or contaminated soil cannot be assumed to apply directly to COW on a trading tanker, where the inert-gas regime, equipment configuration, and shipboard procedures create different operational constraints.

The choice of cleaning method requires care when interpreting results from different industries. Studies of tank cleaning outside maritime transport examine mechanical methods for shore-based crude-oil storage (Di et al., 2014), oil removal using microemulsions (Hernandez et al., 2019), and washing or wastewater treatment associated with refinery desalting operations (Pak & Mohammadi, 2008). These contributions clarify the range of available residue-management techniques, but they do not displace tanker-specific design and operating requirements. The environmental purpose of MARPOL Annex I makes prevention of operational discharges central to the assessment of cleaning choices, rather than merely the speed at which deposits are removed (Maes, 2025).

The case examined in this article concerns MT Swordfish during tank cleaning associated with preparations for dry docking. Field evidence describes a corrosion-related leak in a COW

line, failure of fixed washing-machine drives to operate automatically, and seized threads in manhole and purging equipment. Although research addresses tanker-cargo safety and general cleaning technologies, the combination of equipment-specific defects, actual crew responses, and the resulting delays in one shipboard operation warrants closer investigation (Altun & Arslan, 2013; Maljković et al., 2022; Park & Lee, 2025).

Accordingly, this study aims to identify the principal technical and operational obstacles encountered in the implementation of COW on MT Swordfish, describe the corrective responses reported by the crew, and formulate maintenance and training recommendations grounded in the observed conditions. Its contribution is a qualitative, vessel-level account of how ageing equipment, preventive maintenance, and procedural readiness affect cargo-tank cleaning before dry docking.

2. LITERATURE REVIEW

COW differs from conventional tank washing because it uses crude oil rather than water as the primary cleaning medium. The controlled washing jets mobilise deposits so that the mixture can be stripped and managed through the cargo system. The design, testing, operating procedures, and in-port verification of the equipment are addressed in the IMO revised specifications and accompanying COW manual framework (IMO, 2000). The advantages include improved cargo discharge and reduced oil retained on tank surfaces, but they depend on compliant operating conditions, adequate equipment performance, and effective crew communication (Altun & Arslan, 2013; Maljković et al., 2022).

The physical behaviour of petroleum sludge helps explain the need for appropriate cleaning methods. Petroleum deposits vary in oil, water, and solid content, and their accumulation can accelerate corrosion or interfere with operations (Hasan et al., 2024). Various industrial processes use surfactant mixtures, thermal washing, mechanical separation, and chemical treatment to recover oil or remove deposits (Bao et al., 2022; Gao et al., 2021; Wang et al., 2019; Yan et al., 2024). These studies support the general importance of residue properties and equipment selection but are not direct evidence that a particular shipboard COW installation will perform adequately.

Tank-cleaning technology has evolved toward mechanisation and reduced human entry. Reports on automated oil-tank cleaning and specialised in-place equipment describe potential reductions in exposure and handling effort (Pagcatipunan, 2003; Schindler & Suba, 2009; Wetlesen, 2006). Nevertheless, even automated installations depend on serviceable pipework, valves, drive gears, and reliable inspection. An equipment-maintenance review identifies

planned and risk-based strategies as important to marine-system availability, particularly where infrequently operated components may deteriorate between uses (Park & Lee, 2025).

A shipboard tank-cleaning study involving MT John Caine likewise places planning and execution at the centre of cargo-readiness tasks (Imran et al., 2022). Descriptions of chemical cleaning and degassing in refinery installations highlight that residue removal and atmosphere-related preparations are linked yet technically distinct operations (Otzisk, 2008). Research on thermochemical cleaning of oily sludge examines the effects of treatment conditions on oil removal (Wang et al., 2022), again emphasising that process performance depends on the surrounding system. These examples are used here as contextual comparisons; they do not establish that similar chemicals or cleaning regimes were used aboard MT Swordfish.

Technical reliability and human readiness are therefore complementary: defects can disrupt pressure delivery or machine movement, while insufficient procedural familiarity may prolong diagnosis and task coordination. Established tanker-safety guidance emphasises communication, system checks, entry controls, and cautious management of hazardous work (International Chamber of Shipping et al., 2020). The present study uses these principles to interpret reported shipboard events without treating general maintenance guidance as evidence of actions that were not documented in the case.

The regulatory and operational context also affects how the term “effective cleaning” should be interpreted. Tank cleanliness may be relevant to cargo discharge and inspection, but it is not the only performance criterion. A COW operation must protect the integrity of the tank atmosphere, maintain washing-machine coverage within the approved plan, prevent avoidable releases from piping, and leave a documented record of the procedure carried out. The IMO specification includes equipment and operational controls, while tanker-industry guidance addresses the hazards associated with hydrocarbons, enclosed spaces, and cargo-handling equipment (IMO, 2000; International Chamber of Shipping et al., 2020). Consequently, a short-term decision to resume work after a temporary repair should not be interpreted automatically as confirmation of technical compliance. The reported events must instead be evaluated in terms of the available evidence for operational continuity and the separate need for lasting corrective action.

3. METHODS

This research adopted a qualitative descriptive case-study design focused on the implementation of COW aboard MT Swordfish. Field observations covered the period from 2 November 2023 to 15 November 2024. The central case concerned a tank-cleaning operation

associated with the vessel's preparations for its planned dry docking in May 2024, including activities during the voyage from Khawr Fakkan to Dubai. This approach was intended to explain the observed equipment defects and crew responses rather than estimate causal effects statistically (Sugiyono, 2020).

Primary data were obtained from participatory observation of tank-cleaning activities and interviews with personnel directly involved, including the Chief Officer, Second Officer, Third Officer, Pumpman/Boatswain, and an Able Seaman. The available account does not provide verbatim transcripts or a complete interview schedule; consequently, individual statements are treated as reported interview summaries rather than as independently authenticated quotations. Secondary material comprised operational checklists, field photographs, shipboard maintenance information, and other documentation described in the source article.

Qualitative analysis involved selecting information relevant to the research questions, grouping evidence into equipment-related and operational themes, comparing interview accounts against the observation and photographic record, and drawing conclusions from convergent findings. This reduction–display–conclusion sequence is consistent with the approach described by Miles et al. (2014). Triangulation was applied by comparing the reported interviews with documented physical conditions and operational outcomes. The evidence is sufficient to describe the reported defects and corrective efforts, but it does not establish unrecorded repair approvals, pre-wash atmospheric measurements, or comprehensive equipment-performance testing.

4. RESULTS AND DISCUSSION

4.1. Vessel Context and Preparation for Crude Oil Washing

MT Swordfish was reported as a Marshall Islands-flagged crude oil tanker, IMO No. 9248849, with a length overall of approximately 250.17 m, beam of 44 m, gross tonnage of 62,371, and 12 cargo tanks plus two slop tanks. Recorded vessel particulars indicate a Hyundai B&W 7S60MC main engine. These vessel particulars provide context for the extensive cargo system and the importance of coordinating tank cleaning with subsequent inspection and docking tasks. Figure 1 shows the vessel.



Figure 1. MT Swordfish

The available operational account states that a COW campaign was carried out over approximately five days during a voyage from Khawr Fakkan to Dubai in preparation for dry docking. A shipboard checklist was used to support preparation and monitoring of the washing activities (Figure 2). The checklist covers items such as drainage arrangements, leak checks, washing-system condition, and post-wash steps. These recorded controls demonstrate the need to assess equipment readiness systematically rather than treating COW as an isolated spray-cleaning task.

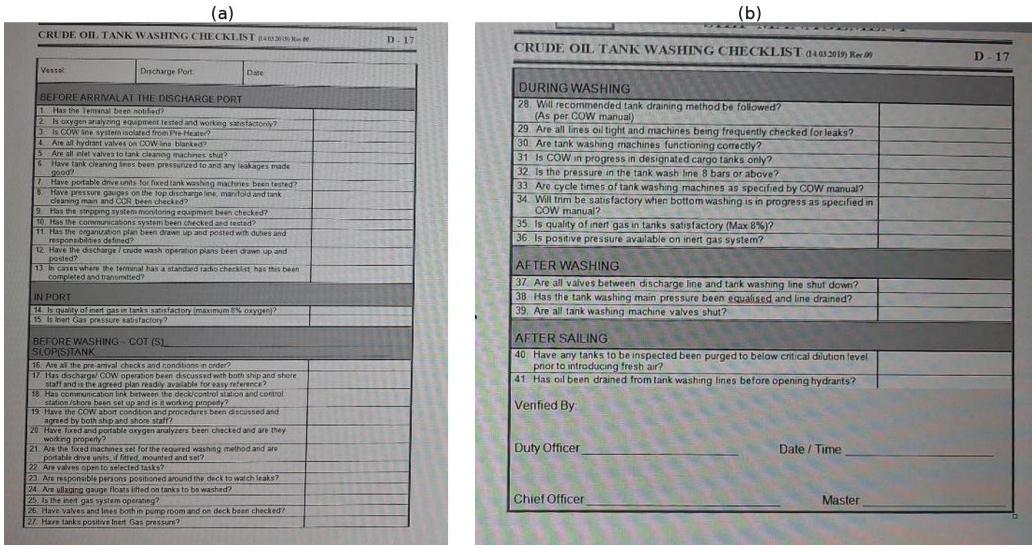


Figure 2. COW checklists: (a) pre-wash checks and (b) washing and post-wash checks

Operational documentation describes tank heating, inerting, washing, stripping, gas freeing, deslopping, and demucking in its description of the overall cleaning programme. These are related activities but not interchangeable steps. Under the applicable COW specifications,

crude oil washing is conducted with the prescribed inert-gas protection; entry-related gas freeing requires separate controls and confirmation of a safe atmosphere (IMO, 2000; International Chamber of Shipping et al., 2020). Since detailed time-stamped records of every step were not supplied, the order of each activity cannot be independently reconstructed from the available narrative.

A checklist provides a systematic record of what personnel intend to inspect, but it is not by itself proof that all observations were made correctly or that every measured operating condition was compliant. For the Swordfish case, Figure 2 documents the presence of a checklist format, while the equipment failures described in subsequent sections show why periodic physical verification and corrective maintenance remain necessary. This distinction is particularly important when tanks must be prepared for inspection on a demanding operational schedule. The reported maintenance and crew-readiness problems therefore constitute practical implementation gaps, rather than evidence that the COW method itself is intrinsically ineffective.

4.2. Corrosion-Related Leakage in Starboard COW Line No. 4

One major obstacle occurred when a leak was detected in starboard COW line No. 4 while the crew was preparing to clean the No. 4 port and starboard cargo tanks. Field notes indicate that the event delayed operations for approximately eight hours. The pumpman had aligned the cargo pump, tank-cleaning heater, and COW distribution line to a fixed washing machine; the operational account states a nominal washing-machine capacity of 90 m^3/h at approximately 10 bar. These values are reported operating particulars, not independently measured performance results.

Interviews with the Chief Officer, Second Officer, Third Officer, Pumpman, and Able Seaman attributed the leakage to deterioration of ageing pipework exposed to seawater and insufficient inspection during periods of limited use. The Chief Officer described leakage from the lower section of a corroded pipe; other interviewees also referred to weakened pipe material and the pressure applied during washing. The damaged section and subsequent repair are illustrated in Figure 3. The correspondence between the visible pipe condition, the location of the leak, and the interview summaries provides a reasonable basis for identifying corrosion-related loss of integrity as the principal reported failure mechanism.



Figure 3. Section of the COW pipework highlighted in the field photograph

According to the field report, the operation was temporarily stopped and the crew took steps to contain the spill using the shipboard oil-pollution response arrangements. A temporary steel-plate repair was reportedly installed with welding assistance from the Boatswain and Fitter, after which cleaning could resume. Permanent replacement of the affected line was planned for dry docking. The underlying condition was therefore not resolved by the temporary intervention alone. The reviewed records do not document a hot-work permit, formal gas test, or other authorisation for the reported welding; such safeguards must not be presumed and remain essential wherever hot work is contemplated on a tanker (International Chamber of Shipping et al., 2020).

Corrosion, failure to test seldom-used piping, and unexpected loss of containment form a connected chain of operational vulnerability. Similar concerns about tank-cleaning safety and pollution exposure have been identified in studies of cargo operations and oily residue management (Adigwe et al., 2022; Altun & Arslan, 2013; Maljković et al., 2022). A more reliable approach would include line-by-line external inspection, pressure or integrity tests as required by the approved shipboard procedures, consistent defect logging, and timely renewal of deteriorated pipework.

4.3. Malfunction of Fixed Butterworth Washing Machines

A second difficulty involved fixed Butterworth-type tank-washing machines in the No. 1 port, No. 3 port, and No. 6 starboard tanks. Field observations indicated that these units failed to rotate automatically. Inspection reportedly found corrosion deposits and slight wear in the

gear components. Infrequent use and inadequate routine maintenance were identified in the interview summaries as contributing conditions. Figure 4 shows the machine highlighted in the field photograph.



Figure 4. Fixed tank-washing machine identified in the field documentation

Under the Chief Officer's instructions, crew members reportedly cleaned and lubricated the drive arrangement and moved the mechanism manually using a ring spanner, allowing limited continued operation. This was recorded as a temporary workaround pending replacement of defective parts during dry docking; it does not provide coverage tests confirming that the full planned washing pattern was achieved. This distinction matters because a machine that can be moved manually is not necessarily equivalent to a properly functioning automatic washing system.

The finding reinforces the need for periodic functional checks, inspection of gear motion, and recording of wear in a planned-maintenance system. Automated tank-cleaning equipment can reduce manual handling, but only when its associated rotating mechanisms and control components remain serviceable (Pagcatipunan, 2003; Wetlesen, 2006; Park & Lee, 2025).

4.4. Corrosion of Manhole and Purging-Valve Components

A third problem emerged in components used to support access and atmosphere-related preparations: corrosion was reported on the threaded operating wheels of the manhole cover and butterfly purging-pipe valve. Accumulated rust impeded operation of the mechanisms and delayed the associated gas-freeing work by several hours. The original photograph shows the

affected area (Figure 5). Interview and observation records attributed the corrosion to exposure to rainwater and seawater coupled with insufficient cleaning and lubrication.



Figure 5. Corrosion around the manhole operating arrangement reported in the case

Crew members reportedly removed surface rust with a wire brush and a penetrating lubricant, applied grease, and used additional hand tools and lifting assistance to free the seized components. These measures enabled work to continue but did not demonstrate long-term restoration of the parts. The case highlights the importance of maintaining ancillary valves, covers, seals, and threaded operating mechanisms as carefully as the principal washing equipment. Routine inspection also reduces the likelihood that access difficulties will create time pressure immediately before hazardous work.

The three equipment failures required different immediate responses. A failed pressure boundary called for control of the oil flow and containment of any release; a jammed rotating device required assessment of its mechanical drive and washing coverage; and a seized access-related component required careful attention to atmosphere control and the integrity of seals and operating hardware. Grouping them under “lack of maintenance” is useful as an initial theme, but does not replace a component-specific diagnosis. The interviews largely associate the defects with age, corrosion, and limited maintenance, whereas the photographs only document the condition of selected external surfaces. In the absence of metallurgical inspection or maintenance-interval records, the precise rate of deterioration and the date on which each defect became detectable cannot be established.

4.5. Cross-Case Synthesis, Crew Factors and Preventive Actions

Taken together, the three incidents reveal a common theme: equipment remained vulnerable when parts exposed to the marine environment were used intermittently without systematic functional checks. The consequences differed—loss of containment, impaired

washing coverage, and delayed access preparation—but all increased workload or interrupted the cleaning schedule. Interviews also referred to gaps in procedural familiarity and fatigue associated with limited personnel availability. The documentary record supports these as reported operational concerns; it does not quantify fatigue, staffing adequacy, or its independent contribution to each fault.

Table 1. Summary of reported COW obstacles and corrective measures

Observed obstacle	Immediate reported response	Longer-term priority
Starboard COW line No. 4 leak (about eight hours lost)	Stop and contain spill; temporary plate repair	Assess/renew pipe; inspect and test the system
Fixed washing-machine drive seizure	Clean/lubricate gears; manual movement	Replace worn parts; check full operating cycle
Seized manhole and purging-valve threads	Remove rust, lubricate and release mechanism	Protect and inspect operating components regularly
Reported uneven procedural readiness and work pressure	Briefing and redistribution of duties	Task-specific training; sufficient supervision and rest

The evidence also suggests that reporting and escalation procedures should distinguish minor defects from faults that can compromise a safety-critical barrier. Pipe leakage presents an immediate containment and potential pollution concern; loss of rotation can leave unwashed tank surfaces and weaken confidence in cleaning completeness; and restricted movement of gas-freeing accessories can interfere with safe planning of subsequent work. The practical response should therefore be based on defect severity, the operating procedure, and appropriate authorisation, not solely on whether the crew can devise a temporary workaround. This interpretation is consistent with the focus on prevention and inspection in tanker-cargo safety guidance (Altun & Arslan, 2013; International Chamber of Shipping et al., 2020).

The results align with prior reviews emphasising equipment condition, crew competency, and procedural planning in safe tanker cargo operations (Altun & Arslan, 2013; Maljković et al., 2022). They also accord with the broader maintenance literature, which favours proactive inspection and timely repair over repeated corrective work on deteriorated components (Park & Lee, 2025). Research on refinery-tank cleaning demonstrates useful alternatives for sludge recovery (Chrysalidis & Kyzas, 2020; Schindler & Suba, 2009; Su et al., 2023), but this case does not establish a quantitative comparison between those approaches and COW on MT Swordfish.

Practical recommendations are therefore to schedule periodic visual and functional checks of COW lines, washing-machine drives, and purging accessories; maintain a clear register of defects and repair histories; confirm the readiness of the inert-gas and washing

systems through the approved operational checklist; and conduct task-specific crew briefings before washing. The temporary measures reported in the case should be treated as interim controls requiring formal assessment, not as substitutes for permanent repair. Atmosphere testing, enclosed-space entry and any proposed hot work must follow applicable tanker procedures and permits (IMO, 2000; International Chamber of Shipping et al., 2020).

The study is limited to one vessel and a qualitative description of events. Corrosion thickness measurements, trend data on pressure fluctuations, verified machine-coverage tests, complete work-permit records, and a quantitative staffing analysis were not provided. Accordingly, the findings support a context-specific diagnosis and preventive recommendations, but not generalised failure probabilities or claims of measured improvements in environmental performance.

4.6. Implications for Equipment Assurance and Safety Barriers

The case points to the need for an equipment-assurance process that begins before the commencement of cargo-tank washing. Such a process should identify each COW line to be used, check the condition of exposed bends and fittings, ensure valves can be operated without abnormal force, and confirm that the intended washing machines are mechanically capable of completing their prescribed cycle. Where equipment is operated infrequently, the period between cleaning campaigns may allow corrosion or deposits to progress without an obvious indication during ordinary cargo handling. A documented pre-operation inspection is therefore a practical means of linking the planned-maintenance programme with the immediate decision to proceed. This is proposed as an improvement rather than presented as a procedure fully demonstrated by the available case records (Park & Lee, 2025; Maljković et al., 2022).

For pipework, visual evidence of rust should trigger a proportionate integrity assessment, particularly where the pipe is exposed to the marine atmosphere or where fluid pressure will increase during washing. Surface appearance alone does not determine the remaining wall thickness, and the reviewed case documentation contains no thickness survey or corrosion-rate history. An inspection regime should therefore combine routine external checks with suitable non-destructive examination and testing where specified in the ship’s approved system documentation. Findings should be logged against specific pipe sections, followed by repair or replacement decisions based on engineering assessment. The eight-hour delay on MT Swordfish illustrates the operational consequence of discovering a deteriorated pressure boundary only after cleaning preparations are underway; the delay itself does not establish the rate of corrosion or the interval at which inspection would have prevented the failure.

For fixed washing machines, operational readiness concerns the complete cleaning pattern and the condition of the drive, rather than the mere presence of pressurised flow. A motor-free or hydraulic rotating cleaning head may continue to pass fluid even when the intended movement is impaired. The field account of seized gears thus raises the possibility that spray coverage could be incomplete, but no independent coverage assessment was reported. Proposed controls include careful examination of the gear mechanism, periodic movement and function tests consistent with manufacturer requirements, maintenance of lubrication and protective arrangements, and clear recording of units requiring replacement. If a temporary manual action is considered, the responsible officer must evaluate its limitations under the approved procedures rather than assume it achieves the same washing coverage as automatic operation (IMO, 2000; Pagcatipunan, 2003; Wetlesen, 2006).

For manholes and purging assemblies, operability is linked directly to the organisation of later access and atmosphere-related work. A stiff or jammed wheel may delay preparation and encourage the use of improvised tools. The reported use of wire brushing, penetrating fluid, and additional mechanical force confirms the practical difficulty encountered by the crew, but the available record does not demonstrate whether components remained within their design tolerances or whether seals were subsequently inspected. Maintenance of operating threads and corrosion protection should therefore occur before they become critical to a scheduled task. The integrity of a manhole closure and the management of the atmosphere must be assessed separately from whether a threaded handwheel can be made to turn (International Chamber of Shipping et al., 2020).

The distinction between corrective work and formally controlled hazardous work is particularly important in the pipe-leak episode. Field documentation describes a welded temporary repair, but it does not contain the documentation needed to establish the circumstances under which welding was authorised. On a tanker, hot work raises ignition concerns that require rigorous permits, isolation, cleaning, atmospheric testing and other controls prescribed by the operator and applicable guidance. The present study therefore records welding only as a reported action; it does not endorse that action as a standard shipboard response to a leaking COW line. The recommended operational lesson is to secure the system and obtain an approved engineering and safety assessment before selecting any repair technique (International Chamber of Shipping et al., 2020; Maljković et al., 2022).

4.7. Recommended Maintenance and Competency Programme

A practical improvement programme should join equipment assurance with crew familiarisation. Maintenance records can identify the location, observed defect, inspection date, temporary measure, replacement requirement, and person responsible for follow-up. Pre-operation briefings can then address tank sequence, expected pump and line arrangements, contingency actions for leakage, washing-machine malfunction, and the restrictions that apply to enclosed-space entry and hot work. Such briefing records help establish procedural readiness, but they must be supported by actual equipment checks and effective supervision. The recommendations in Table 2 are derived from the combined interpretation of field observations and safety guidance; they are proposed measures rather than additional activities claimed to have been observed aboard MT Swordfish.

Table 2. Proposed verification and maintenance controls for future COW operations

Control point	Verification approach	Required follow-up
COW pipe integrity	Inspect accessible sections and verify required pressure/integrity checks	Isolate and assess leaks; renew unserviceable sections
Fixed cleaning machines	Verify drive operation and planned spray movement	Log seized or worn parts; repair and test
Manhole and purge components	Operate valves/covers during planned inspections	Restore movement and check related seals
Atmosphere and hot-work barriers	Follow manual, inert-gas, gas-testing and permit arrangements	Escalate unsafe conditions before work
Crew familiarity and workload	Brief tasks, responsibilities, and contingency actions	Record gaps and arrange refresher training

A central contribution of the study is that the operational interruptions arise from several interacting aspects of readiness rather than one isolated equipment fault. Corroded pipes compromise containment, seized washing machinery compromises functional coverage, jammed manhole accessories delay later tasks, and unfamiliarity with procedures may lengthen the response to any of these events. Treating those dimensions as connected requirements for preparedness creates a clearer basis for prioritising maintenance expenditure and training. Nevertheless, the available evidence does not support a numerical ranking of the four factors, because the study contains neither comparable defect-frequency records nor measured indicators of competence and workload. Future research could examine these indicators across several vessels and assess whether planned inspection and targeted training reduce interruptions without compromising essential safety controls.

5. CONCLUSION

The implementation of crude oil washing on MT Swordfish was disrupted by three principal equipment problems: leakage in starboard COW line No. 4 associated with corrosion, failure of several fixed washing machines to operate automatically because of affected gear mechanisms, and seized manhole and purging-valve threads that delayed preparations for gas freeing. The pipe leakage reportedly caused an operational interruption of approximately eight hours. Interview evidence also identified variable crew familiarity with COW procedures and workload concerns.

Temporary actions including stopping and containing the leak, repairing the damaged line, cleaning and lubricating seized parts, and manually assisting equipment movement enabled operations to continue but did not eliminate the underlying deterioration. Planned component renewal, documented inspection and function testing, crew familiarisation, and systematic workload planning are recommended. Future studies should combine field interviews with maintenance records, measurable corrosion and equipment-condition data, and verified operational checklists to assess the effectiveness of these measures more rigorously.

6. DECLARATIONS

Author contributions: I.: Conceptualization, Methodology, Supervision, Writing – review & editing; P.: Validation, Formal analysis, Writing – review & editing; R.M.B.A.P.: Investigation, Data curation, Writing – original draft; C.C.A.: Methodology, Visualization, Writing – review & editing. All authors have read and approved the final manuscript.

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AI usage statement: The authors did not use generative AI tools in preparing this manuscript.

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Data availability: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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