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RESEARCH ARTICLE

**An ethical committee approval and/or legal/special permission has not been required within the scope of this study.*

THE RELIABILITY EVALUATION OF THE DECK MACHINERY AND GALLEY EQUIPMENT OF A BULK CARRIER BY UTILIZING THE FAILURE RECORDS

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ABSTRACT

Among various modes of transportation, maritime transportation holds critical importance since it provides substantial carrying capacity with low unit costs. To perform seamless and efficient operations in maritime transportation plays a pivotal role in achieving sustainable development goals and the International Maritime Organization (IMO) targets. The execution of uninterrupted operations can only be carried out with the existence of reliable systems. Creating reliable systems onboard is possible through the implementation of planned and proactive maintenance strategies and leveraging experiences gained from past failures. One decade of failure records has been scrutinized within the scope of system reliability to determine critical equipment and units on bulk carriers. The failure data has been categorized into fundamental headings and sub-headings considering marine experts' opinions and literature review. Subsequently, reliability analyses have been conducted on each sub-heading. The scope of the sub-heading equipment, the navigation instrument with (1.967E-04) failure rate has the worst reliability curve. Especially, the failure occurrence in the Radio Detection and Ranging (RADAR) equipment affects officers' on-watch performance and triggers emergencies such as collisions, groundings, and more. The high failure rate of navigation instruments is followed by fire-fighting systems (1.489E-04), cargo equipment (1.218E-04), and Global Maritime Distress and Safety System (GMDSS) (9.831E-05) instruments, all of which should have high-reliability rates to ensure sustainable, smooth, and environmentally friendly operations in the maritime sector. To strengthen equipment reliability, it is recommended to keep regular failure records and implement planned and proactive maintenance strategies.

Keywords: *Reliability Analysis, Navigation Equipment, Communication Devices, Cargo Equipment, Failure Records*

BİR DÖKME YÜK GEMİSİNDE GÜVERTE MAKİNALARI VE KUZİNE EKİPMANLARININ ARIZA KAYITLARINDAN YARARLANILARAK GÜVENİLİRLİK DEĞERLENDİRMESİNİN YAPILMASI

ÖZ

Çeşitli taşıma modları arasında deniz taşımacılığı, düşük birim maliyetlerle önemli miktarda taşıma kapasitesi sağlaması nedeniyle kritik öneme sahiptir. Deniz taşımacılığında kesintisiz ve verimli operasyonlar gerçekleştirmek, sürdürülebilir kalkınma hedeflerine ve Uluslararası Denizcilik Örgütü (IMO) hedeflerine ulaşmada önemli bir rol oynamaktadır. Operasyonların kesintisiz yürütülmesi ancak güvenilir sistemlerin varlığı ile gerçekleştirilebilir. Gemide güvenilir sistemler oluşturmak, planlı ve proaktif bakım stratejilerinin uygulanması ve geçmiş arızalardan elde edilen deneyimlerden faydalanılmasıyla mümkündür. Dökme yük gemilerindeki kritik ekipman ve ünitelerin belirlenmesi için sistem güvenilirliği kapsamında on yıllık arıza kayıtları incelenmiştir. Arıza verileri, denizcilik uzman görüşleri ve literatür taraması dikkate alınarak temel başlık ve alt başlıklar halinde kategorize edilmiştir. Daha sonra, her bir alt başlık için güvenilirlik analizleri gerçekleştirilmiştir. Alt başlık ekipmanları kapsamında, (1.967E-04) arıza oranı ile seyir ekipmanları en kötü güvenilirlik eğrisine sahiptir. Özellikle radarda meydana gelen arıza, zabitlerin vardiya performansını etkilemekte ve çarpışma, karaya oturma gibi acil durumları tetiklemektedir. Seyir ekipmanlarındaki yüksek arıza oranını yangın söndürme sistemleri (1.489E-04), kargo ekipmanları (1.218E-04) ve küresel denizcilik tehlike ve güvenlik sistemi (GMDSS) (9.831E-05) cihazları takip etmektedir ve bunların tümü denizcilik sektöründe sürdürülebilir, sorunsuz ve çevre dostu operasyonlar sağlamak için yüksek güvenilirlik oranlarına sahip olmalıdır. Ekipman güvenilirliğini güçlendirmek için düzenli arıza kayıtlarının tutulması, planlı ve proaktif bakım stratejilerinin uygulanması önerilmektedir.

Anahtar Kelimeler: *Güvenilirlik Analizi, Navigasyon Ekipmanları, Haberleşme Cihazları, Kargo Ekipmanları, Arıza Kayıtları.*

1. INTRODUCTION

The techniques and protocols employed in quality assurance and reliability engineering have undergone significant advancements during the past six decades. Reliability Availability Maintainability (RAM) analysis is employed for intricate systems and equipment to mitigate faults, ensure uninterrupted operations, and decrease expenses (Eriksen et al., 2021; Alamri & Mo, 2023). Before the 1950s, an item was considered to have met quality targets if it left the producer without any instances of failure. In modern times, RAM analysis is employed to assess failures that arise in the item, equipment, or systems over the course of their operation, to achieve quality objectives (Tsarouhas, 2020). The reliability of a system refers to the likelihood of successfully executing an action within a specific timeframe and under specific environmental variables and constraints (Stapelberg, 2009). Reliability refers to the likelihood of failure and the corresponding records collected while a system is in operation (Breneman et al., 2022). Design criteria for manufacturing, testing, and reliability are crucial for effectively implementing reliability, which refers to the quality of a product or system over time (Gullo & Dixon, 2021). Reliability encompasses three crucial factors: the desired purpose, a specific duration, and the designated constraints and circumstances (Yang, 2007). Reliability is quantified through the utilization of mathematical models or statistical factors (Sürücü & Maslakçı, 2020).

Availability refers to the ratio of delivered service to the expected service of objects (Aslanpour et al., 2020). It is the level of reliability of a system, which is determined by the maintainability of the elements within the system (James, 2021). Availability depicts the state in which an object can perform a required function when used in a suitable environment, provided that maintenance is carried out at specified intervals (Bussel & Zaaijer, 2001). Assessing the availability of a system is quite challenging as it is crucial to consider factors such as reliability, maintainability, human factors, and logistical support in the calculations (Smith, 2021). Maintainability is the consideration of the length of time that a system experiences faults during maintenance (Ghosh & Rana, 2011; Tortorella, 2015). It means the capacity of an equipment or system to fulfill its intended purpose when maintenance is conducted under certain conditions, employing the appropriate processes and resources (Velasquez & Lana, 2018). Maintenance has a significant impact on the reliability and availability of the marine sector. It is critical to the life of a ship as it can reduce downtime and operating costs. Maintenance accounts for 20-30% of a ship's operating costs (Stopford, 2009). In addition, given the environmental impact of shipping and the critical need for safe ship operations, ship owners and operators are seeking to implement a maintenance plan and processes that will save costs and improve the long-term durability of the vessel. Reliability is a crucial factor in assessing the duration and degradation of a ship's operating systems under different situations and time intervals (Li et al.,2020). Implementing preventive maintenance planning before high-risk ship operations for systems or system components that have reached the minimum acceptable level of reliability, as determined by the operator or technical manager, can greatly enhance the proper system functioning of the marine vessel (Biçen & Çelik, 2023).

Ensuring the reliability, availability, and proper maintenance of ship safety equipment is crucial in maritime operations. The reliability aspect is concerned with consistent and accurate performance, while availability emphasizes operational readiness when needed. Rigorous maintenance practices, including regular inspections and preventive measures, are essential. Adherence to international regulations and continuous crew training contribute to overall maritime safety and sustainability by ensuring equipment is in top condition. The critical situation of safety equipment is that it needs to be used in rare but vital moments.

The technological aspect of the ship's navigation system evaluated under the deck machinery systems consists of a complex network of different components, subsystems, assemblies, and human-machine interfaces. The bridge team uses this equipment to perform nautical tasks such as monitoring, anticipation, and decision-making to navigate the ship safely throughout the voyage. Ship's navigation systems and their subsystems include sensors, radio navigation, communication equipment, and data sources in addition to data processing, evaluation, and visualization capabilities. The operation and performance of these components and subsystems are influenced by human configuration and control apart from their reliability levels. Ship navigation systems currently in use can therefore be classified either as technological systems, which operate without human intervention, or as socio-technical systems, which require human input. However, when prioritizing the safety and effectiveness of ship navigation, it is imperative to consider the technological system and the crew as a cohesive unit, operating in synchrony with the constantly evolving environment (Engler et al., 2019).

Deck and cargo equipment is critical to the safety of the ship and cargo. Maintenance schedules for this equipment should be prepared using appropriate materials and taking into account the manufacturer's schedule. Maintenance and repairs to the deck and cargo equipment can be carried out while the ship is underway. However, it may not be possible to repair large equipment such as anchors on board. Anchoring is an essential procedure used to maintain the position of vessels securely during periods of waiting for berthing, cargo handling, bunkering, or protection from hazardous environmental and operating circumstances. The anchor and chain facilitate the ship's ability to secure itself to the seabed using the anchor chain, allowing it to remain stationary for a desired duration (Kuzu, 2023). Anchoring equipment should be kept ready for use at all times.

Furthermore, reliable, usable, and well-maintained galley equipment is essential for the smooth running of galley operations on board ships. The proper preparation of the daily meal for the ship's personnel is essential for the smooth running of all other operations. Consistent performance of cooking appliances and refrigeration units is essential to meet the demands of food preparation on board. Availability emphasizes that these systems must be operational at all times required by galley operations. To achieve these objectives, systematic maintenance practices, including regular inspections and preventive measures, are essential. This proactive approach helps to prevent breakdowns and ensures optimum operating conditions for kitchen equipment. Adherence to industry standards, regulations, and ongoing training of kitchen staff is vital to maintaining the reliability and availability of equipment. Prioritizing the proper functioning of galley equipment not only improves the quality of meals on board but also contributes to the overall efficiency and safety of maritime operations.

Academic scholars and maintenance professionals have urged the importance of maintenance management and determining the reliability of systems, especially in marine vessels (Tan et al., 2020; Daya & Lazakis, 2023). Existed systems in the ships have been classified as engine room and deck machinery systems. The reliability of ship machinery systems has been scrutinized to keep uplevel propulsion efficiency within the scope of related sub-systems (Bayraktar & Nuran, 2022; Bahootoroody et al., 2022; Karatuğ et al., 2023; Ceylan et al., 2023). Ivanovskaya et al., (2022) have stated that failures in the deck equipment have resulted in accidents and device malfunctions that diminished the operational and economic efficiency of the ship. Kimera & Nangolo (2022) have revealed that in the deck machinery systems, deck equipment used in towing, docking, lifting, anchoring, loading, and offloading is crucial for maintaining the operation of vessels because malfunctioning of deck equipment can result in unexpected catastrophes. Deck equipment failure is more common in vessels due to the lack of regular maintenance compared to other remaining systems (Kimera & Nangolo, 2022). Zhou and Thai (2016) have used both grey theory and fuzzy theory in failure mode effect analysis (FMEA) to evaluate equipment failure modes on tankers. Navigation equipment and deck machinery have the highest risk, after the main engine both in the grey method and fuzzy method. Planned maintenance efforts of these systems must be carried out carefully considering their high priority risk. Kimera and Nangolo (2022) have employed Weibull and Gamma distributions in the reliability analysis of deck machinery systems utilizing failures and maintenance data. Among the deck machinery systems, capstans exhibit greater reliability compared to winches and cranes based on the outcomes of the analysis. Ship age and ignoring planned maintenance intervals have lowered the reliability of systems.

2. SYSTEM DESCRIPTION AND METHODOLOGY

The failure records of four sister marine vessels have been gathered and the reliability analysis of the deck machinery navigation and galley equipment has been conducted in the paper. Figure 1 illustrates the flowchart of the methodology used in the evaluation.

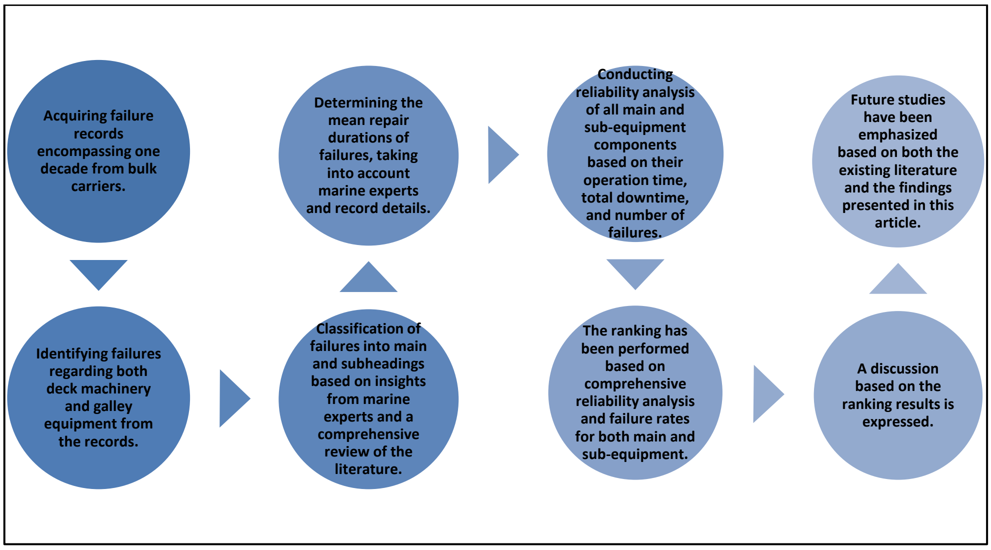

Figure 1. *The methodology flowchart.*

Information about the experts who determine mean repair durations of failures in the flow diagram is given in Table 1.

Based on expert opinions and an extensive literature review, the data has been meticulously prepared for the analysis. The reliability analysis of each system has been conducted by utilizing operating time, failure rate (λ), or Mean Time Between Failures (MTBF). The Failure Rate (λ) is determined by dividing the cumulative number of system failures by the total operational time and it has been expressed in Formula 1 (Zacks, 2012; Bayraktar & Yüksel, 2023).

Table 1. *Information about the experts*

Experts	Educational background	Length of experience	Personal background	Academic titles
Expert I	Marine Engineering	10 Years	Oceangoing Watchkeeping Engineer Academician at Marine Engineering Department	Ph.D.
Expert II	Naval Architecture and Marine Engineering	11 Years	Academician at Marine Engineering Department	Ph.D.
Expert III	Maritime Transportation and Management Engineering	12 Years	Oceangoing Watchkeeping Officer Academician at Maritime Transportation and Management Engineering	Ph.D.
Expert IV	Maritime Transportation and Management Engineering	16 Years	Oceangoing Master Marine Pilot	M.Sc.

$$Failure\ Rate\ (\lambda) = \frac{Number\ of\ Failures}{Operating\ Time} \quad (1)$$

The equation of Reliability depending on the Failure Rate (λ), total operating time, and constant has been described in Formula 2 (Zacks, 2012; Bayraktar & Yüksel, 2023).

$$Reliability = R(t) = e^{-\lambda t} \quad (2)$$

Bulk carrier records are used in the reliability analysis. The technical specifications of the ship are expressed in Table 2.

Based on the DWT classification, the vessel belongs to the Supramax category within the bulk carrier classification. The Supramax classification is widely favored thanks to its substantial cargo-carrying capacity and the inclusion of bridge-handling equipment on board. The Supramax bulk carriers have the largest share in terms of the number of vessels and they hold the second position in overall carrying capacity (United States Department of Agriculture, 2021). The continuous operational performance of Supramax bulk carriers exerts a considerable influence on maritime transportation. Therefore, forecasting the reliability values of each system onboard is quite significant in providing sustainability and applying planned maintenance.

Table 2. *Particulars of the Bulk Carriers (ClassNK, 2024)*

Parameters	Value/Descriptions	Unit
Type of Ship	Bulk Carrier	-
Gross Tonnage	29978	-
Net Tonnage	18486	t
Deadwight (DWT)	53483	t
Summer Freeboard	5.037	m
Summer Draught	12.303	m
Max. Speed	15.7	kt
Engine Power	9480	kW
Engine Revolution	127	rpm
Capacity of Generators	4 AC 1565	kVA
Length*Breath*Depth	183.06*32.26*17.3	m^3
Cargo Capacity (Bale)	65526	m^3
Cargo Capacity (Grain)	68927	m^3
Cranes	4*30.5	mt
Grabs	4*12	m^3
Number of Warehouse	5	-
Capacity of Tanks (Fuel Oil & Diesel Oil)	2317	m^3
Capacity of Tanks (Fresh Water)	408	m^3
Total Enclosed Lifeboats	2*(25)	Person
Rigid Rescue Boats	1*(6)	Person
Inflatable Life rafts	1*(6) and 2*(25)	Person
Radio Installations	GMDSS[1] A1+A2+A3, SSAS[2]	
Navigation Equipment[3]	MC, GYRO, HCS, ECDIS, GPS, RDX, RDS, ARPA, AIS, VDR, LOG, ES, STGTEL, LRIT, BNWAS	

[1] GMDSS = Global Maritime Distress and Safety System [2]SSAS = Ship Security Alert System, [3]ARPA = Automatic radar plotting aids, HCS = Heading Control System, ECDIS = Electrobinc Chart Display Information System, GPS=Global Positioning System, RDX=X Band Radar, AIS = Automatic Identification System, VDR = Voyage Data Recorder, LOG = Speed Log, ES = Ecosounder, STGTEL = Steering Telephıne, LRIT = Long Range Identification and Tracking, BNWAS = Bridge Navigational Watch & Alarm System.

The required data for the analysis have been obtained from 10-year failure records in which nearly a hundred failures have existed. Failures belonging to deck machinery and galley systems have been classified under four systems considering literature review, manufacturer reports, and marine experts. Moreover, repair and breakdown times for failures have been determined by the operating deck officer.

The limitations of this study have been described since both the analysis and the results have been evaluated within the framework of these limitations.

- Ten-year failure records of four sister ships have been utilized in this investigation.
- The failures have been obtained from the record of Bulk Carrier ships.
- Evaluation has been performed only on recorded data.

Failures that have been instantly resolved or not reported have not been included in the analysis.

3. RESULTS AND DISCUSSION

The reliability analysis results of deck machinery equipment have been discussed and shown in Figures 1 to 4 under four systems: Safety equipment; bridge equipment; deck and cargo equipment; and galley equipment respectively. The x-axis of the figures represents the operation time in hours and the y-axis depicts the reliability of the respective equipment. Figure 2 demonstrates the reliability level of the safety equipment onboard.

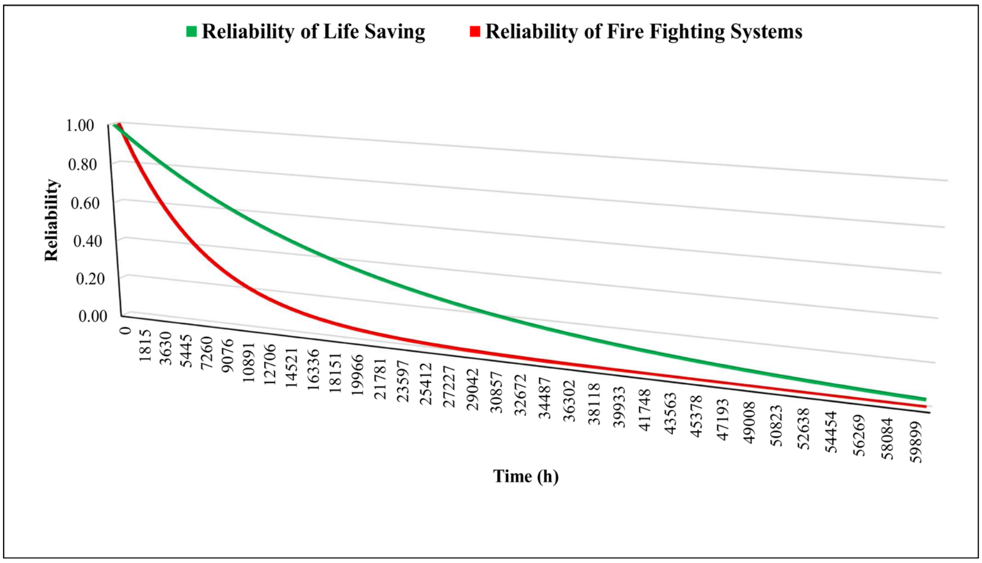

Figure 2. *Reliability of safety equipment*

The reliability analysis of the equipment included in safety systems has been conducted by assessing the failures that occurred over a cumulative operating duration of 60,504 hours. Results of safety equipment reliability have been depicted into two parts considering twelve failures: Life-saving appliances and fire-fighting systems. Their error failure rates are 0.000049596 and 0.000148864 respectively. The number of failures that occurred in life-saving appliances is three and fifteen hours have been needed to fix these malfunctions. The failures have occurred in the lifeboat engine, brake system, and battery charging system. On the other hand, the occurrences of failures in the fire-fighting systems numbered nine, and a total duration of forty-six hours was required for the fixation of these malfunctions. Fire detection systems, emergency fire pumps, and fire alarm systems are the most critical ones because the majority of malfunctions stem either directly or indirectly from these equipment components. The cumulative downtime for all safety equipment amounts to 61 hours. In addition to safety equipment, the reliability of bridge equipment has been described in Figure 3.

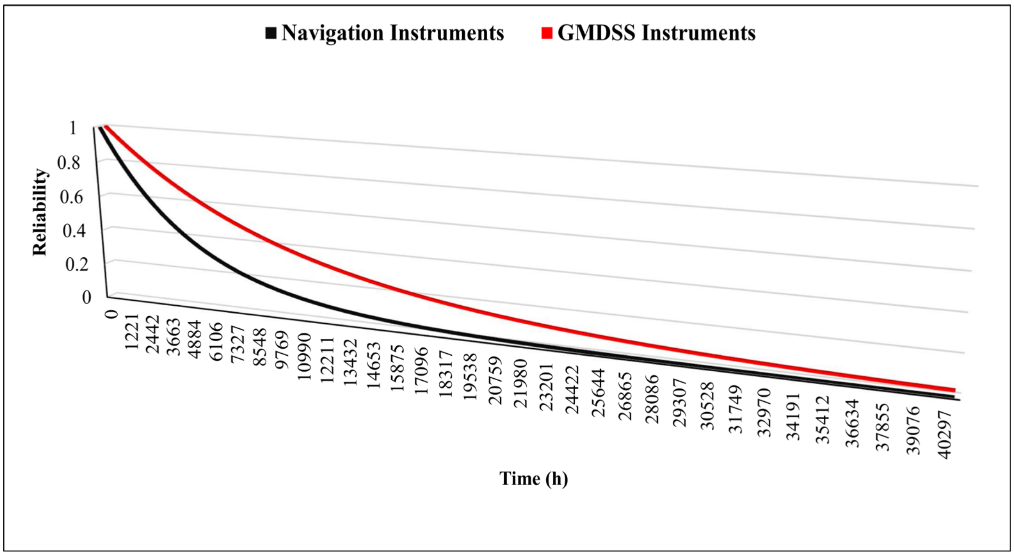

Figure 3. *Reliability of Bridge Equipment*

Bridge equipment has been classified as navigation and GMDSS instruments. A total of 12 failures have occurred in these instruments throughout the 40704 hours. Failure rates of navigation are higher than GMDSS instruments which are 0.00019673 and 0.000098311 respectively. Eight failures requiring forty hours of repair time to fix these issues have occurred in navigation instruments. Furthermore, four failures have occurred in GMDSS (Global Maritime Distress and Safety System) instruments, and forty hours have been required to repair their breakdowns. Under navigation instruments, magnetic compass, ECDIS, Radio Detection and Ranging (RADAR), GPS, and AIS devices have been broken down. On the other hand, failures of GMDSS instruments have occurred in Marine MF/HF SSB (Single Side Band), INMARSAT-C, and emergency position indicating radio beacon (EPIRB) devices. The reliability of deck and cargo equipment has been depicted in Figure 4.

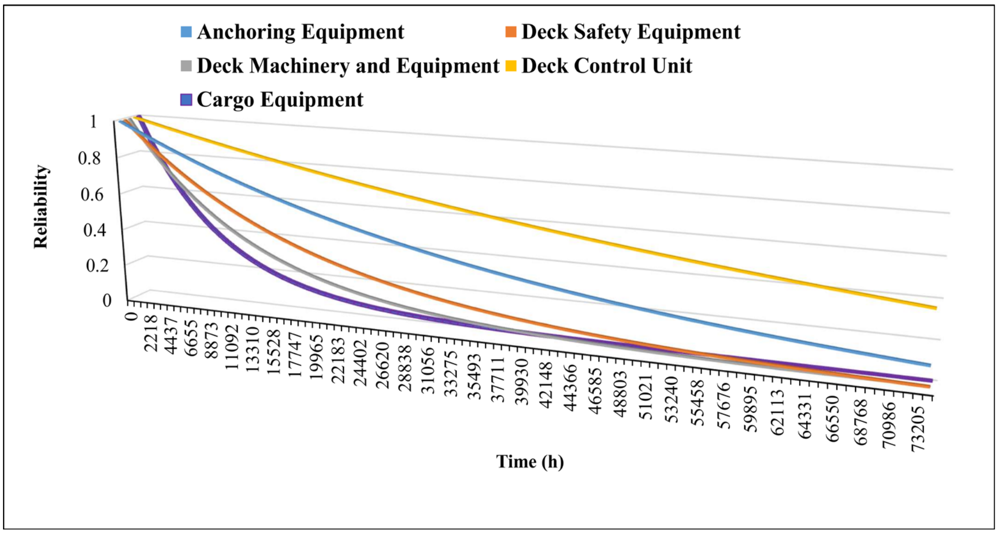

Figure 4. *The reliability of deck and cargo equipment*

The deck and cargo equipment have been divided into five sub-equipment and units. The number of twenty-two failures have occurred in these systems during 73944 hours. Among the sub-equipment and units, the most failures have occurred in cargo equipment with nine failures which were fixed in fifty-three hours. In the realm of deck machinery and equipment, six failures have transpired, resulting in a cumulative breakdown duration of 53 hours. The remaining failures have manifested in anchoring equipment, deck safety equipment, and the deck control unit, totaling six failures and necessitating a collective repair time of 60 hours. At the remaining stage, the reliability of galley equipment has been calculated and placed in Figure 5.

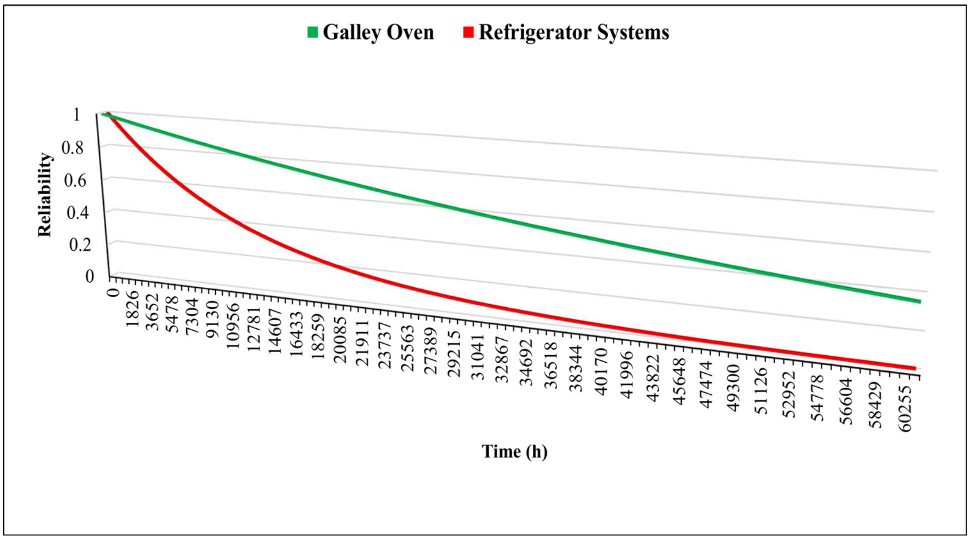

***Figure 5.** The reliability of galley equipment*

The number of one and five failures have been realized in the galley oven and refrigerator systems respectively considering 60864 operation hours. The failure sourcing from the transformer fire that occurred in the galley oven has been fixed within 10 hours. The remaining failures have led to a breakdown lasting 44 hours in the refrigerator systems. Failure rates of all subsystems have been expressed in Figure 6.

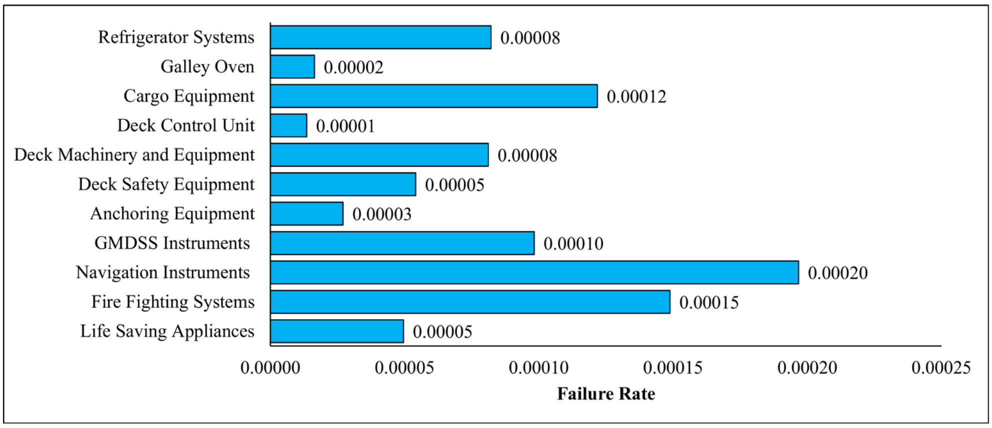

***Figure 6.** Failure rates of all subsystems*

Navigation instruments, fire-fighting systems, cargo equipment, and GMDSS instruments have exhibited the highest rates of failure when examining records. The error rate for these systems surpasses that of the remaining systems by more than two times. While there is a lack of empirical studies on the failure rates and reliability analyses of specified equipment, the detailed information provided in the warranty periods and user manuals of products has been considered in the evaluation. Under the navigation instrument, warranty periods of the magnetic compass, ECDIS, ARPA, GPS, and AIS have been varied between one to ten years (SperryMarine, 2022; BlueLine, 2024; Furuno, 2024; Simrad, 2024; AIS, 2018). Apart from these, some companies offer a never-expiring warranty on some instruments such as ECDIS (ChartWorld, 2024) because the Electronic Chart Display and Information System (ECDIS), provides substantial benefits in maritime navigation, safety, and commerce, and it is a critical and mandatory navigation aid (Xiaoxia & Chaohua, 2002). Regular and planned maintenance is very significant for lifetime warranties. 3-monthly, 6-monthly, and annual maintenance have been recommended for ARPA (Furuno, 2024), which is an important step in preventing collisions at sea (Wärtsilä, 2024). A roundly up to 10-year warranty is provided for malfunctions in electronic components of AIS units (AIS, 2018). Fire-fighting systems can have warranties of up to 3 years with regular maintenance (United Safety, 2024). Warranty periods for cargo equipment are shorter roundly one year (Marine Deck Crane, 2024) since they are used in handling operations. GMDSS instruments warranty periods are similar to navigation instruments, provided that planned maintenance is carried out. The failure rates and reliability outcomes are notably consistent with the warranty durations and user manuals of the products.

Perera et al. (2013) have expressed that failures that occur in ship navigation can cause collision and Zhou and Thai (2016) have highlighted that Navigation equipment is one of the riskiest equipment. For this reason, the reliability level of the system should be kept as high as possible. Perera (2018) has also highlighted that it is especially critical for autonomous ships to perform smooth operations because the advanced systems used in them rely heavily on data from navigation devices.

Therefore, navigation devices must be manufactured and operated with the highest level of reliability for marine vessels.

The firefighting systems hold the utmost eminence in ensuring the operational sustainability and viability of ships. System factors constitute one of the various factors in the application of the firefighting system. Among the system factors, fire ability and misinformation are the most critical ones (Zhang et al., 2013). To prevent the fire ability from being interrupted, the equipment of the fire system must be suitable and highly reliable for operation at all times.

Cargo handling equipment on bulk ships has an important share in the realization of maritime transportation. Failures occurring in this equipment disrupt loading/unloading operations in the ports and cause increased waiting times for ships at the port and congestion. Reliability analysis to be carried out on handling equipment ease periodic maintenance planning management that minimizes equipment failures (Sayareh and Ahouei, 2013). The presence of reliable cargo handling equipment provides both environmental and financial benefits for ship owners, operators, and stakeholders.

The presence of reliable communication systems on ships holds paramount significance in carrying out ship operations, especially in emergency responses. Radio communication failures are the highest frequent ones on the ship and it is followed by GMDSS Operation, EPIRB, and HF/MF failures respectively. Selecting highly reliable equipment for communications prevents excessive delays in getting help in any emergencies (Karahalios, 2018). Therefore, knowing the periodic failures and reliability rates of the devices enables the implementation of a planned and proactive maintenance strategy and ensures smooth ship operations. Bicen et al. (2022) have also highlighted that in addition to maximizing system reliability, it is necessary to provide a comprehensive training program for the ship's crew to enhance their familiarity with the existing systems because numerous errors can be attributed to human factors.

4. CONCLUSION

The comprehensive reliability analysis undertaken on both deck machinery and galley systems has yielded invaluable insights into their intricate operational intricacies and inherent susceptibilities. Through meticulous examination, pivotal revelations have come to light, underscoring the paramount importance of fostering heightened reliability within these domains. Foremost among the discerned insights is the criticality of ensuring robust reliability standards, particularly within pivotal facets such as navigation, firefighting, cargo handling, and communication systems. These subsystems have been identified as focal points warranting heightened attention due to their propensity for elevated failure rates in comparison to other equipment within the maritime infrastructure. Consequently, the imperative for stringent maintenance protocols and proactive interventions aimed at fortifying the operational resilience of these systems is unequivocally underscored. By meticulously attending to the reliability dynamics of these pivotal subsystems, stakeholders can proactively mitigate risks, enhance operational efficiencies, and ultimately bolster the safety and efficacy of maritime endeavors. Such strategic imperatives are pivotal for navigating the dynamic complexities inherent in maritime operations and engendering sustainable advancements within this multifaceted domain.

Additionally, failures within these maritime systems not only pose inherent safety hazards but also engender operational impediments, thereby disrupting the seamless flow of maritime transportation. The elucidated article underscores the imperative of implementing meticulously devised and proactive maintenance protocols. Such protocols are formulated through a comprehensive analysis of the reliability and potential failures of both overarching systems and their constituent sub-systems. This strategic approach is fundamental for ensuring the sustained efficacy of maritime operations amidst the dynamic challenges inherent in this domain.

The conclusions drawn and the subsequent discourse arising from the analytical investigation are poised to yield significant implications for a diverse array of stakeholders within the maritime domain. Principally, shipowners, operators, and regulatory bodies stand to benefit from the insights gleaned, as they offer invaluable guidance for enhancing both operational resilience and safety standards across the maritime sector. Implementing thorough crew training programs is crucial to improving the crew's understanding of onboard systems and reducing errors caused by human factors. Enhancing operational efficiency, safety, and environmental sustainability in maritime transportation can be achieved by optimizing system reliability and investing in crew training. This reliability analysis emphasizes the importance of upholding high equipment dependability standards and promoting a proactive maintenance culture to guarantee the safety, efficiency, and sustainability of marine operations in a changing maritime environment.

Moreover, as we chart a course into the future, it becomes increasingly imperative to perpetuate research endeavors and foster collaborative initiatives aimed at advancing the field of reliability assessment about ship systems. Sustaining such efforts is essential not only for surmounting existing barriers but also for ensuring the seamless operation of vessels in alignment with the targets delineated by the IMO and the overarching aspirations encapsulated within the Sustainable Development Goals. By steadfastly pursuing this trajectory of research and collaboration, stakeholders can collectively navigate the intricate complexities of maritime operations while simultaneously striving toward the attainment of broader environmental and societal objectives on a global scale.

In addition to bulk carriers, oil tankers, container ships and other types of ships also hold significant share in maritime transportation and the interruption of operational continuity in these types of ships results in economic, social, and environmental losses. Therefore, reliability analyzes should be conducted on these ship types as part of future research efforts to fulfill IMO and United Nations objectives.

CONFLICT OF INTEREST STATEMENT

The author(s) declare(s) no conflict of interest.

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