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A Study on Minimizing Potential Accidents in Ship Bunkering Operation Through Use of Failure Mode and Effect Analysis

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ABSTRACT

It is only possible for companies to maintain their position and advance in the competitive environment by preserving their quality and by developing and improving themselves. In this direction, they need to make quality measurements and analyses. For this purpose, more than one quality improvement method has been developed. One of the techniques for enhancing quality is the Failure Mode and Effect Analysis (FMEA) method. FMEA is an operations management and product development method that classifies failures according to similarity, probability, detectability, and severity to analyze potential failure types of a system. It is a technique that focuses on avoiding risks in products and processes during the production phase and documenting these activities. Its purpose is to prevent poor quality, address potential risks that may cause product defects, identify possible types of defects, and determine their consequences and severity. In this study, the bunkering operation between the fuel barge and a ship, the berthing and anchoring of the fuel barge, the fuel transfer process, the unberthing of the fuel barge, and the preparation for the voyage were handled in three stages and the hazards were defined for each stage. Bunkering operation hazards have been identified by using FMEA have been conducted to reduce operational risks, and suggestions have been made.

Keywords: Failure Mode and Effect Analysis, quality improvement, risk, impact, failure

Gemilerde Yakıt İkmali Operasyonunda Gerçekleşmesi Muhtemel Kazaların Hata Türü ve Etkileri Analizi ile Azaltılma Çalışması

ÖZ

Firmaların rekabet ortamında yerlerini koruyabilmeleri ve ilerleyebilmeleri ancak kalitelerini koruyarak, kendilerini geliştirip iyileştirerek mümkündür. Bu doğrultuda kalite ölçümü ve analizi yapmaları gerekmektedir. Bu amaçla da birden fazla kalite iyileştirme yöntemi geliştirilmiştir. Hata Türü ve Etki Analizi (HTEA) yöntemi de kalite iyileştirme yöntemlerinden biridir. HTEA, bir sistemin potansiyel hata çeşitlerini analiz etmek için benzerliğe, olasılığa, saptanabilirlik ve şiddet derecelerine göre hataları sınıflandıran bir operasyon yönetimi ve ürün geliştirme yöntemidir. Üretim aşamasında ürünlerde ve süreçlerde risklerden kaçınılmasına ve bu faaliyetlerin belgelenmesine odaklanan bir tekniktir. Amacı kalitesizliği önlemek, ürün kusurlarına neden olabilecek potansiyel riskleri ele almak, olası hata türlerini belirleyip sonuçlarını ve önem derecelerini saptamaktır. Bu çalışmada yakıt barcı ve yakıt alan gemi arasında gerçekleşen yakıt ikmali operasyonu, yakıt barcının yanaşması ve demirleme, yakıt transferi süreci ile yakıt barcının

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ayrılması ve seyre hazırlık olarak üç aşamada ele alınmış ve her bir aşama için tehlikeler tanımlanmıştır. Tanımlanan tehlikeler HTEA kullanılarak operasyon risklerinin azaltılması konusunda çalışmalar yapılmış ve önerilerde bulunulmuştur.

Anahtar Kelimeler: Hata Türü ve Etkileri Analizi, kalite iyileştirme, risk, etki, hata

1 Introduction

Maritime transport is a significant part of global trade, with many activities involving large-scale vessels. The ship bunker operation is one of these operations. However, bunker operations contain possible hazards and variables that could lead to an accident. This accident can have major repercussions, including pollution, loss of life, economic losses, and ship damage. As a result, reducing potential incidents in bunker procedures is critical. This study investigates how the FMEA method can be used to reduce the risk of accidents in ship bunker operations.

Failure Mode and Effect Analysis (FMEA) is an analysis and evaluation method that systematically investigates the causes and effects of failures that may influence the system's parts (Usug, 2002). The using of the FMEA approach illustrates that good results can be obtained by systematic risk assessment and the deployment of remedial measures to improve the incident's safety and quality. The application of FMEA contributes to the ongoing improvement of the incident regarding safety and quality by assisting in the implementation of risk management measures (Kardos et al., 2021). The FMEA approach can be used to detect, analyze, and minimize probable accidents in ship bunker operations.

This article aims to increase awareness of potential setbacks in ship refueling operations and improve safety through risk assessment using the FMEA approach. By reading this article, stakeholders in the shipping industry can become aware of the potential risks in ship bunker operations and take appropriate procedures to ensure safety.

FMEA is a risk assessment method commonly used in maritime and other industries. To better comprehend the benefits of the FMEA approach and to apply it in this study, it is necessary to first analyze how it is utilized in other industries and what results are obtained. For example, Arabian-Hoseynabadi, H., et al. (2010), investigated the reliability of a wind turbine system utilizing the FMEA method in their study. The FMEA method is applied to a wind turbine system using a proprietary software reliability analysis tool. FMEA quantitative conclusions are compared to confidence field data from real-world wind turbine systems. The unreliability of assemblies, subassemblies, and parts was ranked using FMEA data. This can be used to assist designers in identifying weak points. According to the paper, FMEA has the potential to increase the reliability of offshore wind turbine systems and can play a significant role in the development of maintenance-free or low-maintenance turbines. Finally, this study investigates the applicability and potential of FMEA. In his study, Ceber, Y. (2010) examined the application of FMEA in the manufacturing sector. According to the report, organizations focus on providing higher-quality, more inexpensive, and faster products to meet the challenges of a competitive climate and to remain stable by maintaining consumer happiness. Failure Mode and Effects Analysis (FMEA) is a technique used to avoid existing faults and eliminate potential errors at their source so that their consequences do not occur. FMEA is preferable among other quality procedures since it is simple to implement and can be utilized in various industries. Kaya and Alaykran (2019) estimate the potential error types, causes, and effects that may occur in the production and assembly stages using the Process FMEA method, and the error types that will have the most significant impact on the overall system are prioritized and the risk priority number is determined. It was thus attempted to prevent the incidence of errors and to aid in the planning of activities to minimize the consequences on the client. Asadi, F., et al. (2020) describe a technique for remote monitoring of high voltage transformers in their paper. Based on FMEA, the script functions provided in the study define alert and warning circumstances. This approach detects transformer states early on, allowing errors to be avoided. Tafur, H. D., et al. (2021) investigate the development of reliable control software against hardware failures using an FMEA-based technique, and their findings are promising. Ramere, M. D., and Laseinde, O. T. (2021) provide a novel strategy for using FMEA in the development of care strategies in their study. The performance of engine production equipment must be optimal in the automotive sector. At this point, the FMEA technique aids in the development of a dependable maintenance strategy by identifying potential failure modes and controlling their consequences. A least-cost conflict risk reduction process was integrated into FMEA in a study by Du, Z., et al (2022) to eliminate variations in individual risk estimates in minimum adjustment cost. Using probabilistic linguistic term sets, the suggested FMEA model deals with ambiguity and fuzziness. Risk evaluations can thus be carried out more effectively in complex and uncertain contexts. As a result, risk evaluations can be carried out more thoroughly and sensitively. Hassan, S., et al. (2022) create a modified FMEA model to compensate for a lack of historical data and detect pipeline system hazards more precisely.

These studies in diverse industries show that the FMEA (Failure Modes and Effects Analysis) method has a wide range of applications. These studies demonstrate that FMEA is a successful method for recognizing and mitigating possible accidents in a variety of industries. In addition to FMEA applications in other industries, this method is frequently employed in the marine industry to detect and reduce possible accidents. Cicek, K., and Celik, M. (2013) demonstrate in their studies that FMEA is an effective risk management technique in the maritime industry, providing flexibility to complicated situations such as crankcase explosions. It confronts this difficult maritime engineering problem head on by using FMEA to propose remedies to complex faults such as crankcase explosions. In another study, Zaman, M. B., et al (2014) demonstrate that the fuzzy FMEA method may be employed well for risk assessment of ship collisions in the Malacca Strait. This type of analysis can help improve maritime safety measures and increase maritime transportation safety. Shipyards, another part of marine, are fraught with danger. Ozkok, M. (2014) investigated the shipyard's hull structure fabrication process in a related study. Fault statistics were gathered, faults were classified, and their probability and severity were calculated. This study reveals that FMEA is a useful risk assessment technique in the ship hull structure manufacturing process and offers shipyard strategies to reduce failures and enhance production processes. According to Emovon (2016), a novel FMEA tool incorporating Dempster Shafer Theory and the ELECTRE method is presented to solve the constraints of the FMEA method. The proposed method's practicality is illustrated using a case study of a marine diesel engine. Mentes, A., and Yigit, M. (2020) evaluate the field operations of a ship recycling company in Izmir Aliaga and analyze potential risks using the FMEA approach. The risk priority number (RPN) is calculated for each prospective risk, and conclusions about the prevention or reduction of critical risks are drawn based on the RPN values. Goksu, S. (2021) sought to identify dynamic risk variables in ship operations and to devise a system for assessing the potential consequences of these risks. The FMEA method was used to determine the influence of dynamic risk factors on potential error types. As a consequence of the study, it is suggested that control measures be implemented by identifying the highest priority error kinds. Chang, C. H. et al. (2021) developed a method for assessing the risk levels of major hazards related to Maritime Autonomous Surface Ships (MASS) operation. The FMEA method has made major contributions to hazard classification and risk assessment. Ceylan's (2023) goal is to give a thorough risk evaluation of the ship compressor system. To identify potential failure modes of the ship compressor system, the FMEA method was employed. It ranks risks based on the severity, likelihood, and detectability of each failure mode. Ceylan et al. (2023) provide an enhanced FMEA method for risk analysis of MARPOL Annex-VI ship-related air pollution deficiencies. RPN values are used to list the risk priority of MARPOL Annex-VI deficiencies. The highest risk flaws were discovered in this manner, and the measures that could be performed to mitigate the risks were determined.

According to several research in the literature, the FMEA method has been successfully utilized in various sectors, including the maritime sector. Taking into account all of the benefits of FMEA, this study investigates how the FMEA method might be utilized to reduce potential accidents in ship bunker operations. The fundamental ideas and application methodology of the FMEA approach will be described first. The numerous sorts of faults that can occur in ship bunker operations and the potential consequences of these errors will be explored next. Finally, the outcomes of the FMEA approach will be addressed, as will the measures that can be done to minimize prospective accidents.

2 Method: Failure Mode and Effects Analysis (FMEA)

Once a process is ready for production or is in the production process, it is substantial to ensure the trustworthiness of the process or product. Trustworthiness is an important property of products or processes. It is also a factor that significantly affects customer satisfaction. Customers want the product they use to be long-lasting and at the same time to be a hassle-free process. Therefore, in order to ensure the reliability of a product or process, a risk analysis should be made that can be used to identify possible types of failures and their effects on the product or process and to control its reliability (Yılmaz, 2000).

Issues such as developing sustainable products, increasing the quality of the developed product, production, and logistics are among the challenges faced by manufacturing enterprises today (Kleindorfer et al., 2005). For many years, besides the life cycle evaluation of products, checklists and product guides (Pinheiro et al., 2018) have been used to develop sustainable products. Additionally, various techniques are used to modify the widely used quality management tools to satisfy customer demands and achieve sustainability goals (Luttropp and Lagerstedt, 2006). Failure Mode Effects Analysis is a quality management tool that examines how likely it is for products or processes to fail and how seriously consumers consider the effects of such a failure (Ahsen et al., 2022).

It allows to carry out improvement studies in line with the FMEA result. Thus, improvements can be made on many criteria such as safety, cost, performance, quality, reliability, and environmental standards (Prajapati, 2012).

FMEA has a variety of applications such as System, Design, Process, and Service and covers products and services in sectors. System Failure Mode Effects Analysis is used to analyze a system and its sub-components and to determine the types of failures that may arise from the deficiencies of the system. System FMEA aims to increase the quality and reliability of the system. Design Failure Mode Effects Analysis is used to determine the types of failures that may arise from design failures before production. Design FMEA aims to improve design quality and reliability. Process FMEA is used to prevent failures originating from the production and assembly process. Finally, Service FMEA is used to detect problems that may arise in the organization beforehand. Service FMEA ensures that the failures that occur in the process are taken under control by analyzing the workflow and the process (Özkılıç, 2012).

The Risk Priority Number (RPN) can be determined using the FMEA method. RPN is acquired by multiplying Probability (P), Severity (S), and Detectability (D) values (Ahsen, 2022). The probability degrees in Table 1 indicate the probability of failure (Özfirat, 2021).

Table 1: *The probability and degree of the failure (Özfirat M., and Özfirat P., 2021)*

Probability of failure occurrence	Probability Failure (O)	Rating
Very high: failure is almost inevitable	1/2 or more	10
High: repeated failures	1/3	9
	1/8	8
Moderate: occasional failures	1/20	7
	1/80	6
	1/400	5
Low: comparatively few failures	1/2000	4
	1/15000	3
Remote: failure is unlikely	1/150000	2
	1/1000000 or lower	1

After determining the probability of the failure and the rating corresponding to this probability, the severity value of the effects that may occur as a result of the failure is shown in Table 2.

Table 2: *The Impact and Severity of the Failure (Özfirat M., and Özfirat P., 2021)*

Failure Effect	Severity of Failure (S)	Rating
High hazard without warning	Possible unwarned failure with highly hazardous effects	10
Hazard without warning	Possible unwarned failure with high damage and mass fatality impact	9
Very High	Possible failure with the effect of causing complete damage to the system	8
High	Possible failure causing damage to system components	7
Moderate	Possible failure that adversely affects system performance	6
Low	Possible failure with effects such as broken, permanent minor incapacity, 2nd degree burns etc.	5
Very Low	Possible failure causing injuries such as bruises, minor cuts and scrapes, crushes etc.	4
Minor	Possible failure that slows down the operation of the system	3
Very minor	Possible disturbance to the operation of the system	2
None	No effect	1

After determining the effect and severity of the failure, the detectability of the failure is determined. Detectability refers to the level of detectability of the hazard, and if it is not detected, it refers to the extent of its impact. Its detectability and probability are indicated in Table 3.

Table 3: *Detectability and probability (Özfirat M., ve Özfirat P., 2021)*

Detectability	Detectability Probability	Rating
Absolutely impossible	It is not possible to detect the cause of the possible failure	10
Very remote	Detectability of possible failure is very remote	9
Remote	Detectability of possible failure is remote	8
Very low	Detectability of possible failure is very low	7
Low	Detectability of possible failure is low	6
Moderate	The detectability of the cause of the possible failure is moderate	5
Moderately high	The detectability of the cause of the possible fault is moderate high	4
High	The detectability of the cause of the possible fault is high	3
Very high	The detectability of the cause of the possible fault is very high	2
Almost certain	The detectability of the cause of the possible fault is almost certain	1

A value is obtained by multiplying these numbers with the probability of the error's occurrence, the failure's severity and the detectability numbers for which the Risk Priority Number should be calculated. The RPN Assessment over the calculated value is shown in Table 4.

Table 4: *The Risk Priority Number Assessment (Özfirat M., ve Özfirat P., 2021)*

The Risk Priority Number (RPN)	Precaution to be taken
RPN <40	Existing measures are sufficient.
40 ≤ RPN ≥ 100	It is recommended to take measures in addition to the existing measures.
RPN >100	It is imperative to take measures in addition to the existing measures.

3 Bunker Operation on Ships

Ships refuel in order to use them in the main engine, generators, and boiler and thus continue their course. Although the bunkering operation is routine, it is defined as risky (Kumal, B., and Kutay, Ş., 2021). Although high security measures and procedures have been established for bunkering operations, even the slightest mistake can result in serious problems such as loss of life and marine pollution (Akyüz E., et al., 2018).

The bunker operation stages are shown in Figure 1. The bunker operation begins with the anchoring the ship prepared for the bunker and the berthing of the fuel barge to the ship. When the ship is ready for the bunker operation, the fuel transfer starts by making the appropriate connections with the fuel barge. The bunker operation ends with the disconnection of the fuel supply line after the fuel transfer is completed, the separation of the fuel barge, and the ship's preparations for navigation.

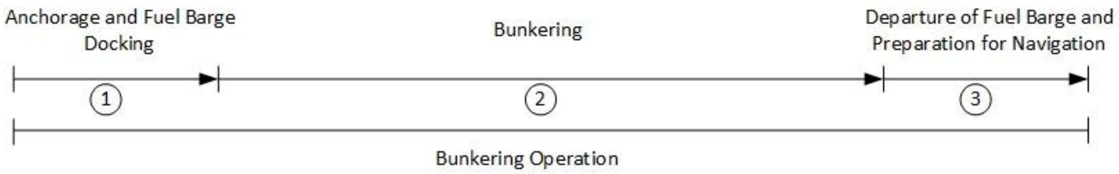

Figure 1: Bunker Operation Steps

The tasks performed during the bunker operation were carried out in three stages: pre-fuel, during, and after the bunker, and are detailed in Section 4.2.

In order for the bunker operation to be carried out safely, it is necessary to have a good command of the current operation steps (Akyüz, E., et al., 2018):

Steps to be taken before the Bunker Operation:

- Conducting the safety meeting
- Taking and recording sounding values from fuel tanks
- Checking the personal protective equipment to be used on the deck
- Checking that all deck brakes are closed
- Making sure the overflow tank is empty
- Checking that the smoking warning is placed
- Ensure that warning signs required for bunkering are placed
- Checking the bunker manifolds
- Checking that Ship Oil Pollution Emergency Plan (SOPEP) equipment to be used in case of fuel leakage into the sea is in suitable places

- Ensure that the fuel barge is safely berthed
- Ensuring correct communication with the fuel barge
- Discussing all the details of the operation with the bunker ship for the bunkering procedure
- Verification of bunkering flowrate.
- Connecting the fuel supply hose to the manifold.

Steps to be taken during bunker operation:

- Opening the manifold valve and starting the supply
- Making sure the flow is kept low during the start of bunkering
- Continuous control of the bunker operation
- Continuous measurement of tank sounders
- Continuous measurement of fuel temperature
- Taking the fuel sample during the bunkering period
- Checking trim and draft
- Closing the manifold valve

Steps to be followed after bunker operation:

- Taking the sounding values of all fuel tanks
- Calculation of the amount of fuel received finally
- Signing the fuel purchase receipt
- Removing the bunkering hose
- Safe separation of the bunker vessel

Table 5: *Failures and definitions*

Failures	Definitions
Personnel Fatigue	The ship's crew may have been out of a busy day before the bunker operation took place. Fatigue may be seen in personnel due to maneuvering, various ship operations, and insomnia before the bunker operation. These reasons can lead to failures.
Insufficient Personnel	The personnel in the bunker operation may not have sufficient knowledge or the ship's crew may have just changed and they may not have operated a bunker on this ship before. The lack of knowledge of the personnel about the operation can lead to failures.
Workload of Personnel	An unexpected problem may arise before or during an operation on board. The crew may be busy with other work other than bunker operation. This situation increases the crew's workload in the bunker operation and can cause failures.
Familiarity	Before the bunker operation, the relevant personnel should be informed about the operation. Bunker operation may take longer than expected and personnel may need to change shifts. The personnel who will change the shift should also be informed about the bunker operation in order not to cause mistakes.
High Level Alarms	High level alarms of fuel tanks should be tested before bunker operation. In case of malfunction, it may cause failures.
Tank Level Sensor	Fuel tank level sensors should be maintained regularly and tested before operation. In case of malfunction during bunker operation, it may not show the level correctly depending on the temperature and density of the fuel taken.
Overconfidence	In the bunker operation, sounding must be taken from the tanks at certain intervals. Many failures can occur when the crew does not care about this situation.

Potential failures in bunker operation steps and their definitions are also shown in Table 5 (Kumal and Kutay, 2021).

It may not follow the chief engineer's instructions or act slowly, which can lead to errors in monitoring.

- Preparing the Bunkering Circuit: The bunkering circuit may have been prepared incorrectly before bunkering. A transfer to a full tank may be initiated due to the opening of the wrong valve, or it may cause overflow on the deck due to a valve not opening.
- Planning: It is of great importance to prepare the bunker operation plan before the bunker operation. Before the operation, how much fuel will be taken into which tank should be calculated correctly. This plan should be known to all personnel. Otherwise, the absence of the plan may lead to failures.
- Communication Between Ship and Fuel Barge: Communication with fuel barge personnel should be established properly. Before starting the bunker operation, how to establish communication should be discussed. Communication with the fuel barge is usually provided by hand signals. For this reason, signs for starting and stopping the operation should be understood before starting the bunker operation. For this reason, personnel should always be assigned to ensure communication on board. It should be checked beforehand that the emergency stop button is also in working condition.
- Onboard Communication: Communication within the ship can be done by radio. Disputes may occur in communication due to environmental effects and weather conditions. This may also cause failures.
- Manifold Connection: The fuel supply line connections should be checked before the bunker operation. The condition of the connection hose is extremely important for the safety of the operation.
- Connection Hose Damaged: The condition of the fuel hose is important, otherwise the damaged hose may cause fuel leakage. This causes major failures.
- Location of the Tank: The location of the ship tanks can negatively affect the bunker operation. If the pumping capacity of the fuel barge is very high and the tank capacity is low, there may be problems during the bunker operation.
- Sea Condition: If the weather conditions are very bad, bunker operation should not be done. Bunker operation may take place when necessary, but bad weather conditions may cause failures.
- Connection hose ruptured: If the fuel connection hose is torn during the bunker operation, it will cause pollution.

4 Bunker Operation Considering the Application Failure Modes and Effects Analysis

When the literature is examined, most studies on the bunker operation have focused on reducing the cost. In addition, some studies analyze the human-induced failures of the bunker operation with various methods (Akyüz et al., 2018). This study analyzed the bunker operation with FMEA and the Risk Priority Number (RPN) was calculated. Additional measures were expressed depending on the RPN and residual risk calculation was made after the additional measures were taken. In this context, the failures to be encountered in the bunker operation are grouped into three stages; the docking of the fuel barge, during the bunkering, and the separation of the fuel barge.

Hazards During Berthing and Mooring of Fuel Barge:

- Conflict Caused by Engine or Rudder Failure (F1)
- Man Overboard During Maneuvering (F2)
- Conflict Due to Bad Weather Conditions (F3)

Hazards During Bunkering:

- Marine Fuel Leakage Due to Incorrect Manifold Connection (F4)
- Fuel Leakage Due to Insufficient Condition of the Connection Hose (F5)
- Fuel Overflows Due to Level Sensor Failure of Fuel Tanks (F6)
- Failure to Properly Conduct the Operation Due to The Inability to Establish Proper Communication Between the Ship and Fuel Barge (F7) [Unable to Adjust the Correct Flowrate, Failure to Stop the Operation in an Emergency Situation, etc.]

Disconnection of Fuel Barge and Hazards During Preparation for Sailing:

- Leakage of Fuel Remaining Inside the Hose While Removing the Hose Connection (F8)
- Man Overboard During Leaving Maneuver (F9)

The probability of occurrence of the hazards described above, the severity that will occur when they occur, the detectability of the hazard, and the risk priority coefficient are expressed in Table 6. Additively, the measures to reduce the hazard are defined in the same table.

Table 6: *Situation Before Taking Action*

Failure	P	S	D	RPN	Precautions to take
F1	5	8	8	320	Performing main engine and rudder checks before maneuvering
F2	5	10	9	450	Ensuring the minimum number of personnel required to be on deck during the maneuver and wearing personal protective equipment of this personnel
F3	3	8	7	168	Considering the weather and sea conditions while scheduling fuel purchase
F4	7	7	7	343	Before the operation, determining the tanks to be fueled and the circuits to be used, making and checking the marking marks on the fuel intake manifold before the operation
F5	5	7	9	315	Periodic checks of hoses and fittings used in the operation
F6	8	7	10	560	Periodic checks of level sensors used in fuel tanks and pre-operation sounding measurements
F7	4	6	9	216	Control of the communication tools before the operation, determination of the hand signals to be used with the bunker barge personnel, placing the emergency stop buttons on the bunker barge and ship side
F8	5	4	6	120	Draining the remaining fuel in the hose circuit to the tank by giving compressed air to the lines after the operation and placing a leak pan under the hose during the removal of the hose.
F9	5	10	9	450	Ensuring the minimum number of personnel required to be on deck during the maneuver and wearing personal protective equipment of this personnel

Table 7: *Situation After Precaution is Taken*

Failure	P	S	D	RPN	Advices
F1	2	8	4	64	In addition to the precautions stated in Table 5, it is recommended to take precautions to reduce severity.
F2	3	5	3	45	It is recommended to take additional precautions to the precautions stated in Table 5.
F3	3	8	2	48	In addition to the precautions stated in Table 5, it is recommended to take precautions to reduce severity.
F4	2	7	3	42	In addition to the precautions stated in Table 5, it is recommended to take precautions to reduce severity.
F5	3	7	2	42	In addition to the precautions stated in Table 5, it is recommended to take precautions to reduce severity.
F6	2	6	2	24	The precautions stated in Table 5 are sufficient and the operation can be carried out by providing safety with continuous monitoring and control.
F7	1	6	2	12	The precautions stated in Table 5 are sufficient and the operation can be carried out by providing safety with continuous monitoring and control.
F8	3	2	2	12	The precautions stated in Table 5 are sufficient and the operation can be carried out by providing safety with continuous monitoring and control.
F9	3	5	3	45	It is recommended to take additional measures to the measures stated in Table 5.

5 Conclusions

Although bunkering operations are routinely performed on ships, they contain serious dangers. Errors that will occur before, during, or after the operation may result in serious marine pollution. In this context, it is important work to reduce the risks in bunkering operations and to carry out a safer operation. The FMEA method is used in this study to reduce the possibility of accidents in ship bunker operations. The FMEA approach was employed for this goal, and the method's benefits and challenges were assessed. Considering the literature research, FMEA has many positive effects. To begin with, FMEA provides a systematic approach for identifying and analysing probable failures in ship bunker operation. This assists in anticipating potential dangers and preventing accidents through preventive actions. Furthermore, FMEA is a method that encourages collaboration and stakeholder participation. This allows multiple viewpoints to be brought together, allowing for a more comprehensive examination. FMEA also aids in resource allocation by getting to the root of problems and focusing on preventative action. FMEA has numerous advantages as well as disadvantages. FMEA attempts to forecast future failures using just available knowledge, however, it is difficult to anticipate all conceivable scenarios. Some FMEA procedures are based on people's subjective assessments. This means that various experts or teams may assess the same fault differently. There may be inconsistency between the outcomes of the evaluation in this scenario.

In the study, the bunkering operation was handled in three stages as the berthing and anchoring of the fuel barge, the fuel transfer process, and the separation of the fuel barge and preparation for the sailing. A total of nine hazards/possible errors belonging to these stages are discussed. The Risk Priority Coefficients of the considered hazards were calculated and the precautions to be taken for each hazard were determined. With the implementation of the measures to be taken, the residual risk score for each hazard has been calculated and recommendations have been added to ensure that the operation can be continued safely.

The bunkering operation usually takes place on the open sea between the bunker and the vessel. The dangers that may arise in the execution of the operation are affected by many parameters such as personnel adequacy, personnel fatigue, sea and weather conditions. Since the bunkering operation takes place in the open sea and is affected by many parameters, small mistakes that cause the realization of hazards have a large impact on the environment and sea pollution.

In this study, it has been found that the measures presented for each hazard reduce the probability and detectability coefficients of the hazards, but do not reduce the severity coefficient as much as the probability and detectability coefficients. It has been found that the measures to be taken in order to reduce the severity coefficients of the hazards considered should be more detailed and comprehensive. In this manuscript, in order to reduce the severity of the hazards in the bunkering operation, a detailed study should be carried out, especially considering the cost/benefit analysis.

Based on the study's findings, we can infer that FMEA is a helpful tool for decreasing the risk of accidents in ship bunker operations. FMEA provides a systematic strategy for identifying and analysing risks and taking preventive measures. However, drawbacks such as subjective judgments and a lack of data should be considered. This study gives ship operators and other stakeholders a vital tool for increasing safety standards in ship bunker operations through the use of FMEA.

6 Declarations

6.1 Competing Interests

There is no conflict of interest in this study.

6.2 Authors' Contributions

Begum DOGANAY: Contribute to the development of the idea of the article, literature review, writing and review of the article

Burak ÇAVUSOGLU: Contribute to the development of the idea for the article, organizing and interpreting the data.

Çagrı Berk GULER: Contribute to the development of the idea for the article, organizing and interpreting the data.

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