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Risk Analysis for Engine Room Fires on Ships: Case Study Using the Fine-Kinney Method

Gemilerde Makine Dairesi Yangınlarına Yönelik Risk Analizi: Fine-Kinney Yöntemi ile Örnek Olay İncelemesi

Research Article

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Özet

Deniz taşımacılığı, verimliliği ve birim yük başına diğer taşımacılık modlarına nazaran ucuz olması nedeniyle küresel yüklerin taşınmasında en çok tercih edilen taşımacılık modu olarak değerlendirilmektedir. Ancak, taşımacılık sürecinde yüklerin elleçlenmesinden, makine ve ekipmanların bakımına kadar çok sayıda önemli ve riskli operasyonu bünyesinde barındırmaktadır. Gemiler, yük ve limanlara nazaran daha karmaşık ve tehlikeli operasyonlara sahip olmaları nedeniyle daha fazla riske maruz kalmaktadır. Bu nedenle gemi yönetimi bu risklerin belirlenmesinde ve gerekli önlemlerin alınmasında büyük rol oynar. Gemilerin en önemli ana parçası olan makine daireleri, yüksek sıcaklık, yanıcı maddeler ve karmaşık sistemler nedeniyle diğer bölgelere göre daha fazla risk barındırmaktadır. Buradaki risklerin değerlendirilmesi gemi yönetimi olarak başta kaptan ve baş mühendis olmak üzere ilgili zabitler tarafından tespiti, değerlendirilmesi ve önlem alınması gemilerin emniyetli işletilmesi bakımından oldukça önemlidir. Çalışmada literatür ile çeşitli gemi kazalarına ilişkin raporlar incelenmiş ve konu gereği gemi yönetiminde yer alan baş mühendis ve 2. mühendislerden oluşan uzmanlardan görüş alınarak makine dairesi yangınlarına ilişkin risk faktörleri belirlenmiştir. Sonraki aşamada bir konteyner gemisinin yaşadığı kaza özelinde Fine-Kinney yöntemi kullanılarak bir risk analizi yapılmıştır. Çalışma soncunda en yüksek risk puanı, makinelerdeki yağ/yakıt sistemi arızaları ve yakıt devrelerinde oluşabilecek kaçaklar olarak tespit edilmiştir.

Anahtar Kelimeler: Gemi Yönetimi, Deniz Taşımacılığı, Risk Analizi, Makine Dairesi Yangınları, Fine-Kinney.

Abstract

Maritime transportation is considered to be the most preferred mode of global transportation due to its efficiency and low cost per unit of cargo compared to other modes of transportation. However, it involves many risky and important operations in the transportation process, from the handling of cargo to the maintenance of machinery and equipment. Ships are exposed to more risks as they have more complex and dangerous operations compared to cargo and ports. Therefore, ship management plays a major role in identifying these risks and taking the necessary precautions. The engine rooms, the most important main part of ships are also exposed to more risks than other areas due to high temperatures, flammable materials, and complex systems. Assessment of the risks here, detection, evaluation, and taking precautions by the relevant officers, especially the captain and chief engineer, as ship management, are very important for the safe operation of ships. In the study, the literature and reports on various ship accidents were examined and the risk factors related to engine room fires were determined by taking the opinions of experts consisting of chief engineers and 2nd engineers involved in ship management as a matter of subject. In the next stage, a risk analysis was carried out using the Fine-Kinney method, specifically for the accident of a container ship. As a result of the study, the highest risk was identified as machinery oil/fuel system failures and fuel line leaks.

Keywords: Ship Management, Maritime Transportation, Risk Analysis, Engine Room Fires, Fine-Kinney.

1. Introduction

Maritime transportation stands out among transportation modes with its economy and efficiency (Efecan & Gürgen, 2019; Usluer et al., 2023) and serves as the primary mode of transporting 80% to 90% of goods traded globally (Brooks & Faust, 2018). Maritime transportation: It is subject to many risky operations, from handling loads to maintenance of machinery and equipment. In Law No. 6331 on Occupational Health and Safety, risk is defined as "the possibility of loss, injury or other harmful consequences arising from a danger". Risk assessment, on the other hand, refers to "the necessary studies to be carried out in order to identify the dangers that exist in the workplace or that may come from outside, to analyze and grade the factors that cause these dangers to turn into risks and the risks arising from dangers and to decide on control measures". Risks may arise from a lack of materials, natural events, or human error. In addition, risks can affect the normal flow of life at unexpected times and in unexpected ways. For example, the Houthi attacks, which started on October 19, 2023, caused a huge loss of 45% to maritime trade in the Red Sea (URL-1). In addition, even the large ships themselves, which are being built as a result of developing technology and increasing population, pose a risk. For example, the ship named Ever Given, which ran aground in the Suez Canal in March 2021, caused the canal to be blocked and maritime trade to stop on this route.

Risk analysis is a subject that is emphasized with importance in our country and intensive research is carried out on it. Huang et al. (2023) emphasized that, according to the criteria determined in the study, Turkey ranked 8th in the world in terms of its contribution to the literature, surpassing countries such as France, the Netherlands, and Spain. Studies included in the literature are of great importance for correctly analyzing risks and taking necessary precautions.

Cargo, ship, and port concepts are the main components of sea transportation. In the absence of one, maritime trade cannot be mentioned. The ship, which is one of the most important of these concepts, is exposed to more risks than others due to its nature. Assessing these risks by the relevant officers, especially the captain and chief engineer, as ship management and taking the necessary precautions is very important for the safe operation of the ships. In this study, existing dangers and risks in the engine rooms of ships were determined by using research in the literature and expert opinions, and a risk assessment was made specific to the accident experienced by a container ship. The main motivation for the study was the absence of a study using the Fine-Kinney method on risk assessment for engine rooms where important fire-causing factors such as flammable materials and high temperatures coexist.

2. Literature Research

Risk analysis covers the process of identifying dangers and evaluating the possibilities and effects of these dangers (Yorulmaz & Sezen, 2023). Marhavilas et al. (2011) examined risk analysis and evaluation methods under 3 main headings: qualitative, quantitative and mixed methods. Qualitative methods are based on analytical estimates and the ability of engineers. In quantitative methods, Risk can be considered as a “quantity” that can be estimated and explained by a mathematical relationship from actual accident data. Hybrid methods, on the other hand, are special methods that can be shaped according to high complexity situations as qualitative, quantitative or semi-quantitative methods.

Olgaç (2021) explained the accident analysis methods that enable finding the causes after maritime accidents with the literature review method. Soares and Teixeria (2001) determined accident categories in their study on accident statistics. In their study, they stated that the most common type of accident between 1983 and 1993 for tankers, bulk carriers, and container ships was fire and explosion. In addition, it was emphasized in the study that the main source of ship accidents is due to the failure of one or more systems that should work, and in the research conducted between 1987 and 1997, approximately 80% of the errors were human-caused. According to the study, sinking, collision, and fire are the most common maritime accidents globally. Yorulmaz and Sezen (2023) conducted a risk analysis within the scope of death, injury, material damage, and environmental pollution risks using the Fine Kinney method for the possible types of dangers on ships (fire, explosion, sinking, grounding, collision, piracy, meteorological conditions, cargo, fault/error of the ship's crew, damages to the ship structure) they obtained by conducting a literature review. As a result of the evaluation, 9 very high, 7 high, 14 important, 7 definite and 3 acceptable risks were determined. In addition, the damages and distortions in the structure of the ship were determined as the highest scoring, and “maritime banditry” was determined as the lowest scoring risky danger. Menteş and Akyıldız (2019) determined the risks that may be encountered in ships with hybrid propulsion systems with large battery systems, and subsequently used the "Brainstorming" method in consultation with experts for SWOT (Strengths, Weaknesses, Opportunities and Threats) analyzes of these risks. By conducting literature research on identifying risks, 26 risks were identified. As a result of the SWOT analysis applied after identifying the risks, the strengths are; reliability, versatility, tested, less maintenance requirement, lower fuel consumption and less noise, and weaknesses are; the need for emission reduction, size problems, weight, operational limitations, standardization problems, and threats are; emission legislation, oil reserves, negative attitudes of local authorities, and opportunity to work with a diesel engine were determined as criteria. Göksu and Arslan (2020) determined the dynamic risks that ships are exposed to during cargo operations and made a risk assessment by consulting expert opinions. As a result of the evaluation, It has been stated that risks increase in average and above fog conditions, winds above 6 Beaufort, current speeds above 1 Knot and tide conditions and that restrictions on operations may be beneficial. Additionally, the study emphasized that the riskiest ship type is tankers. Bayram and Kaya (2022) made a risk assessment for Trabzon port and identified a total of 72 risks, 13 of which cannot be tolerated, 19 of which are fundamental risks and 40 of which are important risks and made recommendations to reduce the risks to an acceptable level. Nas and Zorba (2011) in their study on ship maneuvers in Izmir Alsancak port, determined the risks of contact with the berthed ship and hitting the pier, and in order to evaluate these risks perceptually, they made a potential probability and impact analysis by taking expert opinions from the pilots working in the port, and these analyzes were carried out. Finally, they created a risk matrix. As a result of the study, they recommended that measures be taken such as the supply of tugboats with high maneuverability to the port, meteorological restrictions, and the provision of mooring boat services. Yorulmaz and Yeğin (2023) identified the hazards associated with the handling of dangerous materials in port operations, utilizing both the Fine-Kinney and FMEA methodologies for risk assessment. They posited that the combined application of these two methods, given their distinct advantages, would significantly enhance the effectiveness of risk management strategies in the handling of dangerous goods within port operations. In the study conducted by Okumuş and Barlas (2016), a comparison of the 5x5 analysis matrix and Fine-Kinney methods was made on the risk elements in shipyards, and it was stated that the Fine-Kinney method gave more sensitive results. Usluer et al. (2022) conducted a simulation to analyze the potential impacts that could arise if tanker accidents in the Istanbul Strait were to occur in the Çanakkale Strait, with a particular focus on the Independenta incident in 1979 and the Nassia incident in 1994, and provided recommendations aimed at mitigating the potential effects.

3. Methods

In the study, it was aimed to determine the risks specific to the accident, the details of which will be given in the following sections, and to conduct a risk analysis using the Fine-Kinney method. First of all, the fire incidents that occurred in the engine rooms were examined together with the literature research (URL-2) and the possible fire risks that occurred in the ship's engine rooms were determined by taking expert opinions. In the next step, risk analysis was carried out by Fine-Kinney method by applying to the expert opinion with the most experience among the experts and having the qualification of an ocean-going chief engineer. The Fine-Kinney method provides more sensitive results than other risk analysis methods, thanks to the calculation made with the frequency value. In addition, the method was preferred due to the fact that the necessary prioritizations were made to identify the risks at their source and provide guidance data for the elimination of these risks (Yorulmaz and Sezen, 2023).

The Fine-Kinney method is a quantitative risk analysis method that includes probability, severity and frequency values and determines the risk score by multiplying these values (Fine, 1971; Kinney & Wiruth, 1976). Probability (P), severity (S) and frequency (F) values are shown in Table.1, Table.2 and Table.3, respectively. The risk degree (R) is obtained by multiplying these values and is evaluated within the value range determined in Table 4.

$$R = P \times S \times F$$

Table 1. Probability values

Probability Value	Probability (Likelihood of Realization)
10	Might well be expected
6	Quite possible
3	Unusual but possible
1	Only remotely possible

0,5	Conceivable but very unlikely
0,2	Practically impossible
0,1	Virtually impossible

Source: (Kinney & Wiruth, 1976)

Table 2. Severity values

Value	Severity (Estimated damage it will cause)
100	Catastrophe (many fatalities, or >$\$10^7$ damage)
40	Disaster (few fatalities, or >$\$10^6$ damage)
15	Very serious (fatality, or >$\$10^5$ damage)
7	Serious (serious injury, or $\$10^4$ damage)
3	Important (disability, or $\$10^3$ damage)
1	Noticeable (minor first aid accident, or >$100 damage)

Source: (Kinney & Wiruth, 1976).

Tablo 3. Frequency values

Frequency Value	Frequency (Repeated exposure to danger over time)
10	Continuos (several times an hour)
6	Frequent (daily)
3	Occasional (weekly)
2	Unusual (monthly)
1	Rare (a few per year)
0,5	Very rare (yearly)

Source: (Kinney & Wiruth, 1976).

Table 4. Risk scale of Fine-Kinney method

Risk Value	Risk Assessment
400<R	Very high risk; consider discontinuing operation
200<R<400	High risk: immediate correction required
70<R<200	Substantial risk: correction needed
20<R<70	Possible risk: attention indicated
R<20	Risk; perhaps acceptable

Source: (Kinney & Wiruth, 1976).

4. Application

4.1. Case Study

The explanations related to the case study in this research were presented according to the flow of the incident, based on information obtained from open sources (URL-2). In this study, a fire that occurred on a ship shortly after departing from the Seattle/Washington port at 05:09 on December 8, 2015, was examined. The fire broke out in the auxiliary engine room. The ship in question was a Danish-flagged container ship approximately with a length of 367 meters, a width of 43 meters, and a draft of 15 meters. Information regarding the accident and the related report was accessed through open sources on the internet (URL-2). The fire was quickly extinguished by the ship's fixed fire extinguishing system. As a result of the fire damage, the ship lost its propulsion power and had to return to port with the assistance of tugboats. No environmental damage occurred, and none of the 23 crew members were injured. The damage was estimated to be $380,000. The stages of the accident were explained sequentially.

On November 25, 2015, the ship entered the North American Emission Control Area (ECA) and switched its fuel type from heavy fuel oil to ultra-low sulfur marine gas oil. Immediately after the transition, a fuel leak started in the auxiliary engine. Upon detection of the leak, the ship's third engineer and an oiler replaced the o-rings in the fuel systems of all engines. The third engineer has the necessary qualifications and has previously performed similar tasks. The dates of o-ring replacements for the engines were as follows: November 26, 2015: No. 3

auxiliary engine, December 1, 2015: No. 2 auxiliary engine, December 2, 2015: No. 1 auxiliary engine. After the replacements, the crew tested the system for 10 minutes. However, during the test, fuel flow rates were lower than normal operating conditions.

On December 7, 2015, the ship berthed at the Seattle port. Seven minutes after getting underway to depart for Busan, South Korea, at 05:02 on December 8, 2015, a fire broke out in the No. 1 auxiliary engine, which had been running for three hours. The fire alarm system activated and automatically shut down the engine. As the other auxiliary engine was still operational, there was no power loss on the ship. The fixed fire extinguishing system in the compartment activated automatically and extinguished the fire. Upon activation of the general alarm, two firefighting teams were prepared, and one team entered the fire location at 05:23 and reported the fire extinguished. Subsequently, ventilation of the compartment was conducted, and the ambient temperature was lowered. A malfunction occurred in the generator connected to the engine, affecting the high-voltage electrical system and disabling the AIS system and main propulsion system. The ship's crew failed to repair the main propulsion system, and the ship anchored in the port area at 05:38.

Following the investigation, it was found that the fire stemmed from fuel leakage through a 1.5-inch diameter O-ring dislodged from the fuel line supplying the No. 3 cylinder fuel injection pump on the No. 1 auxiliary engine. As the leaked fuel dispersed in mist form, part of it struck shields, redirecting it towards the leakage tank, while the remainder moved towards the area housing the cylinder heads near the exhaust line. When the leakage tank filled up, an alarm was triggered. It was evaluated that the fire originated from the misted fuel moving towards the exhaust line. The exact start time of the fuel leakage could not be determined, but the leakage tank alarm occurred 13 seconds before the fire alarm.

The researchers noted that the bolts and O-rings in the area where the fuel leakage occurred were found to be in normal condition. Therefore, it was presumed that the cause of the leakage was likely due to the bolts not being adequately tightened. Additionally, it was mentioned that there was no established test procedure required to be implemented after O-ring replacements in the auxiliary engines, identified as a key oversight by the operating company. According to the accident report, it was determined that the probable cause of the fire was an incorrectly installed connector piece on the fuel line supplying the fuel injector pump of the No. 1 auxiliary engine.

4.2. Risk Assessment of Ship Engine Rooms Based on the Case Study

Due to operational systems, high temperatures, flammable and combustible materials, engine rooms are among the places with the highest risk of fire onboard. The hazards and risk factors associated with fires occurring in ship engine rooms were identified through literature review and expert assessments. After identifying the hazard and risk factors, they were evaluated by the expert with the qualifications as an oceangoing chief engineer with longest onboard experience as described in the methodology section. Information about the relevant experts is provided in Table 5.

Table 5. Proficiency of experts.

Education Level	Onboard Experience (Years)	Certificate or Competency
Bachelor's Degree	15	Oceangoing Chief Engineer
Master's Degree	14	Oceangoing Second Engineer
Bachelor's Degree	8	Oceangoing Second Engineer
Master's Degree	7	Oceangoing Chief Engineer

To achieve accurate results in identifying hazards and risks, the opinions of experts with at least the competency of an oceangoing second engineer were consulted. Two of the experts hold the competency of an oceangoing chief engineer, while the other two have the competency of an oceangoing second engineer. One of the oceangoing chief engineers holds a master's degree and has 7 years of onboard experience, while the other holds a Bachelor's degree and has 12 years of onboard experience. Among the experts with the competency of an oceangoing second engineer, one holds a master's degree and has 14 years of onboard experience, while the other holds a Bachelor's degree and has 8 years of onboard experience.

A risk assessment study for ship engine rooms is presented in Table 6.

Table 6. Risk assessment for ship engine rooms using the Fine-Kinney method.

Nu	Hazard	Risk	Probability	Severity	Frequency	Risk Values	Precautions
1	Electrical fire due to electrical faults	Fire, Explosion	3	15	0,5	22,5	All electrical systems should be checked periodically.

2	Bilge vapor presence	Fire, Explosion	6	40	3	720	Fuel oil and lube oil lines should be inspected, leaks should be promptly addressed, and bilges should be kept clean and dry.
3	Excessive ambient temperature rise	Fire, Explosion	10	7	6	420	The cleaning and inspection of engine room coolers should be carried out.
4	Leaks in fuel oil and lubrication oil lines	Fire, Explosion	10	40	3	1200	Fuel oil and lube oil lines should be inspected, and leaks should be propmtly addressed.
5	Low safety awareness among personnel	Fire, Explosion	1	40	1	40	personnel should be informed accordingly.
6	Failure to perform necessary maintenance	Fire, Explosion	1	40	1	40	Planned/unplanned maintenance should be conducted according to system manuals.
7	Leaks in fuel oil and lubrication oil lines in engine	Fire, Explosion	10	40	3	1200	Fuel oil and lube oil lines should be inspected, and leaks should be promptly addressed.
8	Hot work	Fire, Explosion	3	40	1	120	Portable materials should be subjected to hot work outside the engine room. Necessary precautions should be taken before starting any operations in the compartment.
9	Leaks originating from fuel tanks in the engine rooms	Fire, Explosion	0,5	100	0,5	25	The physical condition of the tanks should be checked regularly.
10	Excessive accumulation of soot in exhaust lines	Fire, Explosion	3	40	0,5	60	measures should be implemented to prevent the formation of soot.

5. Discussion and Conclusion

In the risk assessment using the Fine-Kinney method, we found that out of 10 identified risks in the engine rooms, 4 were intolerable, 1 was significant, and 5 were potential risks. The top risks, scoring 1200 each, were " leaks in fuel oil and lubrication oil lines " and " leaks in fuel oil and lubrication oil lines in engine". The main reason for this assessment was the highly flammable nature of fuel and oil vapors, which, when combined with oxygen and heat, greatly increases the risk of fire. A specific incident highlighted a fuel leak due to poor insulation in the fuel circuit as the cause of the fire, consistent with findings from literature review.

Ensuring safety onboard begins with taking necessary precautions before accidents occur. In the case of the fuel leak that led to the fire, it stemmed from a faulty o-ring replaced by the crew days prior. Despite the experienced personnel conducting the replacement, it was noted that pressure tests following the replacement were halted before reaching operational values. Furthermore, the absence of post-maintenance test procedures for the auxiliary machinery fuel system also contributed to creating conditions conducive to the fire.

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