Dangerous Cargo Operation Systematics in Container Terminal Handling Operations and a Study on Turkish Container Terminals*

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Abstract: The capacity for the global transportation of dangerous goods by sea is increasing, primarily driven by economic considerations, but also by factors relating to safety and the high carrying capacity of such vessels. A notable shift in the transportation of dangerous cargo by sea is evident, with container transport emerging as the predominant mode due to its seamless integration with multimodal logistics networks, cost efficiency through reuse, protection against external factors, and mitigation of damage risk. Container transport is regarded as the optimal solution for door-to-door logistics in the supply chain, offering seamless integration with road, rail, and select airlines, with the exception of maritime transport. In the context of transporting dangerous goods, door-to-door transport is particularly favoured due to its ability to effectively control and limit potential hazards associated with the general cargo structure. It is important to note, however, that international regulations pertaining to the transport of dangerous goods are subject to constant change and development, a consequence of the increasing prevalence of such cargoes in maritime transport. Dangerous goods delivered to ports by road or rail under special security measures are subject to the maximum number of container movements with handling operations in special areas under the control of existing legislation. Dangerous cargo containers entering ports are handled in designated areas and subsequently depart by road or rail under stringent security measures.

The present study aims to examine the handling operations and priorities of dangerous cargo containers as assigned to container terminals operating within Turkey. It is observed that, among all container operations, handling operations exhibit the highest number of movements in comparison to other operations. Consequently, during these movements, dangerous cargo containers are exposed to a greater number of risks than other operations. These risks encompass a range of potential hazards, including damage to the containers themselves, accidents due to falling, tipping, damage by handling equipment, and improper loading or discharge of containers. The study examined the literature on international regulations and the handling operation priorities to be implemented in ports. The determined handling operation priorities were determined within the scope of safety management and were recorded with the assistance of questionnaires applied to the terminals. The data obtained from the terminals was then analysed by means of the AHP method, and the priorities were determined according to the order of priority. The findings of this study demonstrate that the handling operations priorities of ports are implemented in a variety of ways and that these priorities vary in accordance with the security management of the handling operations.

Key Words: Marine Transport Engineering, Marine Management, Dangerous Goods, Container Handling Operations.

1. INTRODUCTION

Maritime transport occupies an important place in international transport as it provides safe transport over long distances at sea. Of all the transport models, sea transport comes out on top with features such as low unit transport costs, high speed and the ability to handle large tonnage loads at one time (Arican et al., 2022). In the realm of international supply chain management, Container terminals emerge as pivotal nodes. They facilitate the transfer of cargo via sea, road and rail transport systems. The significance of terminals lies in their operational efficiency, competitiveness and overall effectiveness in supply chain management. The development of container terminals is influenced by technological developments, especially in the field of automation.

The operational characteristics of terminals are shaped by various factors, including efficiency, environmental performance, competition and technological developments. Seven of the world's 10 largest container ports are located in China, and more than 50% of the world's container traffic is handled in Chinese ports (Toygar et al., 2022)

From an operational perspective, the functionality of container terminals is characterised by their capacity to manage substantial volumes of cargo in an efficient manner. The advent of containerisation has precipitated a paradigm shift in port operations, engendering standardised cargo handling processes

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that augment efficiency and curtail turnaround times. From an economic standpoint, container terminals function as pivotal gateways for international trade, exerting a substantial influence on the global economic landscape. As an integral part of the container import and export activities of the countries in which they are located, these terminals have a significant impact on the local and national economies. Xu et al. emphasise that container terminals have evolved from mere cargo handling structures to key components of the global port and shipping supply chain and underline their importance in facilitating trade and economic growth (Xu et al., 2019).

The capacity of container terminals to withstand disruption is a critical component, particularly in the context of global challenges such as the pandemic caused by the Covid-19 virus. This resilience is vital for terminals to adapt to unforeseen adversities and maintain their role as reliable points in the global supply chain. The integration of technology into port operations is a defining feature of modern container terminals (Aronietis et al., 2023).

The general characteristics of dangerous goods encompass a broad spectrum of physical, chemical and biological properties that present significant hazards to human health, property and the environment. The classification of these dangerous goods is imperative for ensuring their safe handling, transport and storage. The United Nations Special Committee on the Transport of Dangerous Goods has established a classification system that categorises these substances into nine distinct classes, encompassing explosives, gases, flammable liquids, flammable solids, oxidising agents, toxic and infectious substances, and radioactive substances (Saffarinia et al., 2021). This classification system is designed to identify the risks associated with each class of dangerous cargo and to provide information on the necessary precautions that should be taken during their transport and storage (Saffarinia et al., 2021). Chemicals are used in all sectors of industry. Most chemicals are transported from one country to another by ship. Most transport is carried out by container ships and chemical tankers (Arican et al., 2020).

The risks associated with the transport of dangerous goods are multifaceted. Accidental leaks during transport can have devastating consequences, including severe injuries, fatalities and extensive environmental damage (Lazić et al., 2022). A substantial volume of documented evidence indicates that a considerable number of accidents occur during the transportation of dangerous goods, with thousands of accidents reported on an annual basis (Shang et al., 2008). For instance, in the United States, a considerable proportion of dangerous goods accidents transpire during transport, underscoring the pressing need for effective risk management strategies (Shen and Wei, 2020).

The risks associated with the handling of dangerous cargoes in ports are a major concern. Research indicates that the nature of the cargoes being transported can vary considerably, resulting in divergent risk profiles depending on the operational context of the terminal and the types of cargo being handled. A comparative assessment of risk assessments for cargo handling at various ports highlights that unique constraints and environmental factors can influence safety outcomes (Zaloom et al., 2020). This underscores the necessity for customised risk management strategies that are tailored to the unique characteristics of each port and the dangerous cargoes it handles.

The intricacies inherent in the management of cargo operations within the confines of a terminal necessitate a multifaceted approach that incorporates a myriad of factors, including but not limited to: risk management, equipment capacity, personnel training, and environmental sustainability. The development of a robust framework for the assessment and improvement of dangerous cargo handling operations is imperative to enhance terminal performance and ensure personnel and environmental safety (Đelović, 2024). This comprehensive approach necessitates a multifaceted evaluation of existing terminal practices, the identification of areas that require enhancement, and the implementation of best practices tailored to the specific risks posed by dangerous cargoes.

The safety assessment of dangerous goods operations at terminals is of the utmost importance. Tseng and Pilcher (2023) emphasise that the ability to detect dangerous cargoes at the initial handling stages is vital to prevent adverse consequences at later stages of other operations. This assertion is further substantiated by Zhao et al. (Zhao et al., 2018), who underscore the imperative for transporting dangerous goods to prioritise safety measures, including the identification of undeclared dangerous cargo, to mitigate the risks associated with air transport. The integration of these safety assessment models is imperative for the effective management of dangerous cargo, as it provides a structured approach to assess risks and implement necessary measures.

2. DANGEROUS GOODS HANDLING OPERATIONS AT CONTAINER TERMİNALS

The management of dangerous cargo at container terminals is of paramount importance 24echnol facilitation of maritime commerce. Stringent security measures and operational protocols are requisite 24echnolo purpose. The escalating 24echno of dangerous cargo being transported through container terminals necessitates the establishment of stringent regulations to mitigate the risks associated with their handling, storage, and transport.

The management of dangerous goods at container terminals poses a multifaceted challenge, intricately entwined with considerations of safety, efficiency, and regulatory compliance. The burgeoning demand 24echnol transportation of dangerous goods necessitates a nuanced understanding of the inherent risks and the implementation of efficacious management strategies.Container terminals function as pivotal nodes within the intermodal transport network, where diverse modes of transportation intersect. This inherent complexity is further compounded by the risks associated with dangerous cargoes, which, if not properly managed, can lead to serious accidents (Tseng and Pilcher, 2023).

In the context of the management of dangeorus cargo, adherence to safety regulations constitutes a paramount concern. Ruscă et al. Underscore the imperative for operations involving containers loaded with dangerous goods to be conducted in accordance with stringent safety protocols, overseen by personnel with specialised training (Ruscă et al., 2019).

In a similar vein, Molero et al. Underscore the significance of conceptualising inland terminals for containers carrying dangerous goods in a manner that enhances safety and operability. This, in turn, contributes to the mitigation of risks associated with terminal congestion and CO2 emissions (Molero et al., 2017).

The application of integrated scheduling optimisation 24echnol management of operations has been demonstrated to have the capacity to engender a substantial enhancement in the efficiency of container terminals. Qian et al. Have demonstrated that the optimisation of the scheduling of handling equipment has the potential to reduce the waiting time of container ships and thus engender an improvement in overall operational efficiency (Qian et al., 2013). This is particularly the case for terminals dealing with dangerous goods, where delays have been shown to engender an increase in the risk of accidents.

As Tseng and Pilcher (2023) have demonstrated, safety assessments are of great importance in identifying and mitigating the risks associated with the handling of dangerous goods. In order to better manage potential risks and ensure compliance with safety regulations, terminal operators must focus on improving detection capabilities. This proactive approach is crucial to prevent accidents and ensure the safe handling of dangerous goods.

In order to ensure the safe handling of dangerous cargoes in port operations, it is vital to implement effective inspection procedures and to ensure regulatory compliance.Haryanto et al. (2020) examined the inspection system of port authorities in Indonesia and found that inadequate facilities and personnel can hinder effective inspection. Their findings highlight the importance of optimising inspection practices to ensure compliance with safety standards and to improve the handling of dangerous cargoes. The enhancement of the regulatory framework and the augmentation of the capabilities of port authorities have the potential to engender safer operations at container terminals.

The integration of decision support systems has the potential to enhance the efficacy of risk management practices in container terminals. A review of various decision support systems designed to assess the risks associated with the transport of dangerous cargoes was conducted by Torretta et al. (2017). These systems have been shown to provide valuable insights into potential hazards and facilitate informed decision-making, ultimately improving safety outcomes. The utilisation of technology and data analytics by terminal operators has been demonstrated to enhance their risk management capabilities and ensure the safe handling of dangerous goods.

The management of dangerous cargo at container terminals is a multifaceted process that encompasses regulatory compliance, technological innovation and operational efficiency.The synthesis of safety protocols, reliability analysis and advanced management techniques is imperative to reduce risks and ensure the safe transport of dangerous cargo. As the demand 24echnol transport of dangerous cargo continues to grow, ongoing research and development in this area will be crucial to improving safety and operational efficiency.

The management of dangerous goods at container terminals necessitates a multifaceted approach encompassing safety assessments, technological

integration, training and effective risk management.The increasing demand 25echnol transportation of dangerous goods necessitates a proactive stance in addressing the associated risks.Stakeholders can significantly enhance security outcomes in container terminal operations by implementing comprehensive security protocols, improving detection capabilities and utilising advanced 25echnologies. The promotion of a safety culture and the efficient handling of dangerous cargoes is dependent on cooperation between various stakeholders, including terminal operators, regulatory authorities and technology providers.

The handling of dangerous cargo containers in terminals is an area of operation which is the subject of the following main headings.

2.1. Operation Planning of Dangerous Goods Containers

Operation planning of dangerous cargo containers is a critical aspect of logistics and transport management, especially given the inherent risks associated with these cargoes.Effective planning requires a thorough understanding of safety protocols, regulatory frameworks and operational strategies across various modes of transport, including air, rail and road.In the context of in-port dangerous cargo handling operation planning, a comprehensive understanding of risk assessment, operational efficiency and safety protocols is crucial. The handling of dangerous cargo, which includes a wide range of chemicals and materials with inherent risks to human health and the environment, poses significant risks.Effective risk management frameworks are essential to mitigate these risks and ensure safe operations in port environments.

In the domain of operation planning for dangerous goods containers, effective management of information pertaining to these cargoes constitutes a primary concern. Zhang et al. underscore the intricacy and expansiveness of the information imperative for the secure transportation of dangerous cargo, accentuating the significance of effective organisation and management of this information to enhance transport safety (Zhang et al., 2019). The creation of knowledge graphs, as discussed in their study, can facilitate a better understanding and management of various types of dangerous cargo, thus improving safety protocols and operational efficiency.As proposed by Wan and Tian, the development of intelligent control platforms for the stowage and segregation of dangerous goods can significantly enhance the operational capabilities of transport companies by ensuring compliance with international regulations and improving the accuracy of the handling of dangerous goods (Wan and Tian, 2023).

The role of port authorities in the supervision of dangerous goods is vital for the effective planning of operations. Research by Haryanto et al. (2020) reveals that the inspection system at ports such as Tanjung Perak in Surabaya is often inadequate due to a lack of adequate facilities and personnel. This inadequacy can lead to deficiencies in safety protocols and an increased risk during the handling of dangerous goods. Consequently, it is imperative for port authorities to enhance their inspection capabilities through the provision of adequate training, the investment in infrastructure, and the adherence to standard operating procedures, in order to ensure the safety of dangerous goods operations.

The implementation of a robust cargo handling plan is vital to ensure the safe and efficient movement of dangerous cargo through ports (Kuznetsov et al., 2021). Effective operations planning includes rational allocation of containers and careful consideration of the stability and safety of vessels during handling operations. Such planning should also take into account potential disruptions, such as environmental factors or equipment failures, which may affect the safety and efficiency of cargo handling operations.

A multifaceted approach is required for the planning of in-terminal dangerous cargo handling operations, which includes conducting comprehensive risk assessments, providing enhanced employee training, integrating advanced technologies, and implementing effective cargo handling plans.By addressing these critical areas, terminal authorities can significantly improve safety outcomes and operational efficiency in the handling of dangerous cargoes.In the context of in-terminal dangerous cargo handling operation planning, a comprehensive understanding of risk assessment, operational efficiency and safety protocols is essential. The handling of dangerous cargoes, which include a wide range of chemicals and materials with hazardous properties, poses significant risks to both human health and the environment.Effective risk management frameworks are essential to mitigate these risks and ensure safe operations in port environments.

2.2. Physical Conditions of Handling Equipment

In the context of in-terminal dangerous cargo container handling, effective management of

equipment and processes is imperative to ensure safety, efficiency and environmental protection (Khan et al., 2021). The operational dynamics of terminals involve a complex interplay of risk assessment, equipment efficiency and regulatory compliance, particularly in the case of dangerous cargoes (Matviienko, 2022). Ports' infrastructure plays a crucial role in the ability to handle dangerous cargoes safely and efficiently (Khan et al., 2021). Ports equipped with modern facilities and advanced cargo handling equipment are better positioned to manage the complexities associated with dangerous goods (Matviienko, 2022). The utilisation of reliable machinery, in conjunction with the implementation of rigorous maintenance protocols, is imperative to ensure the safe handling of dangerous cargo (Khan et al., 2021). Moreover, the design of port facilities must align with the specific requirements of dangerous cargoes, encompassing suitable storage solutions and emergency response capabilities (Matviienko, 2022).

The handling of dangerous cargo necessitates specialised equipment and trained personnel in order to effectively mitigate the risks involved. Holder et al. (2024) discuss the role of reliable energy supplies and appropriate handling equipment in ensuring efficient cargo transfer operations, with a particular focus on dangerous cargoes that may require special handling protocols. The integration of advanced technologies, such as automated systems, is also emphasised as a way to improve safety and operational efficiency in cargo handling (Okere, 2022). Automated systems have been shown to reduce human error, a major contributing factor in accidents involving dangerous goods (Saruchera, 2020). Saruchera (2020) identifies human factors as critical determinants in high-risk cargo logistics.

In the realm of dangerous goods, the efficacy of cargo handling operations stands as paramount. The incorporation of advanced technologies and automated systems has been demonstrated to enhance the velocity and safety of these processes. For instance, the utilisation of automated systems in cargo handling operations has been shown to minimise human errors and augment service quality, thereby facilitating punctual operations (Okere, 2022). The utilisation of contemporary cargo handling equipment, such as automated cranes and forklifts, has been demonstrated to optimise loading and unloading processes, a consideration of particular relevance to the handling of dangerous cargo, where risks are to be minimised (Adekunle and Aworemi, 2023).

A primary concern with regard to dangerous goods containers pertains to the potential for accidents during handling and storage. Research indicates that the inherent characteristics of dangerous goods, when combined with inadequate storage practices, can result in significant incidents, including fires and explosions (Xie et al., 2021;). For instance, Xie et al. (2021) emphasised the significance of evaluating the safety risks associated with the storage of dangerous cargoes in port container yards, noting that inappropriate storage modes and substandard packaging are substantial contributors to accident hazards. Moreover, an examination of past incidents reveals that a considerable proportion of container ship fires are associated with the handling of dangerous cargoes, underscoring the necessity for stringent safety protocols (Krmek et al., 2022).

2.3. Dangerous Cargo Operation Shift Intervals

The handling of dangerous goods in port operations is governed by strict safety regulations and protocols (Tseng and Pilcher, 2023). According to Tseng and Pilcher (2023), the initial identification of dangerous cargoes is crucial to avoid negative consequences later in the operation process (Tseng and Pilcher, 2023). This identification process should be integrated into the operational workflow, including the effective management of shift intervals (Zhao et al., 2018). A well-structured shift schedule facilitates continuous monitoring and assessment of dangerous cargo, ensuring adherence to safety protocols throughout the operation (Tseng and Pilcher, 2023). Additionally, Zhao et al. underscore the imperative of prioritising dangerous cargo operations, emphasising that safety must take precedence, followed by the management of equipment and facilities (Zhao et al., 2018). The idea of leaving a job comes at a time when staff are at their most demotivated and disengaged, which can lead to accidents at work (Arican and Unal, 2023).

The management of shift intervals has been identified as a key factor in operational efficiency in port operations (Gao et al., 2023). Gao et al. emphasise the need for safety design in ro-ro terminal engineering, including considerations for shift management to prevent accidents during the handling of dangerous goods. Optimising shift intervals has been shown to reduce congestion and improve the flow of operations, thus minimising the risks associated with the handling of dangerous cargoes (Gao et al., 2023). Furthermore, the integration of advanced technologies, such as

machine learning and data analytics, has been shown to enhance operational efficiency and safety during shift changes (Romano-Moreno et al., 2022).

The importance of training and awareness among port personnel cannot be overstated. Chen and Yang discussed the application of virtual reality technology in training for dangerous cargo operations, ensuring that employees are prepared to handle dangerous cargoes safely (Chen and Yang, 2022). This training is particularly important when considering shift changes, as it ensures that all personnel are equipped with the necessary knowledge and skills to effectively manage dangerous goods during their shifts. Furthermore, Eski and Tavacıoğlu's research shows that general awareness of dangerous cargo handling among port employees is critical to minimise risks during loading and unloading operations (Eski and Tavacıoğlu, 2021). This awareness should be reinforced during shift transitions to maintain a high level of safety.

The challenges associated with the handling of dangerous cargoes are compounded by the need for effective inspection and enforcement of safety standards. Haryanto et al. analysed the inspection mechanisms used by port authorities in Tanjung Perak, highlighting the importance of rigorous oversight in ensuring that safety protocols are adhered to during loading and unloading operations (Haryanto et al., 2020).

The management of shift intervals in in-terminal dangerous cargo operations is a multi-faceted issue, covering aspects such as safety, training and operational efficiency. The effective management of shifts is imperative to ensure the adherence to safety protocols, the adequate training of personnel and the smooth operation of processes. By prioritising safety and efficiency in the planning of shifts, ports can achieve a substantial reduction in the risks associated with the handling of dangerous cargoes.

2.4. Dangerous Goods Container Damage

Several factors contribute to the integrity and safety of container handling operations with regard to in-terminal damage to dangerous goods containers. In particular, the risk of damage to dangerous cargo containers is increased by operational inefficiencies, environmental conditions and human factors.

The impact of container damage goes beyond immediate safety concerns to include environmental and economic factors. The M/V X-Press Pearl incident is a poignant example, where an on-board fire resulted in the release of dangerous cargo into the sea, causing widespread environmental damage off the coast of Sri Lanka (James et al., 2023). This incident highlights the need for stringent safety measures and effective response strategies to manage the risks associated with dangerous cargo in maritime transport.

The operating environment in ports is inherently risky. Factors such as mishandling by cranes and inadequate maintenance can cause significant damage to containers. A study of container handling at Soekarno-Hatta Port revealed that careless crane operation is the main cause of container damage and lack of maintenance leads to corrosion (Komalasari, 2023). Furthermore, automation of container damage detection has been proposed as a solution to mitigate these risks, using advanced technologies such as deep learning models to improve inspection accuracy and efficiency (Phuong, 2025).

Human error remains a significant contributor to container damage. One study highlighted that mismanagement during cargo handling, particularly when cranes are operated without adequate supervision, causes physical impacts that can lead to container damage (Jakovlev et al., 20-23).

The management of in-terminal damage to dangerous cargo containers in ports requires a multi-faceted approach that includes regulatory compliance, operational best practices and the integration of advanced technologies. By addressing the inherent risks associated with dangerous cargoes, improving staff training and implementing robust monitoring systems, ports can significantly reduce the likelihood of accidents and their associated consequences. Continued research and development in this area will be essential to improve safety practices and ensure the sustainable transport of dangerous goods in the maritime sector.

The interaction of operational handling practices, environmental challenges and human factors has a significant impact on the risk of damage to dangerous goods containers in ports. Addressing these issues through improved technology, training and operational protocols is essential to maintain container integrity and ensure the safe handling of dangerous goods.

2.5. Fumigation Process in Dangerous Cargo Operations

The management of dangerous goods in ports, particularly disinfectants used in containers, requires attention to ensure safety and compliance with health regulations. Disinfectants contain

dangerous cargo that can pose a risk to human health and the environment if not used properly.

Disinfectants commonly used in port operations may contain chemicals such as glutaraldehyde, which has been shown to pose significant health risks to workers exposed during cleaning and disinfection processes (Jara et al., 2013). Exposure to such hazardous exposures can lead to respiratory problems, skin irritation and other occupational health problems (Ilesanmi et al., 2015). In addition, improper disposal of these chemicals can lead to environmental contamination, further increasing public health risks (Carraro et al., 2016). Therefore, it is essential to implement strict protocols for the use and disposal of disinfectants to reduce these risks.

In addition to health risks, the environmental impact of dangerous cargo in disinfectants cannot be ignored. Improper management of these substances can lead to significant ecological damage, as they can leach into soil and water systems (Polorecká et al., 2021). Regulatory frameworks such as the European REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) regulation aim to control the use of hazardous substances and promote safer alternatives (Luechtefeld, 2016). Compliance with such regulations is essential for port authorities and shipping companies to avoid legal repercussions and ensure the safety of their operations.

To eliminate these hazards, it is recommended that ports implement comprehensive training programmes for workers handling disinfectants, emphasising the importance of Personal Protective Equipment (PPE) and safe handling practices (Lee et al., 2023). In addition, regular auditing and evaluation of cleaning protocols can help identify areas for improvement and ensure compliance with safety standards (Lee et al., 2024). The integration of advanced monitoring technologies, such as Raman spectroscopy, can also provide an additional layer of security in port operations by improving real-time detection of dangerous cargo (Cletus et al., 2013).

Disinfection protocols for dangerous goods containers are also important to prevent contamination and ensure public safety. The use of disinfectants such as peracetic acid has been shown to be effective in reducing microbial contamination on surfaces, which is particularly important in the context of cold chain logistics where food safety is a concern (Hu et al., 20-22).

In conclusion, the management of dangerous goods in ports, particularly disinfectants, requires a multi-faceted approach that prioritises worker safety, environmental protection and regulatory compliance. By implementing effective training, monitoring and disposal practices, ports can reduce the risks associated with hazardous substances and promote a safer working environment.

2.6. Weather in Dangerous Cargo Container Operations

Operations involving dangerous goods in port environments are heavily influenced by port weather conditions, which can have a significant impact on safety, efficiency and risk management. The handling of dangerous goods, particularly in container operations, requires a comprehensive understanding of the environmental factors that can increase the risks associated with these dangerous goods. This response summarises various scientific studies to elucidate the interaction between port weather conditions and the operation of dangerous goods containers and highlights the importance of sound safety assessments, risk management strategies and operational protocols.

Port weather conditions have a significant impact on dangerous cargo operations at container terminals. The interaction between extreme weather events and port operations is particularly important when handling dangerous cargoes. Research shows that ports are highly vulnerable to various meteorological events such as storms, floods and extreme winds, which can disrupt operations and pose safety risks (Verschuur et al., 2023). For example, Chhetri et al. have developed a Container Terminal Operations Simulation (CTOS) that highlights how extreme weather events can affect the efficiency of port operations, particularly in the context of handling dangerous goods (Chhetri et al., 2016). This simulation highlights the need for robust risk assessment methodologies to prepare for and mitigate adverse weather conditions.

The handling of hazardous cargoes in ports requires stringent safety measures, especially in adverse weather conditions. Tseng and Pilcher stress the importance of port operators' detection capabilities and safety training to minimise the risks associated with hazardous cargoes (Tseng and Pilcher, 2023). Their study shows that regular review of safety certificates and contingency plans is essential to prevent accidents, especially during extreme weather events. This is in line with Saruchera's findings that both natural and man-made disruptions can significantly affect the logistics of high-risk cargoes and require comprehensive risk management strategies (Saruchera, 2020).

Weather conditions such as high winds, heavy rainfall and extreme temperatures can have a direct impact on the stability and safety of containers carrying hazardous cargo. Gkonis and Psaraftis analyse the interdependent safety issues created by container transport and emphasise that adverse weather conditions can affect safety investments and operational decisions at ports (Gkonis and Psaraftis, 2010). This interdependence suggests that port authorities should consider weather forecasts and historical weather data when planning operations involving dangerous goods. In addition, the simulation analysis conducted by Qiao et al. provides insights into the types of accidents that can occur at container terminals, especially under changing weather conditions, which can inform risk management strategies (Qiao et al., 2020).

In addition to the direct effects of weather, the human factor also plays an important role in the safe transport of dangerous goods in adverse weather conditions. Bęczkowska and Grabarek discuss how human error, exacerbated by harsh weather conditions, can lead to accidents in the transport of dangerous goods (Bęczkowska and Grabarek, 2021). This highlights the importance of training and preparing port personnel to identify and respond effectively to weather-related risks. Incorporating weather risk assessments into training programmes can increase the situational awareness of personnel, enabling them to make informed decisions during operations involving dangerous goods.

Furthermore, the impact of climate change and extreme weather events on port operations cannot be ignored. The increasing frequency of severe weather events requires a re-evaluation of existing safety protocols and risk management frameworks. The design of port facilities must adapt to these changing conditions to ensure the safe handling of dangerous goods, as highlighted by Gao et al. (Gao et al., 2023). This includes implementing robust contingency strategies that are sensitive to weather forecasts and potential environmental impacts.

Consequently, the safe handling of dangerous goods in port operations is closely linked to port weather conditions. Mitigating the risks associated with the transport of dangerous goods requires a multi-pronged approach that includes safety assessments, technological advances and regulatory compliance. As the frequency and intensity of extreme weather events continue to increase, port authorities should prioritise the integration of weather risk assessments into their operational protocols to ensure the safety and efficiency of dangerous cargo container operations.

3. LITERATURE

In the study by Zhang et al. (2019), the construction of knowledge graphs for maritime dangerous goods is introduced. The methodology employed is termed the Knowledge Analysis of Maritime Dangerous Goods Based on Multi-Granularity, and this divides the information into two categories. The knowledge structure of MDG is created with three layers.

In their study Designing the layout of terminals with dangerous goods for safer and more secure ports and hinterlands, Hervás-Peralta et al. (2020) evaluated layouts associated with straddle carriers, forklifts, stackers, platforms and gantry cranes with a group of ten experts, using the Delphi method and the Analytic Hierarchy Process (AHP) method.

Khan et al, (2021), in their study titled analysing human factor involvement in sustainable hazardous cargo port operations, investigated the multifaceted role of human factor in hazardous cargo accidents occurring in ports. A Bayesian network (BN) was created for inference based on past accident reports from 1960 to 2018.

In their research on safety risk, prevention and control in port dangerous goods container yards, Xie et al. (2021) undertook a comprehensive analysis of storage, safety risks and risk factors of dangerous goods container yards in ports, accident hazards and impact scope. These were evaluated through simulation calculations.

In this 2022 study, Okere examined the relationship between cargo handling equipment and port performance in Nigeria. To do so, he employed the cross-sectional survey method.

Tseng and Pilcher (2023) developed a safety assessment model for handling dangerous goods in port operations, utilising a Fuzzy Analytical Hierarchy Process (FAHP) approach based on a literature review to prevent potential risks and reduce losses.

In their 2024 study, Khan et al. (2024) utilised a risk analysis approach incorporating Conditional Probability Tables (CPTs) and Bayesian Networks (BNs) to assess the risk posed by seaport infrastructure during hazardous cargo operations. This analysis enabled the identification of the comprehensive risk factors and their interconnections, thereby providing a comprehensive understanding of the complex effects associated with these operations.

In the study by Ma et al, (2024), a novel risk analysis method for hazardous cargo operations at port was proposed. This method integrates the HFLC model and DEMATEL method. It is based on hazardous cargo accident analyses and previous literature. The DEMATEL method for hazardous cargo operations was extended to the HFLC environment. The degree of centrality and causality of different risk factors in the HFLC form were calculated.

Unal, (2024). Dangerous cargo operations systematics in container terminal gate operations and a study on turkish container terminals. in his study, the operations of dangerous cargoes at the entrances to container terminals were evaluated by Analytical Hierarchy Process (AHP).

As demonstrated in the preceding research, a general and comprehensive body of studies has been conducted on dangerous cargoes. These studies have identified the risks and security management of dangerous cargoes in ports and terminals as a primary focus. The present study aims to investigate the priorities of ports according to six criteria determined in the handling operations of dangerous cargo containers in ports.

4. METHOD

In this study, international legal regulations were analysed and the six handling operation priorities determined were disseminated to 20 container terminals operating in Turkey and participating in the study through a questionnaire. The terminals were asked to evaluate them. The data obtained from the terminals was analysed by using the AHP research method.

The Analytic Hierarchy Process (AHP), first introduced by Thomas L. Saaty in 1980, has emerged as a widely used ethod for Multi-Criteria Decision Making (MCDM). AHP allows decision makers to structure complex problems in a hierarchical manner, facilitating analysis by decomposing a problem into its constituent parts, thus enabling more informed decision making (Sipahi and Timor, 2010). As posited by Ho and Ma (2018), each decision contains a series of criteria and sub-criteria that can be evaluated using pairwise comparisons. This systematic approach serves to simplify complex decisions and reduce cognitive overload for decision makers by decomposing the problem into manageable components (Ho and Ma, 2018).

A critical facet of the AHP methodology pertains to its capacity to address the inherent inconsistencies in human judgment. The AHP approach encompasses not only the measurement of preferences but also the assessment of consistency amongst preferences, thereby facilitating the reduction of bias in the decision-making process (Dey & Ramcharan, 2008). The mathematical properties of AHP render it a reliable tool, with important implications for areas such as financial evaluations and project evaluations where multifaceted considerations need to be analysed comprehensively (Daoutis et al., 2023).

A review of the extant literature indicates that the AHP has evolved into more sophisticated models, such as the Analytic Network Process (ANP), which extends its applicability by introducing interdependencies between criteria (Liu et al., 2014). This evolution demonstrates the adaptability of the method and its ongoing suitability to assist in complex decision-making situations.

The following briefly summarises the steps to be followed in this process.

The steps to be followed in this process are given below:

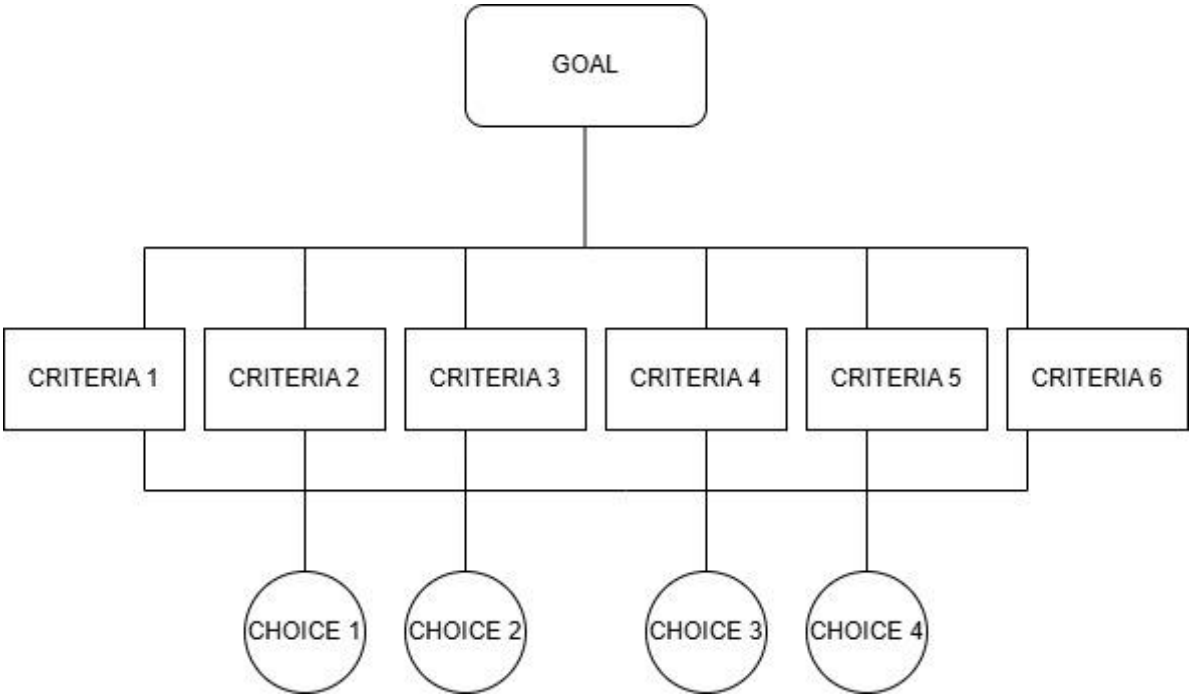
Step 1 Make a list of objectives,

Step 2. List the criteria for the realisation of the objectives,

Step 3 Determination of (n) possible decision alternatives for each criterion,

Step 4 Determination of the Hierarchical Model.

Figure 1: Analatic Hierarchy Process



The initial step in AHP is the establishment of the hierarchical structure, following which the subsequent stages are to be implemented:

- The creation of a 'Comparison Matrix' to facilitate the execution of AHP operations,

- The conversion of the matrix into a 'Priority Vector', and

- The calculation of the 'Concordance Ratio'.

The utilisation of relative or absolute measurements is imperative for the attainment of pairwise comparisons in AHP. According to the information obtained in this way, judgements in AHP should be transformed into a 'Comparison Matrix' (Timor, 2011).

Aij represent the pairwise comparison value between the i-th feature and the j-th feature, and aji represent the pairwise comparison value between the j-th feature and the j-th feature. According to the non-reciprocal property;

aji - 1 / aij.

The general form of the pairwise comparison matrix is given below.

$$A=\begin{bmatrix} a11 & an \\ an1 & ann \end{bmatrix}=\begin{bmatrix} 1/a12 & a2n \\ 1/an1 & ann \end{bmatrix}$$

The prior W (eigenvalue vector) is obtained from the pairwise comparison matrix. It is denoted by W = (w1, w2, …, wn), and Wi is defined as the priority (eigenvalue). The basic properties of the pairwise comparison matrix are as follows:

Basic properties of the pairwise comparison matrix:

1. A pairwise comparison matrix is a square matrix of positive values,

2. If the pairwise comparison matrix is fully consistent, the following threshold is satisfied:

$$\sum_{1}^{n}=1\ \sum_{j}^{n}=1\ \sum_{i}^{n}=1$$

aij.ajk =aik (i, j, k = 1, …,n)

$$|aij|.|ajk| = (wi/wj).(wj.wk) = (wi/wk) = aik$$

3. If matrix A is fully consistent, all other elements of the matrix can be easily obtained from any row,
4. It is equal to a 2-way combination of n, the total number of comparisons to be made,
5. The eigenvector matrix corresponding to the largest eigenvalue of this matrix is called the weight (priorities vector) in AHP,
5. The diagonal values of matrix A are equal to 1 (Saaty, 2000).

After the creation of the hierarchical structure, the following steps are applied respectively when solving problems with AHP:

Step 1. In order to perform the operations in AHP, a 'Comparison Matrix' must first be created.

Step 2. This matrix is then transformed into a 'Priority Vector'.

Step 3. The 'Concordance Ratio' is calculated (Saaty and Vargas, 1987).

The Consistency Ratio, which is indicative of the consistency between comparisons, should be calculated as follows. A Consistency Ratio of less than 0.1 is considered to be favourable. If the ratio is greater than 0.1, a reassessment is required.
Steps to be followed in the calculation of the Compliance Ratio:
Step 1. For each row of the Comparison Matrix, the sum of the weights of the elements in the columns is calculated.
Step 2. The Normalised Matrix is calculated by dividing the element in each column of the Comparison Matrix by the total column weight.
Step 3. The Priority Vector is calculated by averaging each row of the Normalised Matrix.
Step 4. After the Priorities Vector is calculated, the vector obtained is multiplied by the Comparison Matrix given at the beginning, and the All Priorities Matrix, which takes into account the Comparison Matrix, is created.
Step 5. Consistency index is calculated using the following formula:
CI= (λmaks – n) / (n – 1)
The following formulations are used to calculate the Consistency Ratio (CR):
CR = CI / RI
The maximum value between the eigenvalues of a square matrix is expressed by λmax. (To calculate λmax, each element of the All Priorities Matrix is divided by the elements of the Priorities Vector and the new matrix elements are averaged).
RI represents the Random Value Index, and is employed in the processes by selecting the appropriate value from the provided table (Timor, 2011).

The questionnaires returned from the terminals were evaluated in the package programme named Superdecision, and the analysis results were obtained. The results obtained are tabulated and presented in detail. The average weights of the priorities given by the terminals to the handling operations are also presented graphically.

The Analytic Hierarchy Process (AHP) has been identified as a critical methodology in the context of decision-making frameworks, which provide structured, consistent and comprehensive assessments of complex problems in the evaluation of ports in logistics. The AHP has been shown to effectively strengthen applications in a wide range of fields, including project management and environmental planning.The AHP continues to be an important tool in the field of multi-criteria decision making, providing a structured approach to complex problems in various fields. Its ability to integrate subjective judgements with systematic analysis renders it invaluable for decision makers confronted with complex scenarios.The feedback from the ports was analysed using the superdecision software package, and the results obtained are tabulated and presented in the findings section. The average weights of the priorities given by the ports to the handling operations are also given in a practical way.

5. RESULTS

Dangerous cargo containers are a distinct category of cargo, necessitating specialised handling procedures at terminals. These containers are subject to meticulous operations, including the transfer of cargo between the ship and the dock. During such operations, meticulous attention must be accorded to averting accidents, particularly during transfers between carrier equipment, the dock, and the ship, as well as transfers to and from the ship. The inherent risks associated with the handling of dangerous cargoes, such as potential damage due to the nature of movement and the inadequacy of handling equipment, render handling operations a priority. International legal regulations have been reviewed, and the order of priorities in handling operations in container ports has been outlined in Figure 2 below.

Figure 1: Priority Ranking in Dangerous Goods Container Handling Operations

In the context of handling operations, the primary objective is to ascertain the quantity of containers to be operated, the number of pieces of equipment to be utilised, the number of personnel to be deployed in the field, the hazard classes of the containers, and the categorisation of containers

according to load class, ranging from the most to the least hazardous.It is imperative to minimise the number of personnel operating within the designated area. The movement of equipment must be strictly regulated, and stringent measures must be implemented to ensure that unauthorised individuals do not access the site during operations. Furthermore, emergency response equipment should be prepared for any possible accidents.

The second priority pertains to the physical integrity of the handling equipment, which must be maintained in a state of readiness and undergo scheduled and regular maintenance. The number of pieces of equipment must be adequate to facilitate the operation of containers within the designated field, while also ensuring sufficient carrying capacity.Operators of the equipment must be certified personnel who have undergone training in the handling of dangerous goods. The equipment must be free from exhaust outlets that could potentially emit uncontrolled heat. In the event of an accident, it is imperative that the equipment is isolated from dangerous cargoes and securely stored. Furthermore, it is crucial that handling equipment is removed from the site in the event of malfunction and replaced with new equipment.

The third priority is the prevention of damage to dangerous cargoes.Containers may be damaged during other operations in the port, and if such damage is observed during a handling operation, the operation must be stopped immediately and the container secured.The container must be isolated and monitored for the risk of fire and spread.If solid cargoes can be transferred to another container, they should be transferred and the available quantity should be reduced. For liquid cargoes, protection pools should be used to secure them.Gaseous cargoes should be left in an open environment and personnel should be provided with a respirator to avoid exposure to the hazardous atmosphere. Damaged containers should be isolated from other containers under the supervision of specialists.

The fourth place in terms of priorities is the weather in dangerous cargo operations. Weather is a factor that is completely out of control and it both affects the structure of the cargoes and causes them to pose a danger and causes accidents to the equipment and personnel during the operations. In extreme heat, the risk arises when the temperature of the cargoes themselves rises, while snow and heavy rainfall can activate the cargoes by leaking inside the packaging of the cargoes. Moisture affects the inner parts of the packages and excessive sweating causes the loads to get wet. It is important to take necessary precautions for the safety of both cargoes and operations when the weather is at extreme levels.

In the hierarchy of maritime priorities, the management of dangerous cargo operations is considered the fifth most pressing concern. The necessity for continuous operational capacity has led to the prevalence of night shifts in container ports, where personnel are exposed to heightened risk of accidents during nocturnal hours. The deployment of specialised and trained personnel in dangerous cargo operations is paramount to ensure operational safety. These personnel must be consistently present at the forefront of these operations. Furthermore, personnel should be cognisant of the risks involved in dangerous cargo operations and be able to work with a high level of awareness. Night-time dangerous cargo operations pose a heightened risk due to the reduced capacity for concentration and risk perception that is characteristic of nocturnal conditions.

In terms of priorities, fumigation operations in dangerous cargo operations are of least importance. The process of applying poisonous gas in container operations to protect the cargo from all kinds of rodents and other harmful organisms is known as a disinfectant operation, or fumigation, in the context of ports.Disinfectant operations should be carried out by personnel who have been trained in its implementation, and should be marked with warning signs. During the handling of containers that have undergone disinfectant treatment, personnel should exercise caution and utilise respiratory protective equipment if necessary to combat the effects of any toxic gas emanating from the container. In the event of an accident during container handling operations, the release of toxic gas from the container may have a detrimental effect on nearby personnel and can spread into the atmosphere. It is therefore imperative that such containers are handled in open areas rather than in enclosed spaces and that the necessary safety precautions are taken.

Questionnaires were administered to the terminals in order to ascertain the criteria for dangerous cargo handling operations that had been prioritised above. The responses of the 20 most effective terminals in Turkey were analysed using a program called Superdecision programme.

The data obtained from the analysis of the responses provided by the terminals in the Superdecision software are presented in table 1 below. This table illustrates the distribution of the order of importance assigned by each terminal to the criteria for handling operations. It should be

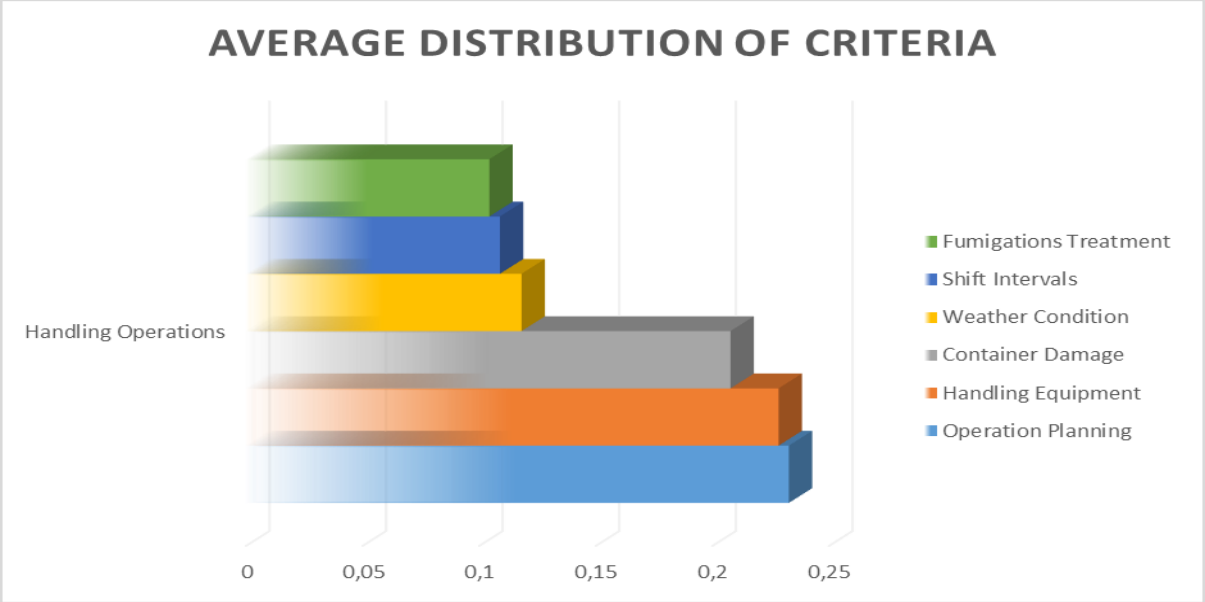
noted that the names of the terminals have been coded for confidentiality purposes and will not be disclosed.

Table 1: Distribution of Container Terminal Handling Operation Criteria

Terminal	Operation Planning	Handling Equipment	Container Damage	Weather Condition	Shift Intervals	Fumigations Treatment
Ter. A	0,09355	0,43650	0,30452	0,04672	0,03262	0,08609
Ter. B	0,19966	0,41258	0,17116	0,06326	0,05197	0,10137
Ter. C	0,51299	0,27562	0,05737	0,01980	0,11062	0,02360
Ter. D	0,17664	0,21129	0,33555	0,04030	0,21867	0,01755
Ter. E	0,22599	0,17805	0,36663	0,03129	0,05818	0,13986
Ter. F	0,30563	0,21961	0,23827	0,15845	0,05687	0,02117
Ter. G	0,29137	0,29343	0,04594	0,03961	0,29988	0,02977
Ter. H	0,12644	0,13874	0,06992	0,47412	0,13874	0,05204
Ter. I	0,03841	0,12039	0,34328	0,19302	0,07515	0,22975
Ter. K	0,22821	0,10625	0,19383	0,16637	0,10623	0,19911
Ter. L	0,08120	0,08497	0,14243	0,16868	0,07394	0,44878
Ter. M	0,16667	0,16667	0,16667	0,16667	0,16667	0,16667
Ter. N	0,25095	0,15345	0,08038	0,32942	0,13452	0,05128
Ter. O	0,25010	0,10373	0,56156	0,02321	0,01892	0,04248
Ter. P	0,02680	0,43515	0,12520	0,19195	0,04691	0,17399
Ter. R	0,50795	0,05594	0,19046	0,06056	0,05594	0,12915
Ter. S	0,52983	0,25484	0,03818	0,08230	0,06676	0,02809
Ter. T	0,11405	0,46894	0,14456	0,01428	0,22725	0,03092
Ter. U	0,36801	0,28194	0,10911	0,0503	0,14034	0,05030
Ter. Z	0,16056	0,16882	0,46886	0,04158	0,09653	0,06363

As demonstrated in the above table, terminals assign varying degrees of priority to different criteria. It is evident that the operation planning priority is accorded the highest priority by the terminals. This prioritisation underscores the pivotal role and criticality of planning in operational contexts. The mean values of the criteria priorities obtained from the data collected from 20 terminals across Turkey are presented in Figure 3 below.

Figure 3: Distributions of Handling Operation Criteria in Terminal Preferences.



As demonstrated in the graph above, the distribution of terminal priorities has been realised in the order determined. The primary priority is the dangerous cargo operation plan, which ranks first in general priorities. It is evident that terminals have taken this priority into consideration, as evidenced by their approach to safe equipment. The second priority is the condition of handling equipment, indicating a focus on occupational health and safety practices. The necessity for safe equipment in order to facilitate safe operations is also emphasised.Container damage is prioritised thirdly, as would be expected, with any accidents resulting from such damage having the potential to cause serious harm to personnel and equipment, as well as posing a significant fire risk through the possibility of serious spillages.

As anticipated, the fourth priority of the terminals is container operation weather, the monitoring of which is of paramount importance since adverse weather conditions have the potential to compromise the safety of container operations. The condition of the cargoes is also a significant consideration, and as such, must be closely monitored. The terminals prioritise dangerous cargo operation shift interval. It is acknowledged that terminals predominantly operate during daylight hours, recognising the heightened safety risks associated with particularly hazardous cargoes.Nevertheless, shift scheduling emerges as a pivotal consideration in scenarios where cargoes arrive at the port with last-minute permits, necessitating direct loading onto vessels. It is acknowledged that personnel may experience fatigue during such operations, and security measures must be taken seriously until the final minute.The disinfectant process in the container, despite being the least urgent task in container operations, must not be overlooked. It is anticipated that terminals will prioritize this task last, and as anticipated, this has been correctly ordered by the ports. Container disinfection is carried out in limited numbers and is a situation that can be easily controlled with the necessary markings and the intervention of trained personnel with sufficient equipment in case of possible accidents.It is behind other priorities in terms of risk since prior information is provided during the operations.

A thorough examination of the data obtained in the study and the results of the analyses reveals that the terminals adhere to a priority ranking system in accordance with the priorities established. This adherence is further evidenced by the terminals' deliberate prioritisation processes, suggesting a robust security culture and effective security management practices.

6. CONCLUSION

This study analyses the approaches and priorities of Turkish container terminals with regard to hazardous cargo operations. The data obtained from international regulations and questions directed at ports were analysed using the Analytic Hierarchy Process (AHP). The results obtained from

the research indicate that terminals prioritise 'Operation Plans' as the primary strategy for dangerous cargo container handling operations. This prioritisation is hypothesised to be influenced by the terminals' recognition of the significance of safety and operational stability.

Operation plans represent the initial phase in the realm of safe and planned container operations, with terminals determining handling equipment as the secondary priority. The rationale behind this can be ascribed to the cautious approach adopted towards handling equipment due to its substantial cost and the perilous nature of the cargo containers it handles. The findings reveal discrepancies in the priorities assigned by ports to handling operations and the overall assessment. These variations can be ascribed to the divergent safety cultures and management systems prevalent in terminals. The management of dangerous cargo containers in terminal environments necessitates a multifaceted approach encompassing safety, environmental protection and operational efficiency. The implementation of strict security protocols to mitigate the risks associated with dangerous goods requires the integration of effective advanced technologies. Furthermore, the promotion of cooperation between stakeholders in the intermodal transport of dangerous goods is imperative for ensuring safe and efficient movement in port facilities.

The implementation of automated systems to monitor and manage the stowage of dangerous goods has the potential to enhance safety and efficiency in terminal operations (Wan and Tian, 2023). The integration of advanced technologies, such as virtual reality and simulation models, has the potential to further enhance training and preparation for handling dangerous goods in terminal environments. As Chen and Yang (2022) emphasise, virtual reality technology has the potential to train personnel to respond effectively to emergencies when handling hazardous cargo. Similarly, Ruscă et al. (2019) demonstrate how simulation models can provide valuable insights into the dynamics of container terminal operations, enabling better planning and risk management strategies.

In the context of future research endeavours, a novel study could be conducted by undertaking a comparative analysis of the priorities assigned to the handling operations of dangerous goods within Ro-Ro terminals. This analysis would benefit from the incorporation of factors that have the potential to enhance safety management and safety culture, including staff training and simulation training. The development of evidence-based strategies and policies that are designed to further enhance the safety and efficiency of dangerous cargo handling operations is of paramount importance for the safety and development of seaborne trade.

In conclusion, the management of dangerous cargo containers in port environments necessitates a multifaceted approach encompassing safety, environmental protection and operational efficiency. The implementation of strict safety protocols, effective disinfection practices and the integration of advanced technologies are imperative to mitigate the risks associated with dangerous goods. Furthermore, fostering cooperation between stakeholders in the intermodal transport of dangerous goods is paramount to ensure the safe and efficient movement of these materials through terminal facilities.

Note: The plain and summary version of this study was presented as a paper at the IBANESS Economics, Business and Management Sciences Congresses Series-Plovdiv/Bulgaria Congress (15/16 March 2025). Paper title: A Study on Ports' Approaches to Handling Operations of Dangerous Cargo Containers.

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