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A Quantitative Risk Management Methodology: The Case of Offshore LNG Terminals and Marine Ports

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Abstract

In marine and offshore industry although there has been major development towards loss prevention concepts such as internal and external audits, inspections, surveys, upgrades, maintenance, physical and technical modifications, enforcing new regulations *via* united nation's agencies such as IMO and ILO and technical standards *via* classification societies to avoid the potential hazards and risks of damage to assets e.g. fixed offshore structures and environment or harming people etc., but the moves toward managing the hazards and risks in a methodological way which are linked directly to the management and decision making processes have been very slow. Furthermore, in marine and offshore industry most perceptions, frameworks and methodologies of dealing with hazards and risks are for their assessment rather than their management. This trend reveals the fact that in different marine and offshore industry sectors such as logistics, oil and gas there is a lack of coherent Quantitative Risk Management (QRM) methodology from which to understand the risk-based decisions especially for the purpose of appropriate risk management e.g. offshore terminals and marine ports. Therefore, in this paper initially, Fuzzy Set Theory was applied to deal with vagueness of the uncertain risk-based data. In the next stage Fuzzy Fault Tree and Fuzzy Event Tree methods were used to achieve the sequence of quantitative risk analysis. In the final step a Fuzzy TOPSIS model was used for implementation of the mitigation phase. Finally, the practicability of the addressed QRM methodology under Fuzzy Environment was verified with the use of a suitable case study.

Keywords: Quantitative risk management; Offshore LNG terminal and marine port; Decision making; Fuzzy fault tree analysis; Fuzzy event tree analysis; Fuzzy TOPSIS method

Introduction

Marine and offshore industry strategically plays a great role in energy market. The upstream sector of the global oil and gas industry represents one of the world's greatest concentrations of risk, both in terms of a single risk devastating accident (i.e. fire and explosion), such as Piper Alpha in 1998 [1], as well as multiple claims (i.e. fatalities and environmental and properties' damages) from a single source, such as those from the major Gulf of Mexico windstorms in 2005 [2]. The accident in the Gulf of Mexico which was the explosion on 20th April of 2010 on board the Deepwater Horizon, an offshore drilling platform working on a well one mile below the surface of the Gulf of Mexico, has led to a major oil spill [3].

From midstream sector of the energy industry also as an example it can be referred to the oil Tanker Sanchi collision accident case in 6th January of 2018, as the addressed vessel was carrying natural gas concentrate cargo of 136,000 metric tons, caught fire immediately after the collision with other bulk carrier vessel and following continuous burning, multiple explosions and drifting for eight days, it was sank at the end due to structural failure [4]. This accident also caused multiple claims (i.e. multiple deaths, actual total loss of the ship and its cargo, environmental damage, salvage, damage to other ship, wreckage, and third-party liabilities etc.) from its single source of collision. These losses, as well as the other accidents that have occurred through the years, demonstrate the need for formal and intelligent professionals (e.g. inspectors, safety engineers and risk managers) handlers specializing in marine and offshore industry. These individuals must possess a combination of commercial and technical skills and decision-making tools and methodologies integrated to their computer programs to meet the challenges posed by catastrophic losses and, perhaps more importantly, during the periods following major events [3].

Literature Review

Based on the available literatures from Sharp [3]; Mokhtari [5] and Claude et al. [6] the marine and offshore industry is huge, complex surroundings that extent several different processes and professions. Because it is so complicated and covers so much of areas, therefore it can be divided into three separate oil and gas industry related sections based on the steps from offshore drilling to production and ultimately shipping of the refined products to the end user at final destinations. These three distinct subdivisions are as follows:

- The marine and offshore related upstream can be broken into many components, but the main ones are offshore exploration and searching out and selecting potential oil and gas sites (i.e. seismic) at sea, evaluation of these sites, offshore drilling exploratory wells, and operating these offshore wells to extract crude oil and natural gas.
- The marine and offshore related midstream industry involves the transportation through ships and storage of oil and gas in marine ports and offshore floating units such as Floating, Production, Storage, Offloading (FPSO) units and offshore structures. Midstream takes the oil and gas recovered in the upstream sector and gets it to the downstream processing

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facilities so that it can be turned into the various finished products in consumers' daily lives. There are quite a few logistical pathways that the midstream sector may follow, including gathering and processing (e.g. through FPSO units), logistics, pipelines, compressor stations, trucking, barges and rail in petrochemical seaports and terminals.

- The marine and offshore related downstream sector provides the closest connection to everyday consumers. In the downstream sector, crude oil or natural gas can arrives at processing plants (i.e. normally in petrochemical seaports) where it is refined and eventually turned into various products which will then be sold and distributed, including: Gasoline, Diesel Fuel, Jet Fuel, Asphalt, Fertilizers, Liquefied Natural Gas (LNG), and Liquefied Petroleum Gas (LPG) among others.

Marine and offshore related energy insurance coverage is generally arranged on a "package" basis by specialist insurance brokers for upstream, midstream, and downstream exposures, with the latter sector dominating business interruption. These insurance packages typically include covers for offshore property, business interruption, offshore well control/re-drilling, and some include third-party liabilities in marine and offshore activities related areas, including marine pollution clean-up etc.[6].

In addition, according to the physical borders existing in marine and offshore industry, these areas can be extended from inland terminals or dry ports inside coastal or land locked states up to the other locations beyond the oceans. Figure 1 simply illustrates these boundaries. In this regard also see the author's previous works such as Mokhtari [5].

It must be taken into consideration that in insurance market in respect of marine and offshore industry there are other types of insurance buyers that will not fall under oil and gas sectors or be limited to energy industry as discussed earlier. There are lots of insurance products as per ICS [7] that still will be related for example to operations and managements of marine ports and offshore terminals. There are insurable cargoes such as dry bulk cargoes (i.e. Grain, Iron Ore and Coal etc.); general break bulk cargoes; bagged cargoes; pallets; drums; liquid cargoes such as vegetable oils; containers; International Maritime Dangerous Goods (IMDG) cargoes; finished products such as metals, refrigerated goods; cars and semi manufactured goods etc. As it can be noted many of them naturally are hazardous and dangerous cargoes such as coal and Sulphur as there is a risk of spontaneous combustion. For others there are risks associated with their carriage such as danger of their shifting during their transit at sea specially in bad weather; danger of cargo damages due to ingress of sea water into cargo holds due to any reason; danger of ice formation on board ships and/or ships entering into ice regions at sea in upper latitudes; danger of cargo sweets during transits of cargoes; damaging of cargoes during their loading and/or discharging while ships are berthed alongside commercial sea ports. As is shown in Figure 1 these cargoes can be transported using shipping industry and/or using multimodal transports systems which will be fallen under logistics industry in different locations of the world. Therefore, subject of insurance and risk management in marine and offshore industry covers huge geographical, technical and commercial areas and are not only limited to a single industry users and clients.

Moreover, based on various sources (IMO [8]; ABS [9]; OCIMF [10]; Maclachlan [11]) and there are literatures in marine and offshore industry which mainly relates to the legislation and safety Acts such as Mineral Working Act (MWA) 1971, Health and Safety at Work Act

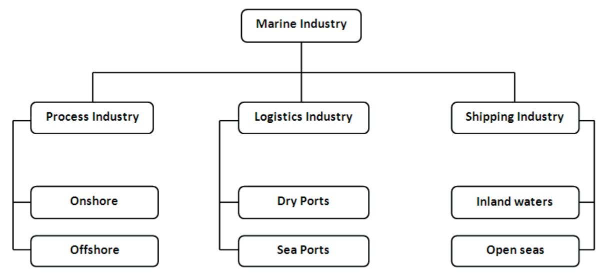

Figure 1: Segments associated with operations and managements of offshore terminals and marine ports (Source: Mokhtari).

(HSWA) 1974, Statutory Instrument (SI) Number 289 in 1974 in the UK. All of them have discussed comprehensively about the issues such as safety cases and safety reports; Safety Management System (SMS); Formal Safety Assessment (FSA); Health, Safety and Environment (HSE); ISPS Code; safety case regulations; Quantitative Risk Assessment (QRA); the concept of As Low As Reasonably Practicable (ALARP) in judging the level of acceptable of the risk. Moreover, in onshore process sectors, risk-based process activities and safety aspects are discussed mainly under integrity management, safety and reliability management or engineering [12]. None of them have described at a holistic level a generic or even specific QRM methodology or framework which consequently could encompass all the above-mentioned issues. Conversely phrases such as hazards, safety, security, reliability, disaster, emergency, and crisis can all be categorized under the phrase of "risk" itself and even phrases such as quantitative risk assessment, quantitative risk evaluation, quantitative risk analysis, quantitative risk mitigation, also can be considered as subcategories for the phrase of "management". Therefore, using a phrase of "QRM" alone can justify these scattered impressions.

In the shipping, logistics and process industries and based on the available literatures from several sources such as ICS [7] and IMO [8], rules and regulations or safety and security issues have been discussed in detail. Among them there are topics such as marine insurance, including Hull and Machinery (H and M), Protection and Indemnity (P and I), Freight Demurrage and Defense (FD and D), War risk and Strike insurances; Construction All Risk (CAR) related to Offshore Installations and Structures Insurances; International Labour Organization (ILO) and International Maritime Organizations (IMO); Conventions e.g. SOLAS 1974 and MARPOL 73/78; ISM and ISPS Codes; Collision avoidance regulations i.e. COLERG and International Maritime Dangerous Goods (IMDG) Code. They mostly emphasize on quality, health, safety, environmental and security protection issues. Some of them, such as COLERG, are designed for the purpose of preventing a risk of collision. Based on Trenerry [13] insurance covers are being used for risk transferring purposes of the pure risks (i.e. uncertainty of damage to property by fire, flood or the prospect of premature death caused by accidents) rather than the speculative risks (i.e. risks which are linked directly to the business function, decision making processes and management). In fact, there is still a lack of development and integration of the QRM perception within the above-mentioned areas particularly in insurance sector. Ultimately in terms of legislation in practice, the marine and offshore industry has suffered a lot and in the past produced disorderly, conflicting regulations, mainly in response to disasters involving considerable loss of life, culminating in the destruction of the Piper Alpha installation in the UK waters in 1988. Based on Sharp [3] the Piper Alpha tragedy proved to be the catalyst for a radical change in the way the industry was both certified and regulated. Lack of compliance with safety practice and mistakes in proper inspections have been found as main root causes for this case and for the case of Deepwater Horizon accident in the Gulf of Mexico. Still no one has argued for lack of complying with a generic or any specific QRM methodology.

A Proposed QRM Methodology

This part demonstrates the key features of the methodological approach aimed at a consistent quantitative risk management; the process and functional analysis of offshore terminals and marine ports and the valuation of risk management system. Figure 1, after identification of the risk factors (i.e. hazards) illustrates the quantitative assessment and mitigation schemes in the risk management process, which are briefly described later in this paper. The main aim of the QRM methodology is to detect, quantify and manage the potential risk factors in all processes and operations that compose the core business of the system under analysis [14]. Among the available techniques for QRM methodologies Fuzzy Set Theory (FST); Analytic Hierarchy Process (AHP); bow-tie method; Fault Tree Analysis (FTA); Event Tree Analysis (ETA) and TOPSIS (i.e. Technique for Order of Preference by Similarity to Ideal Solution) method are used under fuzzy environment in this paper to model the addressed QRM methodology in Figure 2 for the purpose of offshore terminals and marine ports.

Therefore, as is shown in Figure 2 after detecting the potential risk factors in marine ports and offshore terminals through carrying out an intensive literature review with the aim of hazard identification, then these identified risk factors will be assessed and ranked *via* using FAHP method. The required risk-based data with having qualitative and quantitative natures will be gathered and combined through expert judgements' and AHP method to produce quantitative data at the end. In order to deal with the vagueness of the data they will be treated under fuzzy environment using FST. Once the identified risk factors are assessed and ranked, each risk factor can be dealt with independently regardless of their global risk-based calculated weights (Table 1). In this situation it depends to the decision makers, risk managers, safety engineer and claim handlers in the addressed industry when to deal

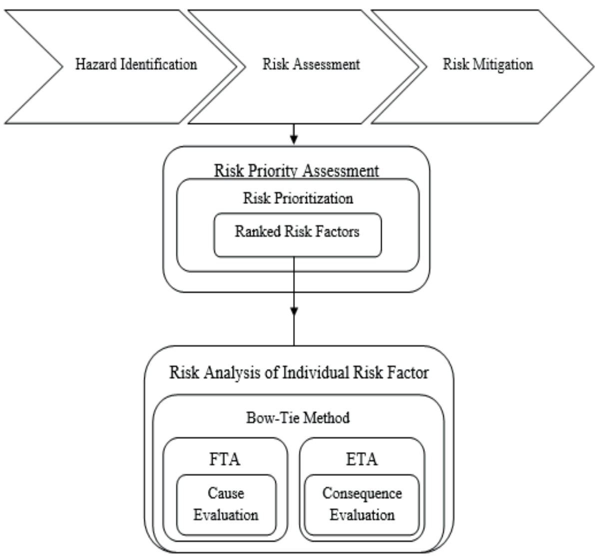

Figure 2: Proposed QRM methodology in marine and offshore industry under fuzzy environment.

and/or to choose and take which one of the risk factor(s) into their considerations first. Ideally it is expected to choose the most significant risk factor first into their account in order to take care of it more rapidly to mitigate it. Therefore, as it can be seen from Figure 2 in order to analysis each one of the selected risk factors in a quantitative manner bow-tie method will be used to investigate the potential causes and consequences of the addressed selected risk factor(s) again under fuzzy environment. In this part FTA will quantify the potential basic events initiating and releasing the addressed risk factor and subsequently ETA will be used to show and calculate the possible occurrences and outcomes. This offered quantitative risk analysis process for each individual risk factor will ensure that there is an adequate treatment practice and procedure in place for the purpose of implementing and completing the quantitative risk assessment phase. In the last part FTOPSIS method will be used to select the best strategy and/or solution from among of the multiple choices of introduced strategies *via* a quantitative evaluation process to mitigate a previously assessed risk factor in earlier phase to complete the QRM cycle.

As a result, a proposed framework as shown in Figure 2 is used to describe a generic methodology that can develop a QRM capability by enhancing a holistic RM view that can be contributed in different offshore and marine applications. This framework can be used practically by safety engineers for the purpose of further diagnosis or can be used by risk managers during their decision-making processes. In this regard the QRM methodology and framework for the marine and offshore application can be discussed more through the following phases.

Hazard identification phase

Most primarily and first phase in any QRM methodology is hazard identification (World Bank [15]; GAO [16] and Chartres et al. [17]). "*Hazard identification should be approached in a methodical way to ensure that all significant activities within the organization have been identified and all the risk factors flowing from these activities are defined*" [18]. In this respect although in general terms many companies, organizations and government bodies are using the phrase of "risk identification" for the first phase in their QRM procedures but more principally in engineering and industrial sectors such as in offshore structures and marine systems as it is argued by (Paltrinieri et al. [19]; Ren et al. [20]; Pillay and Wang [21]) the phrase of "HAZID" (i.e. Hazard Identification) is used rather than the first one. HAZID is a general term used to express an exercise whose objective is to identify hazards (i.e. risk factors) and the related events that have the potential to result in a significant consequence. For example, a HAZID of an offshore terminal or offshore installation may be conducted to identify potential hazards which could result in consequences to personnel e.g. injuries and fatalities, environmental oil spills and pollution and property damages or lead for example to production losses and delays. The HAZID process can be applied to all or part of a marine port, an offshore terminal, a tanker vessel or it can be implemented to examine operational procedures of organizations. Depending upon the system being evaluated and the resources accessible, the process used to conduct a HAZID can be different [9]. As an example, in sea ports and offshore terminals especially in crude oil, LNG and LPG import and export terminals HAZOP (i.e. Hazard Operability) is the best solution for hazard identification purposes. In this respect HAZOP is a structured way of examining the planned or existing process operation. The main aim of a HAZOP study is to identify problems that may expose hazard to personnel or equipment or prevent efficient operation [22]. Based on Mokhtari [5], literature search is one of the HAZID

Main Risk Factor	Level 1 Risk Factors	Local Weights	Level 2 Risk Factors	Local Weights	Global Weights	Rankings
Operational Risk	Safety Risk Factors	(0.171)	Composition of Calling Fleet	(0.040)	**(0.007)**	21
			Traffic Conditions	(0.340)	**(0.058)**	7
			Weather Conditions	(0.102)	**(0.017)**	19
			Waterway Configuration	(0.398)	**(0.068)**	5
			Potential Consequences of DG Trans.	(0.035)	**(0.006)**	22
			Potential Impacts of not having VTM	(0.085)	**(0.014)**	20
	Security Risk Factors	(0.185)	People's Safety in area	(0.650)	**(0.120)**	**1**
			Port/terminal Asset	(0.251)	**(0.047)**	10
			Port/terminal Profit	(0.099)	**(0.018)**	18
	Pollution Risk Factors	(0.167)	Ship Related Pollutions	(0.505)	**(0.085)**	**3**
			Cargo Related Pollutions	(0.174)	**(0.029)**	13
			Port/terminal Related Pollutions	(0.215)	**(0.036)**	12
			City Related Pollutions	(0.106)	**(0.019)**	17
	Legal Risk Factors	(0.142)	Regulatory Changes	(0.545)	**(0.077)**	4
			Delays in Contracts	(0.465)	**(0.066)**	6
	Human Error Factors	(0.177)	Pilots Related Errors	(0.554)	**(0.098)**	**2**
			Ships Personnel Related Errors	(0.150)	**(0.026)**	15
			Port/terminal Personnel Related Errors	(0.161)	**(0.028)**	14
			Stevedores Related Errors	(0.135)	**(0.024)**	16
	Technical Risk Factors	(0.158)	Lack of Equipment Maintenance	(0.351)	**(0.055)**	9
			Lack of IT Technology	(0.293)	**(0.046)**	11
			Lack of Dredging and Navaids Maint.	(0.356)	**(0.056)**	8

Table 1: Operational risk factors in offshore terminals and marine ports – Global weights and Rankings.

techniques used to express an exercise whose goal is to identify hazards and associated events that have the potential to result in a major effect. As Saunders et al. [23] have explained the benefit of literature search is to save time as the required risk-based data is previously searched and available, and it is less costly than other techniques. It is also likely to be of higher-quality, and the data can be used in conjunction with the other qualitative and quantitative methods, tools and techniques.

Risk assessment phase

The key phase of any QRM methodology or cycle is the quantitative risk assessment phase to assess and analysis the identified hazards or risk factors [24-26]. In this regard ABS [9] explains that the competence to make sensible decisions is crucial to a successful business scheme. Furthermore, in today's complex world, business decisions are rarely straightforward or easy. For this purpose, risk assessment is typically applied as an aid to the decision-making process. There are a variety of qualitative and quantitative risk assessment methods which are used for different situations and in various industries. However before carrying out a quantitative risk assessment phase first there is a need to effectively make a generic model for the purpose of assessing the risk factors (i.e. hazards) identified. In this regard Haimes [27] argues if the adage, "*To manage risk, one must measure it with appropriate metrics*," constitutes the compass for RM, then modelling constitutes the road map that guides the analyst throughout the journey of risk assessment. However quantitative risk assessment in the marine and offshore industry for example in some sectors such as in sea ports and offshore terminals is a new and challenging task as much of the available data is highly uncertain and vague, and many of the mechanisms may not be fully understood. As a result, a methodical approach is needed to handle quantitative and qualitative data when new knowledge and data become available. For this purpose, in order to deal with vague, unavailable and insufficient data; techniques such as FST and AHP method can be used for assessing and prioritization of the identified hazards or risk factors from the previous phase. Furthermore, other risk analysis techniques such as bow-tie method, FTA and ETA can be used for investigating of the potential causes and consequences, as a result of the risk factors identified from first phase of the addressed QRM methodology. Literatures, methodologies, equations and procedures regarding FST, AHP, bow-tie method, FTA and ETA techniques are completely mentioned and can be found from the author's previous works such as Mokhtari et al. [28] which are outside the scope of this paper.

Risk mitigation phase

Risk mitigation is a decision-making process whereby actions are taken in view of the outcomes of risk assessment. Standard risk prevention strategies aim either at reducing the probability of an incident (i.e. pre-accident intervention) or at minimizing the degree of losses if the accident occurs (i.e. post-accident intervention). This process is generally combined with Cost-Benefit Analysis (CBA) for optimal decision-making [29]. Therefore, in order to complete the addressed QRM methodology it is necessary to accomplish it *via* a risk mitigation phase. In this respect for mitigating the identified and assessed risk factors first it is essential to distinguish the different mitigation strategies or sources and then by utilizing an appropriate quantitative and methodical technique to priorities them for their proper application purposes.

For the purpose of this paper in marine and offshore industry there are exist many hazards that all are already identified analyzed and assessed for their associated risks but now they must be properly mitigated *via* using QRM expert method in order to identify the most significant strategies to take care of the risk factors. Therefore, the mitigation phase of a QRM methodology plays a vital role to complete the addressed cycle. There are complementary literatures about risk mitigation [30] and other subcategories of risk mitigation process such as risk avoidance [31], risk reduction [32], risk sharing [33] and risk retention [34] practices that can be referred to.

Ideal strategies for the purpose of risk mitigation: Nevertheless, in order to manage the identified and assessed risk factors it is necessary to classify the most ideal strategies for their mitigation purposes. In this respect the most significant risk mitigation factors for the purpose of offshore terminals and marine seaports are identified as follows:

Privatization and deregulation: To meet challenges of globalization, ports have to increase both capacity and efficiency while reducing costs. Traditionally, ports were not only publicly owned but also politically controlled and regulated. This replaces the possibility of market failure (because the port is a monopoly and not subject to competitive disciplines) with state failure: inefficient ports, choking trade and development. To overcome these sorts of problems there are two possible remedies, deregulation or privatization [35-38]. Deregulation is the reduction of the role of the government in an enterprise, with market forces replacing government regulation as the regulator of acceptable industry performance [36,39]. When valuable competition can be maintained in the related markets and activities, privatization has been demonstrated to have huge prospects for reducing costs and getting better service quality. Without competition, privatization can still bring some improvements, but the gains are quite restricted [15]. A review of the top 100 container ports in the world carried out in 1997 showed that 88 of these ports have been privatized to some degree [40]. The extensive carrying out of port privatization policies in Asia, North America, Europe and Latin America is explained, respectively in ICS [36].

Quality standards: IMS (ISO: 9000, 14000, 18000) and ISO 20000: Economic uncertainty has forced companies to find ways to become more efficient in order to maintain their profitability and integrity. Formal performance improvement programmes such as ISO series of 9000, 14000, 18000 which are called Integrated Management Systems (IMS), and ISO 20000 helps companies to improve their quality and operational efficiency, granting companies a competitive edge [36,41,42]). One of the earlier examples of Quality Management Systems is the case of the Port of Nantes in France which is available in UNCTAD [43] monographs on port management. In the monograph the following features of the Quality Management Systems used within the mentioned port are detailed:

- The development of quality schemes:
    - Beginning of the projects.
    - Design of the schemes.
    - Choice of activities.
    - The question of certification.
- Quality management at the agricultural-food terminal:
    - Treatment of incoming vessels-quality charter.
    - The quality of the agricultural-food terminal technical facilities.
    - Cargo handling.
- Another aspect of quality-safety at the oil terminal:
    - Use of industrial hazard analysis.
    - Production of safety recommendations.
    - Recommendations for vessels calling at the oil terminal.
    - Evaluating the benefits.

Additionally, one of the latest examples for IMS implementation is the case of the Port of Felixstowe in February 2011. Based on BPM [44] and others the following are brief descriptions for ISO series that can be used as risk mitigation options (alternatives) during ports and offshore terminals operations and managements.

<u>**ISO 9000**</u>*:* Quality Management ISO 9000 is rapidly becoming the most essential international standard since it ensures quality, saves money and helps ports and offshore terminals to convince customer expectations [43]. ISO 9000 provides a quality management system for recovering and controlling the quality of services and products. It also decreases the costs linked with lesser quality management processes, making ports and terminals more competitive [44,45].

OCIMF [10] explains that marine terminals should have a management system in place which is able to demonstrate and document proof of compliance with regulatory requirements and company policy and procedures. Terminal management should designate a person to be responsible for ensuring compliance with the regulations and company policy and procedures. Furthermore, terminals should seek assurance that vessels visiting their berths comply with applicable international, national and local marine regulations.

<u>**ISO 14000:**</u> Environmental Management ISO 14000 ensures that offshore terminals and marine ports reduce the consequence of their activities on the environment by executing specific controls at the process stage. ISO 14000 enables ports and terminals to decrease the penalties and fines imposed when environmental laws are violated. Furthermore, the acceptance of ISO 14000 reduces waste, cutting down overhead, and ensuring the efficient use of materials [44].

In this respect as OCIMF [10] explains, marine terminals should have procedures in place for the handling or control of waste and harmful emissions generated as a result of its operations. For this purpose, terminals should have terminal oil/chemical spill response or contingency plans and should at regular intervals carry out oil spill response drills. For this purpose, by implementing ISO 14000, it will help to meet all the required criteria.

<u>**ISO 18000:**</u> Occupational Health and Safety Management System (OHSMS) ISO 18000 can be applied by sea ports and offshore terminals as a part of their RM scheme to address changing legislation and look after their labor force. An OHSMS promotes a safe and healthy working environment by providing a framework that permits ports and terminals to constantly discover and manage their health and safety risks, reduce the probability of accidents, help legislative fulfilment and improve overall performance [44].

As per OCIMF [10] marine terminals should have dynamic and broad safety programmes intended to deliver a high level of safety performance in respect of fire protection, access to the terminal, notices (warning/safety/pollution/security), lifesaving, first aid, occupational health and hazardous substances. In this respect ISO 18000 can meet all these challenges.

<u>**ISO 20000:**</u> Technology Management ISO 20000 is an IT governance scheme planned to regulate IT policy by adopting standard best practice procedures in IT service. ISO 20000 is rapidly becoming essential to modern business, while IT and business become more dependent on each other. By attaining fulfilment under ISO 20000, offshore terminals and marine ports can boost the efficiency for delivery of IT services by providing an expertise framework [44,45].

Safety cases and safety reports: Based on Wilson et al. [46] "*the purpose of a safety case is to present a clear, comprehensive and defensible argument supported by calculation and procedure that a system or installation will be acceptably safe throughout its life (and decommissioning)*".

In seaports, especially petrochemical ones and in offshore terminals whether in the form of floating structures such as LNG FPSOs etc. or in the form of fixed structures e.g. fixed offshore terminals for loading and unloading of LNG tanker ships, the safety case and safety reports play an important role in meeting standards, certifications, for insurance purposes etc. Without conducting an appropriate safety case and safety report, if an offshore terminal continues to operate, it will be difficult for the operators to defend any claim raised against them after a potential accident or incident occurs [5,47].

Health, Safety and Environment Management Systems (HSE-MS): As per WG [48] and BP [49] in most countries an inclusive legal structure exists that necessitates companies to handle their own HSE matters in such a way to anticipate, avoid and restrict occupational injuries, ill health and harm to the environment. Availability of an appropriate HSE Management System (HSE-MS) with the intention of fulfilment with these requirements is necessary. It is based on the widely recognized management systems discussed earlier i.e. IMS. Based on Mokhtari [5] HSE-MS can be integrated with the management of other aspects of the business e.g. in offshore terminals and marine ports in order to:

- Minimize risk to individuals and the environment.
- Improve business performance.
- Assist ports and offshore terminals to establish a responsible image within the marketplace and on behalf of stakeholders.

Internal audits and inspections: As per OCIMF [10], Chang et al. [50] and Makofske [51] the internal control system includes the control environment and control procedures. It contains all the policies and procedures (internal controls) adopted by the directors and management of an entity to help in attaining their objective of ensuring, so far as possible, the tidy and competent manner of its business, including obedience to internal policies, the protection of assets, the avoidance and identification of fraud and error, the precision and unity of the accounting records and appropriate preparation of consistent financial information. For instance, inspections of the foreign entering vessels by Port State Control (PSC) under IMO and ILO regulations are examples of internal audits/controls/inspections in sea ports and offshore terminals. This process internationally is known as ships' vetting.

Vessel Traffic Management Systems (VTMS): Successful VTMS is essential to the safety of sea ports, offshore terminals and waterways. The United States and other maritime countries have had complexity in establishing reasonable criteria for selecting ports requiring vessel traffic systems and for knowing the level of complexity of the VTMS required. The importance of the VTM becomes such that the US congress directed the USCG to reconsider the Vessel Traffic Service (VTS) acquirement with focus on meeting user requirements [39,52].

ISPS Code: In recent times offshore terminals and marine ports have turned into parts of critical infrastructure within the trading system. Some places categorize them as "hub Ports" that due to their size and capacity have become vital to the global supply chain [8]. Current post September 11, 2001 concerns about maritime commerce relate to the impact of a terrorist incident in such a location and the disorderly result on seaborne trade. However an efficient ISPS Code regime during maritime trade will require more than just the carrying out of these systems but the recognition and response to organizational complexity at two levels: (1) At sea ports and port-related infrastructures e.g. offshore terminals or petrochemical ports, and (2) Within the interrelated "system of systems" that is the world maritime trading network [53].

Port Risk Manager (PRM): The role of the PRM is like the discussions about the role of port planners in port strategic planning. However, both tasks should be kept firmly within management. Instead, risk managers can contribute to RM development by acting as "finders of strategies", as "analysts", and as "catalysts", in much the same way as Mintzberg [54] planners can contribute to strategy development.

The AIRMIC propose that the corporate risk manager (the same is applicable for port risk manager) should act as a coordinator and advisor with responsibilities such as to:

- Design an integrated RM strategy, philosophy, and policy statement for communication all through the organization.
- Launch and preserve a detailed RM methodology suitable to the company's requirements; to contain formalized hazard identification techniques, quantitative and qualitative risk assessment and cost-effective methods for risk reduction and transfer.
- Monitor the application and efficiency of RM.

Ideal quantitative risk mitigation methodical tool: In this paper it was intended to use FTOPSIS as an ideal decision-making technique to complete the risk mitigation phase. There are many FTOPSIS literatures proposed by various researchers. The latest contributions are described as follows:

Chen [55] has used the extensions of the TOPSIS for group decision-making under a fuzzy environment. As per the theory of the TOPSIS, he has defined a closeness coefficient to conclude the ranking order of all alternatives by calculating the distances to both the fuzzy positive-ideal solution and fuzzy negative-ideal solution at the same time. Yurdakul and Ic [56] by using the FAHP and FTOPSIS methods have developed a performance measurement model that could be used to get an overall performance score by measuring the success of a manufacturing company in its operational activities. In another instance Zarghaami et al. [57] have used the TOPSIS technique as a fuzzy multiple attribute decision making on their water resources projects case study for ranking water transfers to Zayanderud basin in Iran. Buyukozkan et al. [58] for selection of the strategic alliance partner in logistics value chain after creating the evaluation criteria hierarchy and computation of the criteria weights by applying the FAHP method, have used the fuzzy TOPSIS to get the final partner ranking results. Ebrahimnejad et al. [59] have used the TOPSIS in a fuzzy decision-making model for risk ranking with an application to an onshore gas refinery. Torfi et al. [60] have used a FAHP to compute the relative weights of their evaluation criteria and FTOPSIS to rank their alternatives. Prakash and Barua [61] have used AHP and TOPSIS methods to analyses of integrated robust hybrid model for third-party reverse logistics partner selection under fuzzy environment. In the last work Ligus and Peternek [62] have used the integrated fuzzy AHP-TOPSIS method for determination of the most suitable low emission energy technologies development in Poland.

As it was explained before in this paper a FAHP method has been used for calculating the relative weights of the risk factors (i.e. criteria) and here in this part by extending the FAHP; FTOPSIS can be utilized for selecting the most suitable strategies i.e. mitigation factors. As per risk assessment phase while using FAHP, relative weights of the risk factors in offshore terminals and marine ports were calculated. Therefore, in this phase FTOPSIS is based on the existing literatures will be utilized hereafter.

The FTOPSIS Methodology: The principle of a TOPSIS technique is based on selecting the best alternative, which has the shortest distance from the positive-ideal solution and the longest distance from the negative-ideal solution. It is often difficult for a decision maker to allocate an accurate performance rating to an alternative for the criteria under investigation. The good point of using a fuzzy approach is to allocate the relative importance of the criteria using fuzzy numbers instead of precise numbers. This research expands the TOPSIS to the fuzzy environment. The Fuzzy MCDM (i.e. Multiple-Criteria Decision-Making) can be briefly illustrated in a matrix format as shown in Equations 1 and 2.

$$\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{array} \begin{array}{c} C_1 \quad C_2 \quad \cdots \quad C_j \quad \cdots C_n \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \cdots & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \cdots & \cdots & \tilde{x}_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \tilde{x}_{ij} & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \cdots & \cdots & \tilde{x}_{mn} \end{bmatrix} \end{array} = \tilde{D} \qquad (1)$$

$$\tilde{W} = \left[\tilde{w}_1, \tilde{w}_2, \ldots \tilde{w}_j, \ldots, \tilde{w}_n\right] \qquad (2)$$

Where, $\tilde{x}_{ij}$, i=1; 2; . . . ,m; j=1, 2, . . ., n and $\tilde{w}_j$, j=1, 2, . . ., n are linguistic TFNs (i.e. Triangular Fuzzy Numbers), $\tilde{x}_j = (a_j, b_j, c_j)$ and $\tilde{w}_j = (a_{j1}, b_{j2}, c_{j3})$. Note that $\tilde{x}_j$ is the performance rating of the ith alternative, A_i, with respect to the j[th] criterion, c_j represents the weight of the j[th] criterion, c_j. The normalised fuzzy decision matrix denoted by $\tilde{R}$ is shown in Equation 3:

$$\tilde{R} = \left[\tilde{r}_{ij}\right] m \times n \qquad (3)$$

The weighted fuzzy normalised decision matrix is depicted in Equation 4:

$$\tilde{V} = \begin{bmatrix} \tilde{v}_1 & \tilde{v}_2 & \cdots & \tilde{v}_{1n} \\ \tilde{v}_1 & \tilde{v}_2 & \cdots & \tilde{v}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{v}_{m1} & \tilde{v}_{n2} & \cdots & \tilde{v}_m \end{bmatrix} = \begin{bmatrix} \tilde{w}_1\tilde{r}_1 & \tilde{w}_2\tilde{r}_2 & \cdots & \tilde{w}_n\tilde{r}_{1n} \\ \tilde{w}_1\tilde{r}_2 & \tilde{w}_2\tilde{r}_2 & \cdots & \tilde{w}_n\tilde{r}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{w}_1\tilde{r}_{m1} & \tilde{w}_2\tilde{r}_{m2} & \cdots & \tilde{w}_n\tilde{r}_m \end{bmatrix} \qquad (4)$$

The advantage of using a fuzzy approach is to allocate the relative importance of the risk factors using fuzzy numbers rather than exact numbers. This study utilizes the TOPSIS under fuzzy environments. This technique is particularly appropriate for solving the group decision making problems under fuzzy environments. Using the mentioned fuzzy approach, the designed FTOPSIS process is then defined as follows [60]:

Step 1: Select the linguistic variable $\tilde{w}_j$ i = 1, 2, . . ., m; j=1, 2, . . ., n for mitigation options with respect to risk factors and the appropriate linguistic variables ($\tilde{w}_j$, j=1, 2, . . ., n) for the weights of the risk factors. The fuzzy linguistic variable ($\tilde{x}_j$) preserves the property that the ranges of normalised TFNs belong to (0,1); thus, there is no need for a normalisation procedure. For example, the $\tilde{D}$ defined by Equation 1 is equivalent to the $\tilde{R}$ defined by Equation 3.

Step 2: Create the weighted normalised fuzzy decision matrix. The weighted normalised value $\tilde{V}$ is determined by Equation 4.

Step 3: Select the positive ideal (A^*) and negative ideal (A^-) solutions. The fuzzy positive ideal solution (FPIS, A^*) and the fuzzy negative ideal solution (FNIS, A^-) are shown in Equations 5 and 6:

$$A^* = \left\{\tilde{V}_1^*, \tilde{V}_2^*, \ldots, \tilde{V}_n^*\right\} = \left\{\left(\max_i \tilde{v}_{ij} \middle| i = 1, \ldots, m\right), j = 1, 2, \ldots n\right\} \qquad (5)$$

$$A^- = \left\{\tilde{V}_1^-, \tilde{V}_2^-, \ldots, \tilde{V}_n^-\right\} = \left\{\left(\max_i \tilde{v}_{ij} \middle| i = 1, \ldots, m\right), j = 1, 2, \ldots n\right\} \qquad (6)$$

Maximum and minimum operations do not give TFN, but it is likely to state the approximated values of minimum and maximum as TFNs. It is known that the elements $\tilde{v}_{ij} \forall$i,j are normalized positive TFNs and their ranges belong to the closed interval (0,1). Thus, it can define the fuzzy positive ideal solution and the negative ideal solution as $\tilde{V}_i^*$ = (1, 1, 1) and $\tilde{V}_i^-$ = (0, 0, 0), j=1, 2, …, n [58].

Step 4: Determine the separation measures. The distance of any mitigation option from A^* and A^- can be estimated using Equations 7 and 8:

$$d_i^* = \sum_{j=1}^{n} d\left(\tilde{v}_j, v_j^*\right), \qquad i = 1, 2, \ldots, m \qquad (7)$$

$$d_i^- = \sum_{j=1}^{n} d\left(\tilde{v}_j, v_j^-\right), \qquad i = 1, 2, \ldots, m \qquad (8)$$

Step 5: Determine the similarities to ideal solution. This step resolves the similarities to an ideal solution by Equation 9:

$$C_i = \frac{d_i^-}{d_i^* + d_i^-} \qquad (9)$$

Step 6: Ranking the mitigation options. Select a mitigation option with maximum CC_i^* or rank mitigation options according to CC_i^* in downward order.

Case Study

This case study is only an illustrative example of offshore terminals and marine ports which can be explained as follows:

In order to carry out the first phase (i.e. Hazard Identification) of the addressed QRM methodology shown in Figure 2, operational risk factors associated with offshore terminals and marine ports are depicted in Figure 3 where such risk factors were identified through the hazard identification process i.e. HAZID in the authors' previous works such as Mokhtari et al. [28]. In the second phase (i.e. quantitative risk assessment) of the QRM methodology through experts' judgements *via* using a Fuzzy AHP method, the mentioned risk factors were assessed, prioritized and ranked as shown in Table 1. As a result, the most significant risk factor identified was found to be R21 i.e. people's safety in area of offshore terminals and marine ports.

In continuation of the second phase (i.e. Quantitative risk analysis) as per Figure 2 the most significant risk factor (R21) was further investigated for its causes (i.e. basic events) and consequences using a bow-tie method including employment of FTA and ETA under fuzzy environment (Figure 4). This was supported through a predefined scenario in the form of terrorists' attacks to an addressed marine and offshore site (i.e. a scenario planned offshore LNG import terminal along with a commercial export/import marine port) shown in Figures 5 and 6. All the hazards in the form of Basic Events (BEs) are shown in the fault tree diagram of Figure 7.

The occurrence possibility for top event R21 (Figure 8) i.e. people's safety in the area of offshore terminals and marine ports was calculated using FTA under a fuzzy environment. In fuzzy environments

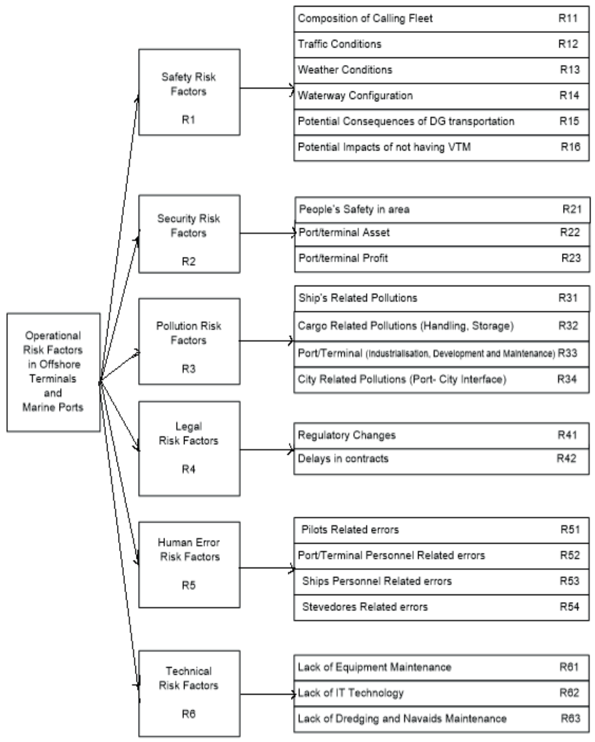

Figure 3: Hierarchy of operational risk factors in offshore terminals and marine ports.

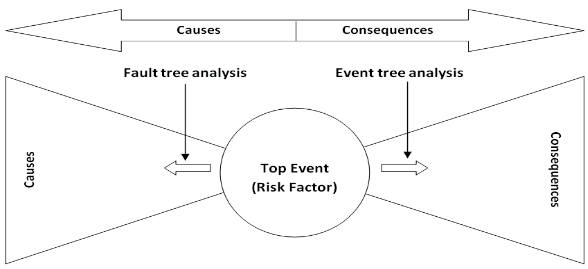

Figure 4: A bow-tie diagram (Source: Adopted from Ferdous et al.).

possibility approaches replace the probability approaches where the traditional FTA is used. The occurrence possibility of R21 (Figure 9) was found to be 0.782. Now by elimination of each basic event new occurrence possibilities will be obtained for the top event (PTE_i) respectively as shown in Table 2. Subsequently the amount for each deviation i.e.($P_{TE(R21)} - P_{TEi}$) has been recorded in the deviation index column shown in Table 2. A greater value means higher importance on the occurrence possibility of the top event. It means that if the basic event or hazard with higher importance is eliminated the occurrence possibility of the top event will be reduced more. As it can be seen from Table 2, Basic Event number 4 (BE4) has the highest importance on the occurrence possibility of the top event. Calculations on FTA and ETA are not shown here and are outside the scope of this paper. Methodologies and full explanations on the mentioned approaches can be found from the author's previous works such as Mokhtari et al. [28].

The results are listed in Table 3 along with rankings for different consequences. As it can be seen consequence S5 i.e. loss of life as a result of an attack to the mentioned offshore terminal and marine port will affect safety of the people within the area more than other consequences. As terrorist attacks are intentional acts carried out deliberately with the intention of making destructions and/or harming

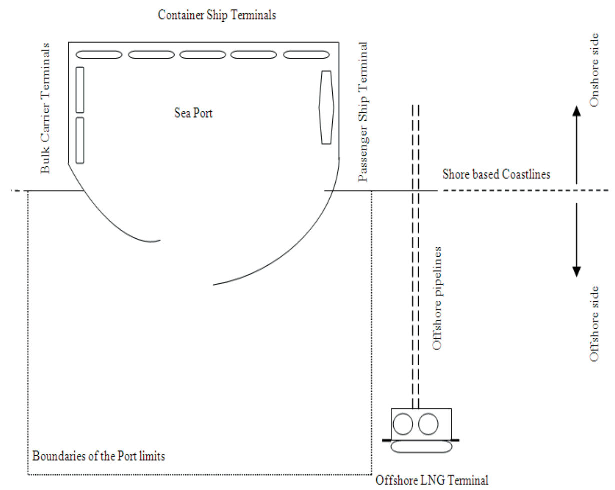

Figure 5: A scenario planned offshore LNG import terminal and a commercial export/import marine port.

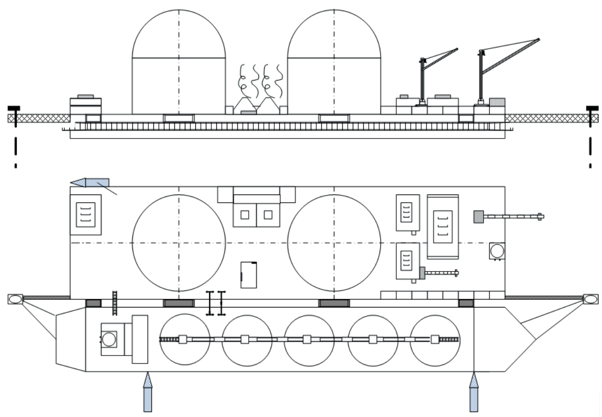

Figure 6: An LNG Tanker berthed alongside of an import Offshore LNG discharging Terminal.

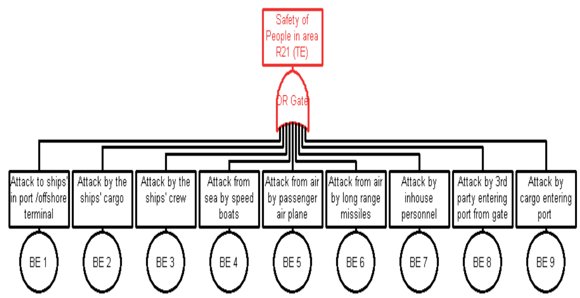

Figure 7: A fault tree diagram for top event (TE) or risk factor R_{21}.

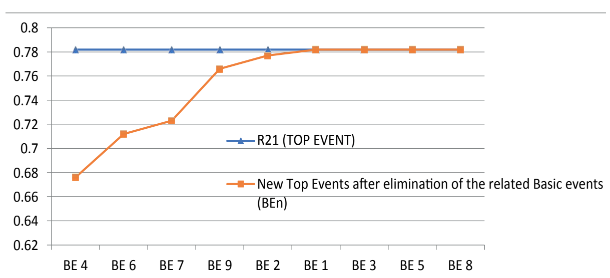

Figure 8: Sensitivity analysis of the top event or risk factor R_{21}

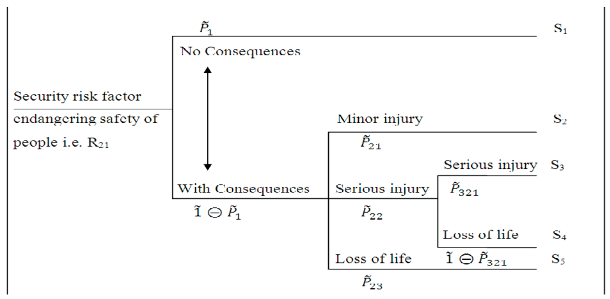

Figure 9: Event tree analysis for hazard number R_{21}.

Elimination of Basic Events	Possibility Approach					
	Fuzzy number			Occurrence possibility (P_{TEi})	Deviation index ($P_{TE(R21)} - P_{TEi}$)	Ranking
	l	*m*	*u*			
BE 1	0.483	0.866	0.995	0.781	0.001	6
BE 2	0.483	0.854	0.995	0.777	0.005	5
BE 3	0.483	0.866	0.995	0.781	0.001	6
BE 4	0.311	0.732	0.985	0.676	0.106	1
BE 5	0.483	0.866	0.995	0.781	0.001	6
BE 6	0.378	0.769	0.989	0.712	0.070	2
BE 7	0.378	0.800	0.991	0.723	0.059	3
BE 8	0.483	0.866	0.995	0.781	0.001	6
BE 9	0.483	0.821	0.993	0.766	0.016	4

Table 2: Importance of elimination of each basic event in-occurrence possibility of the top event.

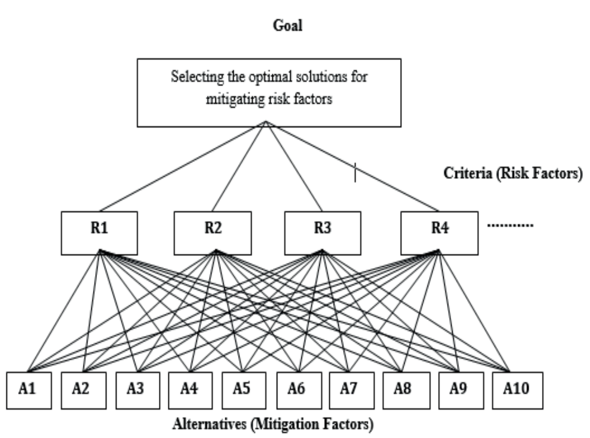

Figure 10: Decision making *via* using 10 alternatives for mitigating risk factors in offshore terminals and marine ports.

Consequences	Occurrence possibility scores	Rankings
No Consequences	0.137	4
Minor injury	0.718	2
Serious injury	0.445	3
Loss of life as a result of serious injury	0.445	3
Direct loss of life	0.807	1

Table 3: Occurrence possibility scores for different consequences.

Alternatives	Names of mitigation factors	CC_i	Rankings
A1	Internal Audits and Inspections	0.0185	9
A2	Privatisation	0.0324	8
A3	ISPS Code	0.0874	6
A4	ISO 20000	0.0724	7
A5	Port Risk Manager	0.1021	4
A6	Safety Cases and Safety Reports	0.1362	3
A7	IMS (ISO: 9000,14000,18000)	0.1536	1
A8	VTMS	0.1521	2
A9	Deregulation	0.0879	5
A10	HSE-MS	0.1536	1

Table 4: Fuzzy TOPSIS results for mitigating operational risk factors.

people (mainly physically) therefore the most significant consequence i.e. S5 found in this case study justifies the nature of the risk factor (i.e. hazard) R21.

All formulas and methodologies used for Bow-tie method (Figure 4), FTA and ETA can be found in the work of Ferdous and Ferdous et al. [63]. All methodologies for experts' judgements, FST, AHP method and calculations for the Fuzzy AHP method are based on extent analysis. In this regard also see the author's previous works such as Mokhtari et al. [28] and Mokhtari [5].

To accomplish the third and last phase (i.e. quantitative risk mitigation) of the QRM methodology and in order to mitigate the operational risk factors shown in Figure 3 for the purpose of this paper it is decided to use a Fuzzy TOPSIS method. With reference to Figure 10, TOPSIS method is one of the best decision-making tools used in many applications as explained earlier.

Based on available literatures and referred references in Table 4 there are different strategies and alternatives to mitigate and control the addressed operational risk factors for the purpose of offshore terminals and marine ports. Ultimately the best alternatives after using experts' judgements and the TOPSIS method under fuzzy environment are ranked as per their priorities shown in Table 4.

Conclusion and Further Suggestions

Offshore terminals and marine ports are critical infrastructures for the purpose of continued existence of every nation's economy that can at any period disturb their financial structures, trade competitiveness and living standards. As explained earlier there are sources of uncertainties (i.e. hazards and/or risk factors) in the offshore and marine industry, all of which necessitate for being concerned in respect of their identification, assessment and mitigation with the use of an appropriate QRM methodological approach, if this industry is going to be responsive to the strategic requirements and future challenges. To achieve this firstly it is essential an appropriate QRM methodology to be incorporated into all the functions and processes e.g. management within the marine and offshore industry and secondly decision makers to have strategic management approach during implementation of the addressed QRM methodology. However, to achieve this initially there is a need to become conversant with the methodology of QRM in the marine and offshore industry at a holistic level. For these reasons a generic QRM methodology for the purpose of marine and offshore industry applications was presented in this paper. The proposed QRM methodology in this paper can cause sea ports' and offshore terminals' risk or risk managers to handle the potential risk-based challenges and sources of uncertainties in a professional manner. Additionally, the proposed QRM methodology in this paper can facilitate safety engineers, regulators, inspectors, insurers and consultants to evaluate and properly analyses the risk of potential hazards in marine ports and offshore terminals and help them during decision making processes. Moreover, the addressed professionals can use the addressed QRM methodology in conjunction with their related software-based decision-making programs to determine likelihood and magnitude of identified hazards and risks. In future works, industry users by examining the different tools and techniques in their QRM methodologies can select the best tools that can suit to their QRM decision making processes. In fact, this will depend on the type, nature and original sources of risks and uncertainties within the organizations. This means that in respect of the marine and offshore industry itself the sources of risks maybe exerted at any time from externally or internally driven sources with having different challenging and novel characteristics.

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