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Risk Management on a Liquefied Natural Gas Export Terminal in the Sultanate of Oman: The case of Qalhat LNG Terminal

Kambiz Mokhtari[a], *Mehrdad Behforouzi*[b*], *Kawkab Abdul Aziz Mohammed Al Balush*[c], *Hamidreza Soltani*[d], *Norhan Ibrahim*[e]

[a]Dept. of Maritime Studies, International Maritime College Oman, Oman, kambiz@imco.edu.om

[b*]Dept. of Maritime Studies, International Maritime College Oman, Oman, mehrdad@imco.edu.om, (Corresponding Author)

[c]Dept. of Maritime Studies, International Maritime College Oman, Oman, kawkab@imco.edu.om

[d]Dept. of Maritime Studies, International Maritime College Oman, Oman, hamid@imco.edu.om

[e]Dept. of Maritime Studies, International Maritime College Oman, Oman, norhan@imco.edu.om

Abstract

In the maritime industry, most perceptions, frameworks and methodologies of dealing with hazards are for their risk assessment rather than their risk management. This tendency discloses the reality that within the maritime sectors in areas like shipping, 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 appropriate risk management such as in seaports' terminals. Therefore, in this paper initially, during priority assessment of the identified hazards, Fuzzy Set Theory was applied to handle imprecision of the uncertain risk-based statistics to get an accurate result. 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 Technique for Order of Preference by Similarity to Ideal Solution tool was used for the implementation of the mitigation phase to complete and conclude the proposed QRM cycle.

Keywords: Risk Management, Sultanate of Oman, LNG Export Terminal and Marine Port, Decision Making, Fuzzy Fault Tree and Event Tree Analysis, Fuzzy TOPSIS Method

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1. An overview of Risk Management (RM) in marine and offshore

Marine and offshore industry strategically play a significant role in the 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 (i.e. offshore oil and gas production platform) in 1998(Shallcross, 2013), 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(Bregy et al. 2018). The accident in the Gulf of Mexico was an explosion on 20th April 2010 on the drilling platform of Deepwater Horizon, operating in an offshore area of the Gulf of Mexico on a subsea oil well at a distance of one mile below the water surface which caused a disastrous oil spill in the history (Sharp, 2009). From the midstream sector of the energy industry, it can be referred to the oil Tanker Sanchi collision accident case in 6th January of 2018. The addressed vessel was carrying natural gas concentrate cargo of 136,000 metric tonnes, caught fire immediately after the collision with other bulk carrier vessel and following continuous burning, multiple explosions and drifting for eight days, it was sunk at the end due to structural failure (CNN, 2018). 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. Moreover, the attacks carried out to 4 ships at UAE port of Fujairah on May 2019, and the later one to 2 ships off the coastline of Iran on June 2019. All in Gulf of Oman underlines for security management everywhere, and there is a need to address physical threats to the countries activities (e.g. oil and gas or shipping activities) and assets, including employees (CNN, 2019). 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 specialised 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 (Sharp, 2009).

Also according to the physical borders existing in marine and offshore industry, the occurrence of catastrophic losses can be extended from inland terminals, refineries, petrochemical complexes, Liquefied Natural Gas (LNG) liquidation/gasification plants, oil and gas transit pipelines (i.e. downstream sector of the energy industry) or dry ports within landlocked countries or states up to the other places away from the open seas Claude et al. (2016).In the downstream sector of the energy industry, one of the most recently occurred accidents which can be referred is the fire accident of Ruwias oil refinery of Abu Dhabi in U.A.E that took place on 11th of January, 2017. As per Marsh (2018) insurance, this accident has caused the largest property damage loss since 1978.

Moreover, based on various sources (ABS, 2003; Matter, 2009; OCIMF, 2012; ICS, 2017; UKHSE, 2018 and IMO, 2019) there is literature in marine and offshore sectors which for the most part narrated about the regulations and safety guidelines, but none of them has explained at a holistic level a comprehensive or even generic Quantitative Risk Management (QRM)framework or methodology which accordingly might cover RM related problems. On the other hand, under the phrase of "risk" expressions such as disaster, security, crisis, safety, hazards, reliability and emergency can all be categorised. Also, terms such as quantitative risk assessment, quantitative risk evaluation, quantitative risk analysis, quantitative risk mitigation can be well thought-out as subsets for the expression of "management". As a result, using an expression of "QRM" only can validate the phrases above.

Ultimately based on existing literature, the Piper Alpha catastrophe demonstrated to be the mechanism for a major transform in the manner the maritime industry was regulated and managed. Deficiency in conformity with safety tradition and mistakes improper maintenance and check-up has been identified as leading root causes for this case and also for the case of Deepwater Horizon accident in the Gulf of Mexico. Still, nobody has claimed for the need of fulfilling with a precise or even a basic QRM method.

2. A proposed QRM methodology

This part demonstrates the key features of the methodological approach aimed at a consistent QRM; the process and functional analysis of marine ports and offshore terminals and the valuation of the risk management system. Figure1, 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 (Sapori et al. 2014).Among the available techniques for QRM methodologies Fuzzy Set Theory (FST); Analytic Hierarchy Process (AHP); bow-tie method; Event Tree Analysis; (ETA)Fault Tree Analysis (FTA)and TOPSIS (i.e. Technique for Order of Preference by Similarity to Ideal Solution) method are used under a fuzzy environment in this paper to model the addressed QRM methodology in Figure 1forRM in marine ports and offshore terminals.

Therefore, after detecting the potential risk factors (i.e. hazards) 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 experts' judgements and AHP method to produce quantitative data at the end. In order to handle the imprecision of the statistics, 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. In this situation, it depends to the decision-makers, risk managers, safety engineers or claim handlers within the addressed industry that at which stage or when decide to deal and/or to take the preferred 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 in order to mitigate it. Therefore, in order to analysis, each one of the selected risk factors in a quantitative manner bow-tie method (i.e. a risk analysis tool) will be used to investigate the potential causes and consequences of the addressed selected risk factor(s) under fuzzy environment. In this part, FTA will quantify the potential essential events (i.e. causal factors) initiating and causing the addressed risk factors and subsequently ETA will be used to show and calculate the possible occurrences and/or outcomes. This offered a quantitative risk analysis process for each risk factor will ensure that there are an adequate treatment practice and procedure in place for implementation of 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 control formerly identified and evaluated risk factors and complete the QRM cycle.

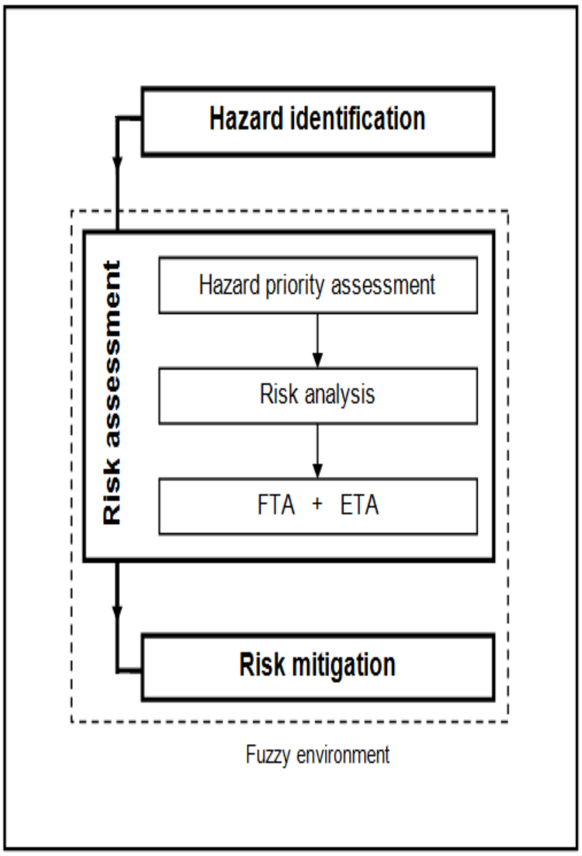

Figure 1: Proposed QRM methodology in the marine and offshore industry under fuzzy environment

As a result, the proposed framework in Figure 1 is used to describe a generic methodology that can develop a QRM capability by enhancing a holistic RM view that can contribute to different offshore and marine applications. This framework can be used practically by safety engineers and other experts for further diagnosis or can be used by risk managers or other RM professionals during their decision making processes. In this regard, the addressed QRM methodology and framework for the marine and offshore applications can be discussed further through the following phases:

2.1. Hazard identification phase

Most primarily and the first phase in any QRM methodology is hazard identification (Chartres et al. 2019). "Hazard identification have to be dealt with systematically to make sure that all-important activities within the management have been recognized and all the risk factors produced from these performances are defined" (UKNRR, 2017). In this respect, while in ordinary conditions, many companies and corporations are utilizing the expression of "risk identification" for the initial stage in their QRM procedures. However, more principally in industrialized and engineering fields such as in offshore structures and marine systems as it is described by (Paltrinieri et al. 2015) the expression of "HAZID" (i.e. HAZard IDentification) has been employed rather than the initial one. HAZID is a common phrase used to state an activity whose intention is to classify hazards (i.e. risk factors) and the associated procedures that have the prospective to result in a valuable outcome. For instance, a HAZID of an offshore installation or offshore terminal may be performed to spot probable risk factors which could lead to negative happenings to employees', e.g. severe injuries and multiple fatalities, environmental pollution and severe structural damages or result into production delays or losses. The HAZID technique can be useful to all or part of a floating offshore structure, a terminal within the seaport, a product carrier tanker ship or it can be employed to examine operational processes of companies. Depending upon the organization being assessed and the resources available, the procedure used to carry out a HAZID can be diverse (ABS, 2003). For instance, in offshore terminals and seaports, particularly in LPG and LNG related export and import petrochemical facilities HAZOP (i.e. Hazard Operability) is the best resolution for hazard identification targets. In this respect, HAZOP is a well-designed technique to investigate a previously intended or any existing practices' operations. The most crucial intention of a HAZOP technique is to spot trouble that may expose hazard to employees or equipment or avoid efficient operation (Sultana et al., 2019). Based on Mokhtari (2020), the literature review is one of the HAZID methods that can be employed to express an exercise whose aim is to recognize and classify risk factors and related happenings that have the prospective leading to a most critical negative outcome. As Saunders et al. (2007) have described the advantage of the literature review is to save time as the necessary risk-based information is studied before and accessible. Also, it is less expensive than all other methods. It is also expected to be of higher quality, and the information can be utilized in combination with the other quantitative and qualitative means and methods.

2.2. Risk assessment phase

The central part of any QRM methodology or phase is the quantitative risk assessment stage to evaluate and analysis the recognized risk factors or hazards (Aneziris et al. 2014; Martins et al. 2016 and Jeong et al. 2018). In this view, ABS (2003) describes that the ability to make reasonable decisions is vital to successful business-related proposals. Moreover, in today's complicated conditions, business decisions are not often simple or straightforward. For this reason, risk assessment is useful as a support to the decision-making progression. There are many types of quantitative and qualitative risk assessment techniques which are employed for different conditions and in different industries. Nevertheless, before conducting a quantitative risk assessment part first, there is a requirement to successfully build a generic model for the intention of evaluating the identified hazards. For this reason, Haimes (2002) debates if the adage, "To manage risk, one must measure it with appropriate metrics," represents the compass for RM, then modelling represents the roadmap that directs the analyst all over the journey of risk assessment On the other hand, in the marine and offshore industry, It is not easy to undertake quantitative risk assessment especially in seaports and offshore terminals because the accessible statistics is highly vague and unclear, and a lot of the systems may not be entirely understandable. Therefore, a systematic approach is essential to deal with qualitative and quantitative information and statistics as soon as new data and facts become accessible. For this reason, in order to deal with vague, unavailable and insufficient data; techniques such as FST and AHP method can be employed for evaluating and prioritization of the identified risk factors from the previous phase.

Furthermore, other risk analysis techniques such as bow-tie method, FTA and ETA can be utilized for investigating of the potential failure causes and resulted in consequences, as a result of the hazards identified from the first phase of the addressed QRM methodology. Also, all formulas and methodologies used for the bow-tie method, FTA and ETA can be found in the work of Ferdous (2006) and Ferdous et al. (2009). All methodologies for experts' judgements, FST, AHP method and calculations for the Fuzzy AHP method are as per Chang (1996) extent analysis which is outside the scope of this paper.

2.3. Risk mitigation phase

A risk mitigation stage is a decision-making practice whereby treatments are prescribed given the conclusions of the risk assessment phase. Benchmark risk avoidance strategies intend both at decreasing the likelihood of an occurrence or at lessening the level of damages if the mishaps take place. This practice is usually used in combination with a cost-benefit analysis technique for most favourable decision-making conditions (UNCTAD, 2006). As a result, to fulfil the addressed QRM methodology, it is essential to achieve it through a risk control or mitigation part. For this reason, in order to mitigate the identified and evaluated hazards first, it is necessary to distinguish several types of ideal solutions or mitigation strategies and afterwards by the help of a proper quantitative and systematic method, prioritize or rank them for their appropriate handling purposes in future.

For this paper in the marine and offshore industry, there are many hazards that all are already identified, analyzed and assessed for their associated risks. However, now they must be adequately mitigated via using QRM expert method in order to determine the most effective strategies to take care of the addressed risk factors. Therefore, the mitigation phase of a QRM methodology plays a vital role to complete an RM cycle. There is complementary literature about risk mitigation (Rimsaite, 2019) and other subcategories of risk mitigation process such as risk avoidance (King, 2016); risk reduction (Morettia et al. 2018); risk sharing (Mirakhor et al. 2017) and risk retention (Guo and Wu, 2014) practices that can be referred to.

2.3.1. Ideal strategies for risk mitigation

However, to manage the identified and assessed hazards, it is required to classify the best available ideal strategies for their mitigation purposes. In this respect, the most significant risk mitigation factors with the intention of their employments within the offshore terminals and marine seaports are introduced as follows:

2.3.1.1. Privatization

In order to be responsive to the international requirements, marine ports ought to enhance both faculty and competence at the same time as decreasing expenses. Conventionally, marine ports were not only in public possessed but also politically ruled and governed. This substitute the likelihood of market collapse with country collapses such as ineffective seaports, unpleasant trade and expansion. To defeat these types of struggles, there are two potential solutions, privatization or deregulation (ICS, 2015; Chen et al. 2017 and Lia et al., 2019). Deregulation is the decrease of the function of the government in business activity, with marketplace forces substituting government bylaw as the controller of adequate industry performance (Mou et al. 2019). When important rivalry can be kept in the related markets and businesses; privatization has been confirmed to have an enormous prediction for decreasing expenses and reaching improved service quality. With no rivalry, privatization can still bring some developments, but the growths are relatively limited (World Bank, 2017). To improve port efficiency, many governments around the globe have introduced private participation in port operations. Different models have been tested. The most common one is the Landlord Port Model in which the private partner leases a port terminal and is responsible for both the operation and related investments (e.g. wharf expansion, cranes and office buildings). However, the public authority remains in charge of common facilities such as breakwaters, entrance channels, utilities and road and rail access to the port (UNESCAP, 2015). The broad conducting of seaport privatization strategies in Europe, North America, Asia and Latin America is described, correspondingly in (ICS, 2015).

2.3.1.2. Integrated Management System (ISM)

Financial ambiguity has forced corporations to find methods to become more resourceful to keep their productivity and reliability. Prescribed routine development programmes such as ISO standards of 9000, 14000, 18000 which as a whole are called Integrated Management Systems (IMS), and ISO 20000 assists corporations to increase their value and operational effectiveness, granting corporations a competitive circumference (ICS, 2015; Baraforta, 2018 and Sui et al. 2018). Also, ISO 31000 provides RM guidelines and decision making recommendations to any organization such as marine ports sand offshore terminals. For example, currently, IMS is utilized within the Port of Melbourne in Australia. Based on BV (2019) these globally recognized standards underpin ports' vision and values as an organization and complement their operational standards, expectations, and requirements that will build, deliver and sustain positive, effective and dynamic working environments. "Accreditation to these international standards is the centerpiece of Port of Melbourne's Integrated Management System, titled 'The Compass', which delivers a systematic and collaborative approach to designing, reviewing and documenting the needed key procedures and processes. The Compass will drive improved business performance while embedding a culture of workplace excellence". As per BPM (2019), subsequent cases are briefly explained for ISO standards that can be utilized as risk controlling alternatives for seaports and offshore terminals operations' and managements'.

2.3.1.2.1.ISO 9000

ISO 9000 in the form of quality management is quickly becoming the most necessary international ISO series since it guarantees quality; reduce costs and assists seaports and terminals to meet clients' prospects UNCTAD (1998). ISO 9000 grants a quality management system for improving and managing the quality of products and services. It also reduces the expenses related to less significant quality management practices, making seaports and offshore terminals further competitive (ISO, 2018) and (BPM, 2019).

OCIMF (2012) describes that terminals must have a managing arrangement in a position which is proficient at presenting and documentary pieces of evidence of fulfilment with regulatory requirements and company plan, policies and procedures. Terminal management has to appoint an individual to be accountable for making sure fulfilment with the rules and company plan, policies and procedures. Moreover, terminals must look for assurance that ships visiting their ports act following related local, national and international maritime regulations.

2.3.1.2.2. ISO 14000

ISO 14000 series facilitates to make sure terminals and ports lessen the effect of their performances on the environment by implementing detailed mitigation strategies at the routeing phase. ISO 14000 allows terminals and ports to reduce the fines and duties forced when environmental protection regulations are ignored. Besides, compliance with ISO 14000 lessens waste, reduces overhead, and warranting the proficient use of resources (BPM, 2019).

For this purpose, as OCIMF (2012) describes, marine ports and terminals must have measures prepared for the managing or organizing of waste and harmful emissions produced due to its operations. For this reason, ports and terminals must have port rerated chemical/oil spill response or contingency plans and have to at feasible periods perform oil spill pieces of training and related drills. By putting into practice of ISO 14000, it will assist in meeting up with all of the essential criteria.

2.3.1.2.3. ISO 18000

ISO 18000 is known as Occupational Health and Safety Management System (OHSMS), and it can be useful for offshore terminals and marine ports as a part of their RM plan to deal with regulations, policies and care for their workforce. An OHSMS supports a healthy and safe operational atmosphere by providing a supportive arrangement that allows terminals and ports to continually determine and control their safety and health-related risk factors, decrease the likelihood of accidents, assist legislative achievement and develop overall performance (BPM, 2019).

Based on OCIMF (2012) terminals and ports should have ongoing health and safety-related programmes planned to generate a high level of safety performance about firefighting, right of entry into the terminal, awareness (warning/safety/pollution/security), lifesaving, medical care, dangerous substances and occupational health.

2.3.1.2.4.ISO 20000

ISO 20000 stands for technology management and is an IT governance system designed to standardize IT policy by approving standard best practice measures. ISO 20000 is quickly becoming necessary to modern business, whereas IT and business become further reliant on each other. By achieving performance under ISO 20000, marine ports and offshore terminals can improve the effectiveness of providing IT services by delivery of skilful supports (BPM, 2019 and ISO, 2018).

2.3.1.2.5. ISO 31000

As per ANSI (2019), ISO 31000 provides strategies and guiding principles for managing risk faced by organizations. The application of these strategies can be modified to any organization and its environment. ISO 31000 provides a conventional approach for management of any risk and is not industry or sector-specific. ISO 31000 can be used during the life of the organization and can be applied to any activity, including decision-making processes at all levels. Moreover, hazards affecting organizations such as ports and terminals can have consequences in terms of economic and financial performance and professional reputation, as well as environmental, safety and security outcomes. Therefore, managing hazard can efficiently assist organizations to perform well in an environment which is full of sources of uncertainty (ISO, 2019).

2.3.1.3. Safety cases and safety reports

As per Wilson et al. (1995), "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 marine ports, in particular with petrochemical facilities and terminals or offshore structures whether in the form of mobile platforms such as FPSOs or the form of fixed rigs like fixed offshore structures for shipment and discharging of tanker vessels, the safety reports and safety cases play a significant part in fulfilling regulations, certifications, for insurance and risk management reasons etc. Without carrying out a proper safety report and/or safety case, if an offshore platform carries on to operate, it will be not easy for the operators to preserve every claim raised against them following a probable event takes place (Acheamponga and Akumperigyab, 2018).

2.3.1.4. QHSES- Risk Manager

As per WG (2018) and BP (2016) in many nations, there is a general law based arrangement that requires corporations to deal with their Quality, Health, Safety, Environment and Security (QHSES)issues in a manner to predict, keep away from and limit occupational harms, ill health and damage to the environment. Accessibility of a suitable QHSES Management System (QHSES-MS) with the purpose of accomplishment with these requests is crucial. It is based on the broadly known management systems explained before, i.e. IMS.QHSES-MS can be incorporated with the administration of other features of the business, e.g. in marine ports and offshore terminals to facilitate followings:

- Reduce hazard to human and the environment.
- Develop better business activity.
- Support offshore terminals and marine ports to set up an accountable image within the market and in support of shareholders.
- In this respect, the function of the risk and QHSES managers are similar to the talks concerning the function of planners during strategic planning of the marine ports and/or terminals. Nevertheless, both of these undertakings should be maintained firmly within the administration. Instead, risk managers can support in RM expansion by performing as "finders of strategies", as "analysts", and as "catalysts", in much the equal manner as planners can donate to strategy improvement (Ward, 2005).

The AIRMIC (2019) suggest that the corporate risk manager (such as port risk manager) have to proceed as a manager and advisor with everyday jobs like the following duties:

- Plan an incorporated RM strategy, attitude, and policy declaration for statement throughout the administration.
- Initiate and protect a comprehensive RM framework appropriate to the corporation's needs; to have compatible hazard identification methods, quantitative and qualitative risk evaluation and cost-benefit analysis techniques for risk transfer and risk reduction purposes.
- Supervise the function and effectiveness of RM.

2.3.1.5. Internal audits

Based on OCIMF (2012); Chang (2019) and Makofske (2019), the internally monitoring scheme contains the supervision of environment and managing of the procedures. It includes all the procedures and policies approved by the administration and directors of a corporation to facilitate in achieving their aim of ensuring, as much as possible, the orderly and proficient approach of its business, together with compliance to internal policies, the security of assets, the prevention and recognition of scam and mistake, the accuracy and harmony of the financial records and performances or proper preparation of reliable financial data.

2.3.1.6. Vessel Traffic Management Systems (VTMS)

Active VTMS is necessary to the safety of offshore terminals, marine ports and inland waterways. In this respect, many maritime nations have had difficulty in setting up practical criteria for choosing ports involving vessel traffic systems and for understanding the level of complication of the VTMS required. The significance of the VTM becomes such that the USA Congress engaged the USCG to review the Vessel Traffic Service (VTS) achievement with a focus on matching with the customers' needs (Olba et al. 2019 and Mou et al.

2019).

2.3.1.7. International Ship and Port Facility Security (ISPS) Code

At the moment, seaports and offshore terminals have turned into parts of significant infrastructure within the transportation network and trading system. Several places classify them as "hub Ports" that because of their extent and facility have become very important to the international supply chains. Recent post-September 11, 2001, worries concerning maritime trade relates to the consequence of a terrorist occurrence in such a place and the uncontrollable effect on seaborne trade. Nevertheless, a well-organized ISPS Code establishment prescribed by Safety of Life at Sea (SOLAS) Convention and ratified by IMO throughout maritime trade will necessitate above just the implementation of these structures but the appreciation and reply to organizational difficulty at two levels: (1) at marine ports and port-related facilities such as offshore terminals or petrochemical plants near port areas and (2) within the interconnected "system of systems" that is the global sea trading system(Barnes, 2004 and IMO, 2019).

2.3.1.8. Port State Control inspections

Based on IMO (2019) Port State Control (PSC) "is the inspection of foreign ships in national ports to verify that the condition of the ship and its equipment comply with the requirements of international regulations and that the ship is human-crewed and operated in compliance with these rules". This procedure globally is recognized as ships' vetting. Port and coastal States, particularly now with the introduction of new SOLAS (i.e. Safety of Life at Sea) regulations on maritime security, have certain rights to exercise authority over ships in their waters. Also, ports States have the power to check that foreign ships visiting their ports meet all the appropriate IMO, i.e. International Maritime Organization's convention standards. Indeed, the origin of port state control can be traced back to the 1929 SOLAS Convention. Convention control provisions can now also be found in MARPOL (i.e. International Convention for the Prevention of Pollution from Ships), the Load Line Convention, STCW and International Labour Organization (ILO) Convention No. 147 (IMO, 2018).

2.3.1.9. Planned Maintenance programmes

Terminals should be structurally surveyed as part of an integrated inspection and maintenance programme. The main focus is on operations at fixed berths. However, all types of terminals are considered, both fixed and floating such as a continuous quay, T-Head jetty, finger pier, island berth, Single Point Mooring (SPM). All structural surveys and inspections should be carried out by suitably qualified personnel at intervals not exceeding five years. For jetties, inspection should cover the structure of the jetty from its superstructure down to the mud line and will generally require the use of diving services. Formal documented visual inspections of the jetty superstructure above the waterline should be undertaken. Terminals should have a planned general inspection and maintenance programme, including a formal documented record of activities OCIMF (2012) and ICS (2015).

2.3.1.10. Performance indicators

Port Performance indicators are control devices or mechanisms that permit port directors to determine terminal's or port's performances', and take remedial decisions to get it better when and where it is essential. For instance, terminal operations performance can be separated under three classes, for example, physical performance (i.e. the performances of the terminal can be estimated as an entire, or the performances for every group or set of facilities like berths, yards, cranes, sheds, storehouses and labour force within each specialized terminal); Quality performance (e.g. reliability, flexibility and application of rules) and financial performance (ICS, 2015) and World Bank, 2017).

2.3.2. 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 literature offered by different researchers. The most recent contributions are expressed as follows:

Chen (2000) has employed the extensions of the TOPSIS for team decision-making under a fuzzy environment. Based on the TOPSIS method, he has defined a closeness coefficient to conclude the prioritizing order of all chosen ideal solutions by estimating the distances to both the fuzzy positive-ideal solution and fuzzy negative-ideal solution simultaneously. Yurdakul and Ic (2005) by employing the FAHP and FTOPSIS techniques have introduced a performance measurement model that could be utilised to get an overall performance score by calculating the accomplishment of an industrialized corporation in its operational performance. In a further case, Zarghaami et al. (2007) have utilised the TOPSIS method as a fuzzy multiple attribute decision making on their water resources development case study for prioritising water transfers to Zayanderud basin in Iran. Buyukozkan et al. (2008) for choosing of the strategic alliance collaborators in logistics value chain after generating the assessment criteria hierarchy and calculation of the criteria weights by using the FAHP technique have employed the fuzzy TOPSIS to obtain the final results after prioritizing of the selected collaborators. Ebrahimnejad et al. (2009) have utilized the TOPSIS under a fuzzy environment for risk prioritizing intention with a demand to an onshore gas-related facility. Torfi et al. (2010) have employed a FAHP to calculate the relative weights of their assessment criteria and FTOPSIS to prioritize their ideal solutions. Prakash and Barua (2016) have utilized AHP and TOPSIS techniques to examine an integrated robust hybrid model for third-party reverse logistics partner selection under fuzzy environment. In the last work, Ligus and Peternek (2018) 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 previously in this paper, a FAHP technique has been employed for estimating the relative weights of the hazards. In this section by extending the FAHP; FTOPSIS can be used for choosing of the most appropriate alternative solutions or best strategies, i.e. controlling or mitigation factors. As per risk assessment phase, while using FAHP, relative weights of the identified hazards in marine ports and offshore terminals were determined (See illustrative Table 1). Consequently, in this stage, FTOPSIS as per available literature will be used after this.

2.3.2.1. The FTOPSIS Methodology

The principle of a TOPSIS technique (See Figure2) is derived from choosing the best choice, which has the shortest distance from the positive-ideal solution and the longest distance from the negative ideal solution (Huang and Yoon, 1981). It is mostly not easy for a decision-maker to assign a precise performance rating to the addressed choice for the criteria under study. The advantage of employing a fuzzy method is to set the relative importance of the criteria employing fuzzy numbers in place of precise numbers. This study extends the TOPSIS to the fuzzy environment. The Fuzzy MCDM (i.e. Multiple-Criteria Decision-Making) can be in brief demonstrated in a matrix set-up as depicted in Equations 2.1 and 2.2.

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

(2.1)

$$\tilde{W} = [\tilde{w}_1, \ \tilde{w}_2, \ldots, \ \tilde{w}_j, \ \ldots, \ \tilde{w}_n]$$

(2.2)

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), $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ and $\tilde{w}_j = (a_{j1}, b_{j2}, c_{j3})$. Note that $\tilde{x}_{ij}$ is the performance rating of the ith alternative, A_i, with respect to the jth criterion, $\tilde{w}_j$ represents the weight of the jth criterion, C_j. The normalized fuzzy decision matrix indicated by $\tilde{R}$ is depicted in Equation (2.3):

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n}$$

(2.3)

The weighted fuzzy normalized decision matrix is shown in Equation 2.4:

$$\tilde{V} = \begin{bmatrix} \tilde{v}_{11} & \tilde{v}_{12} & \cdots & \tilde{v}_{1n} \\ \tilde{v}_{21} & \tilde{v}_{22} & \cdots & \tilde{v}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{v}_{m1} & \tilde{v}_{n2} & \cdots & \tilde{v}_{mn} \end{bmatrix} =$$

$$\begin{bmatrix} \tilde{w}_1\tilde{r}_{11} & \tilde{w}_2\tilde{r}_{12} & \cdots & \tilde{w}_n\tilde{r}_{1n} \\ \tilde{w}_1\tilde{r}_{21} & \tilde{w}_2\tilde{r}_{22} & \cdots & \tilde{w}_n\tilde{r}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{w}_1\tilde{r}_{m1} & \tilde{w}_2\tilde{r}_{m2} & \cdots & \tilde{w}_n\tilde{r}_{mn} \end{bmatrix}$$

(2.4)

The benefit of employing a fuzzy theory is to assign the relative importance of the hazards utilising fuzzy numbers rather than precise numbers. This article employs the TOPSIS under fuzzy environments. This method is mainly suitable for solving decision-making issues under fuzzy environments. Utilising the addressed fuzzy technique, the planned FTOPSIS method can subsequently be processed as follows:

Step 1: To choose the linguistic variable $(\tilde{x}_{ij})$ i = 1, 2, . . ., m; j = 1, 2, . . ., n for mitigation alternatives with respect to evaluated hazards and the corresponding linguistic variables ($\tilde{w}_j; j$ = 1, 2, . . ., n) for the weights of the assessed hazards. The fuzzy linguistic variable $(\tilde{x}_{ij})$ preserves the property that the ranges of normalized TFNs belong to [0, 1]; therefore, there is no requirement for a normalization process. For instance, the $\tilde{D}$ defined by Equation 2.1 is equal to the $\tilde{R}$ defined by Equation 2.3.

Step 2: To generate the weighted normalized fuzzy decision matrix. The weighted normalized value $\tilde{V}$ is calculated by Equation 2.4.

Step 3: To choose 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 depicted in Equations 2.5 and 2.6:

$$A^* = \{\tilde{V}_1^*, \tilde{V}_2^*, \dots, \tilde{V}_n^*\} = \{(\max_i \tilde{v}_{ij} | \, i = 1,\dots, m), j=1, 2,\dots, n\} \quad (2.5)$$

$$A^- = \{\tilde{V}_1^-, \tilde{V}_2^-, \dots, \tilde{V}_n^-\} = \{(\min_i \tilde{v}_{ij} | \, i = 1,\dots, m), j=1, 2,\dots, n\} \quad (2.6)$$

Minimum and maximum operations do not provide TFN, but it is expected to form the approximated values of maximum and minimum as TFNs. It is recognized that the elements $\tilde{v}_{ij} \forall i,j$ are normalized positive TFNs, and their ranges belong to the closed interval [0,1]. Therefore, 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.

Step 4: To estimate the separation measures. The distance of any mitigation alternative from A^* and A^- can be calculated by utilizing Equations 2.7 and 2.8:

$$d_i^* = \sum_{j=1}^{n} d\,(\tilde{v}_{ij}, \tilde{v}_j^*), \qquad i = 1, 2, \dots, m \quad (2.7)$$

$$d_i^- = \sum_{j=1}^{n} d\,(\tilde{v}_{ij}, \tilde{v}_j^-), \qquad i = 1, 2, \dots, m \quad (2.8)$$

Step 5: To verify the similarities to the ideal solution. This step determines the similarities to an ideal solution by Equation 2.9:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \quad (2.9)$$

Step 6: To prioritize the mitigation factors. Choose a mitigation factor with maximum CC_i^* or prioritize mitigation factors in proportion to CC_i^* in descending order.

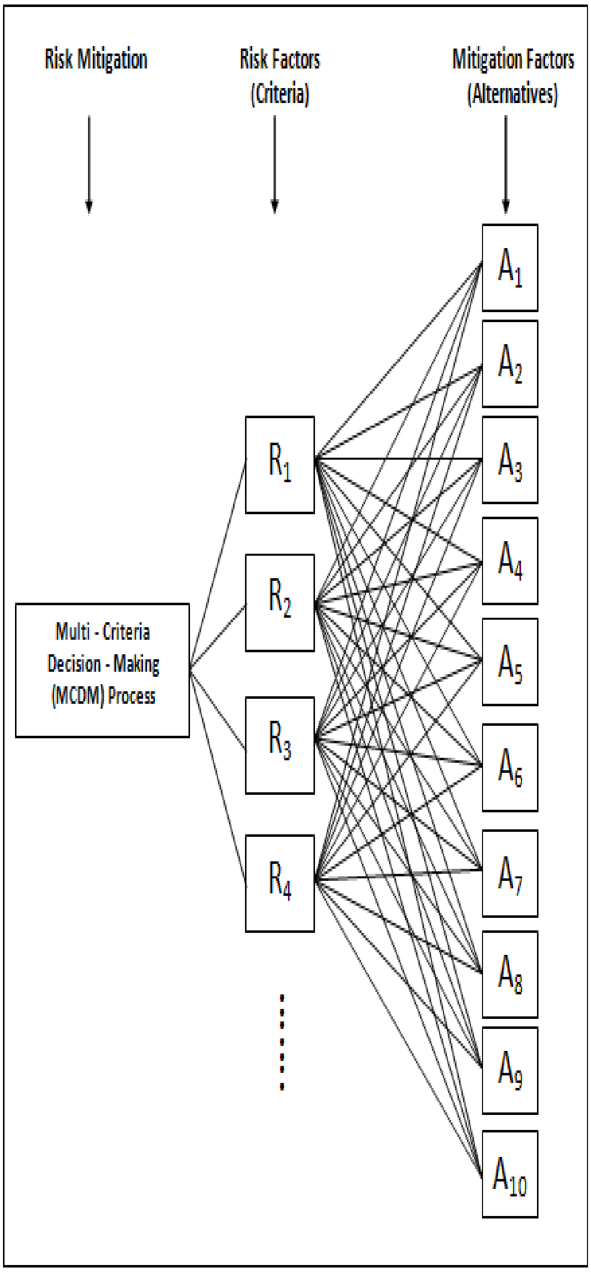

Figure 2: Decision making via using multiple choices to mitigate the identified hazards

3. Case study

In this case study, Figure 3, Table 1.1 and Table1.2 are an only illustrative example of marine ports and offshore terminals to be used for this paper to examine the proposed QRM methodology.

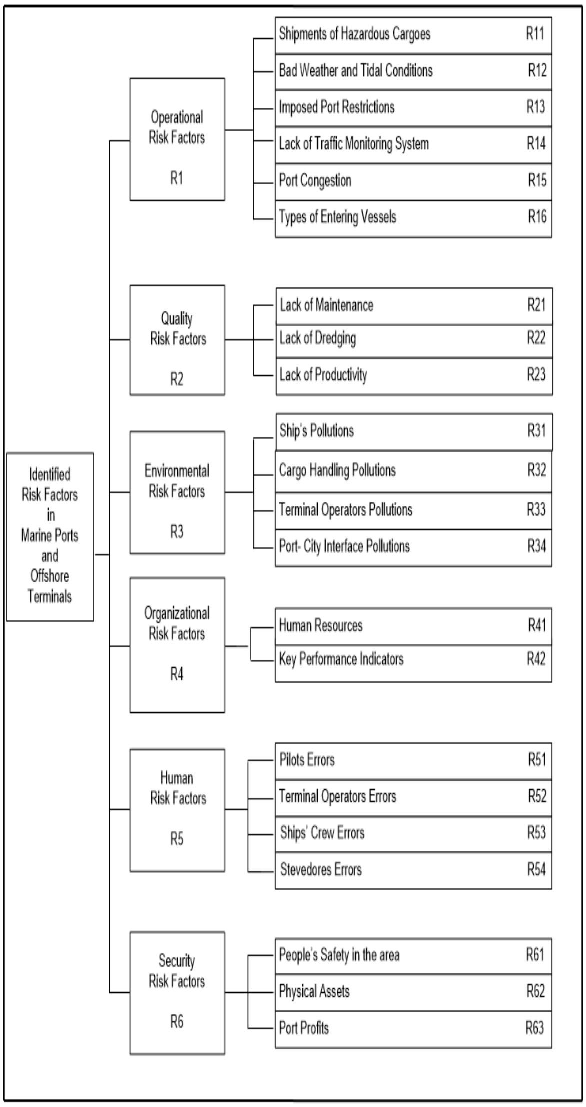

Figure 3: Hierarchy of previously identified Risk Factors in offshore terminals and marine ports

In order to carry out the first phase (i.e. Hazard identification) of the addressed QRM methodology shown in Figure 1, previously identified hazards related to marine ports and offshore terminals are shown in Figure 3 where such risk factors were identified through the hazard identification process, i.e. HAZID. In the second phase (i.e. 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 Tables 1.1 and 1.2. As a result, the most significant risk factor identified was found to be R_{61}, i.e. people's safety in the area of marine ports and offshore terminals

Table 1.1: Results found after hazard priority assessment made on the identified risk factors

Main Risk Factor	Level 1 Risk Factors	Local Weights	Level 2 Risk Factors
Identified Risk Factors in Marine Ports and Offshore Terminals	Operational Risk Factors	(0.171)	Shipments of Hazardous Cargoes
			Bad Weather and Tidal Conditions
			Imposed Port Restrictions
			Lack of Traffic Monitoring System
			Port Congestion
			Types of Entering Vessels
	Quality Risk Factors	(0.158)	Lack of Maintenance
			Lack of Dredging
			Lack of Productivity
	Environmental Risk Factors	(0.167)	Ship's Pollutions
			Cargo Handling Pollutions
			Terminal Operators Pollutions
			Port-City Interface Pollutions
	Organisational Risk Factors	(0.142)	Human Resources
			Key Performance Indicators
	Human Risk Factors	(0.177)	Pilots Errors
			Ship's Crew Errors
			Terminal Operators Errors
			Stevedores Errors
	Security Risk Factors	**(0.185)**	**People's Safety in the area**
			Physical Assets
			Profits

Table 1.2: Results found after hazard priority assessment made on the identified risk factors

Level 2 Risk Factors	Local Weights	Global Weights	Rankings
Shipments of Hazardous Cargoes	(0.040)	(0.007)	21
Bad Weather and Tidal Conditions	(0.340)	(0.058)	7
Imposed Port Restrictions	(0.102)	(0.017)	19
Lack of Traffic Monitoring System	(0.398)	(0.068)	5
Port Congestion	(0.035)	(0.006)	22
Types of Entering Vessels	(0.085)	(0.014)	20
Lack of Maintenance	(0.351)	(0.055)	9
Lack of Dredging	(0.293)	(0.046)	11
Lack of Productivity	(0.356)	(0.056)	8
Ship's Pollutions	(0.505)	(0.085)	3
Cargo Handling Pollutions	(0.174)	(0.029)	13
Terminal Operators Pollutions	(0.215)	(0.036)	12
Port-City Interface Pollutions	(0.106)	(0.019)	17
Human Resources	(0.545)	(0.077)	4
Key Performance Indicators	(0.465)	(0.066)	6
Pilots Errors	(0.554)	(0.098)	2
Ship's Crew Errors	(0.150)	(0.026)	15
Terminal Operators Errors	(0.161)	(0.028)	14
Stevedores Errors	(0.135)	(0.024)	16
People's Safety in the area	**(0.650)**	**(0.120)**	**1**
Physical Assets	(0.251)	(0.047)	10
Profits	(0.099)	(0.018)	18

In continuation of the second phase (i.e. Risk assessment) as per Figure 1, the most significant risk factor (R_{61}) was further investigated for its causes (i.e. basic events or casual factors) and consequences using a bow-tie method, i.e. Risk analysis tool (See Figure 4) including employment of FTA and ETA under fuzzy environment. This was supported through a predefined scenario in the form of terrorists' attacks to an existing LNG Export Terminal site (i.e. an LNG Export Terminal along with a commercial seaport of Qalhat in Sultanate of Oman) depicted in Figure5 and Figure 6. All the causation reasons for happening of the risk factor (R_{61}) in the form of basic events (i.e. BEs) are shown in the fault tree diagram of Figure 7.

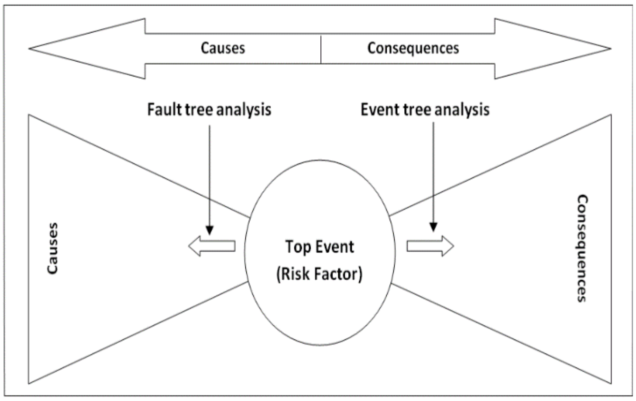

Figure 4: A bow-tie diagram (Risk analysis tool)
Source: Adopted from ABS (2019) and GEXCON (2019)

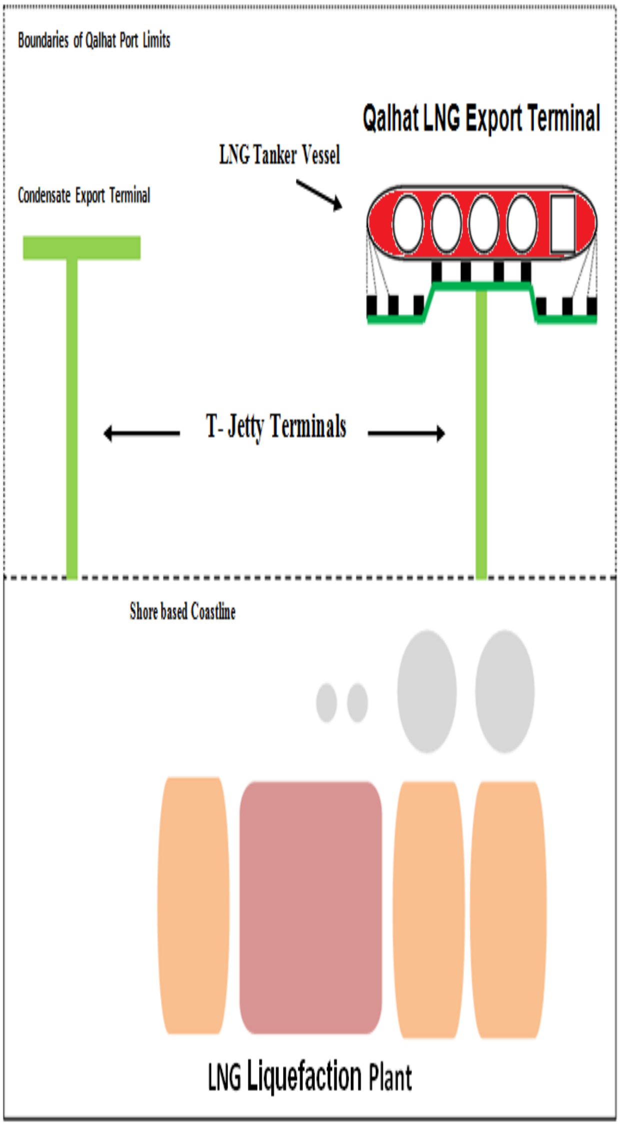

Figure 5: Marine Port of Qalhat in Sultanate of Oman

Figure 6: Qalhat LNG Export Terminal

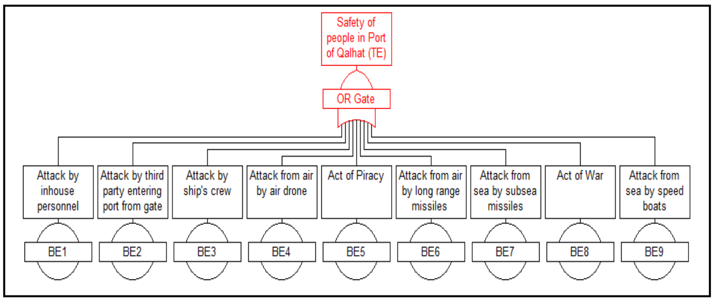

Figure 7: A fault tree drawing for the top event (i.e. TE) or risk factor R_{61}
Source: Expressed types of basic events are based on ISPS (2011), ICS (2017) and NE P&I (2018)

The occurrence possibility for top event R_{61}, i.e. people's safety in the area of LNG Export Terminals and marine port of Qalhat in Sultanate of Oman was calculated using FTA under a fuzzy environment. In fuzzy environments, possibility approaches replace the probability approaches where the traditional FTA is used. The occurrence possibility of R_{61} was found to be 0.782 as per following described details:

Because of the lack of data and the evidence that the entire essential events are imprecise to assess the hazard, i.e. R_{61}, it was preferred to conduct the assessment via experts' judgements. For this reason, to facilitate most favorable experts' judgements in this study, three maritime-related professionals have been chosen to perform the addressed judgement. All professionals have their Bachelor and Master degrees in nautical science and shipping related fields. Additionally, everyone has been acted as a port pilot before for ten years in several seaports and offshore terminals within the Persian Gulf. Each one also has about ten years' experience on ports' and terminals' operations and management. Currently, the addressed professionals shave executive roles in various operational fields in seaports and terminals. The most crucial factor for choosing these professionals was based on their capability that they have similarly contributed to the sectors associated with the identified hazards depicted in Figure3. For this cause, these professionals will have the same weights regarding each other that would influence the assessment procedures evenly. After accumulating the professionals' opinions with a means of the assessment sheet by employing of the Equations 3.0, 3.1 and 3.2 subsequentcomputations are performed to find out the FPSs (i.e. Fuzzy Possibility Scores) for the mentioned basic events shown in Figure 7.

$$\tilde{M}_1 \oplus \tilde{M}_2 = (l1, m1, u1) \oplus (l2, m2, u2) = (l1 \oplus l2, m1 \oplus m2, u1 \oplus u2) \quad (3.0)$$

$$\tilde{M}_1 \otimes \tilde{M}_2 = (l1, m1, u1) \otimes (l2, m2, u2) = (l1 \otimes l2, m1 \otimes m2, u1 \otimes u2) \quad (3.1)$$

$$M_i = \sum_{i=1}^{m} W_{j} A_{ij} \quad ,\ j=1, 2,\ldots, n \quad (3.2)$$

BE1 = W1 ⊗ VL ⊕ W2 ⊗ VL ⊕ W3 ⊗ L = (0.00, 0.08, 0.33)

BE2 = W1 ⊗ VL ⊕ W2 ⊗ L ⊕ W3 ⊗ L = (0.00, 0.17, 0.42)

BE3 = W1 ⊗ VL ⊕ W2 ⊗ VL ⊕ W3 ⊗ L = (0.00, 0.08, 0.33)

BE4 = W1 ⊗ M ⊕ W2 ⊗ M ⊕ W3 ⊗ VL = (0.17, 0.33, 0.58)

BE5 = W1 ⊗ VL ⊕ W2 ⊗ VL ⊕ W3 ⊗ L= (0.00, 0.08, 0.33)

BE6 = W1 ⊗ M ⊕ W2 ⊗ L ⊕ W3 ⊗ VL = (0.08, 0.25, 0.50)

BE7 = W1 ⊗ M ⊕ W2 ⊗ L ⊕ W3 ⊗ M = (0.17, 0.42, 0.67)

BE8 = W1 ⊗ VL ⊕ W2 ⊗ VL ⊕ W3 ⊗ L= (0.00, 0.08, 0.33)

BE9 = W1 ⊗ L ⊕ W2 ⊗ L ⊕ W3 ⊗ M = (0.08, 0.33, 0.58)

Following the collection of the professionals' opinions and combining them via Equation 3.3, the supplementary estimation will be performed to calculate FPS of the nominated top event or hazard, i.e. R_{61} in Port of Qalhat. Therefore, failure possibility of the security-related top event, i.e. people's safety in the area will be estimated via fuzzy fault three analysis utilizing the Equations 3.2, 3.3 and 3.4 as follows:

$$\tilde{P}_{(OR)} = \tilde{1} \ominus \prod_{i=1}^{n} (\tilde{1} \ominus \tilde{P}_i); \qquad \tilde{1} = (1,1,1)\ \Pi \quad (3.3)$$

$$\tilde{M}_1 \ominus \tilde{M}_2 = (l_1, m_1, u_1) \ominus (l_2, m_2, u_2) = (l_1 \ominus u_2, m_2 \ominus m_1, u_1 \ominus l_2) \quad (3.4)$$

Subsequently, as the outcomes of the estimations performed for this study are all in the form of fuzzy numbers, a supplementary a defuzzification process must be conducted to change them into the form of crisp numbers. The center of area defuzzification method is decided to be utilized in this study after this. It is the most frequently used method and is precise. This technique can be declared for fuzzy triangular numbers using below-mentioned formulas:

Triangular fuzzy number $\tilde{M}$= (*l, m, u*) can be defuzzified and converted into a crisp number of M by i.e.

$$M = \frac{(l+m+u)}{3} \quad (3.5)$$

$\tilde{P}_{TE(R61)} = \tilde{1} \ominus [(\tilde{1} \ominus \tilde{P}_{BE1}) \otimes (\tilde{1} \ominus \tilde{P}_{BE2}) \otimes (\tilde{1} \ominus \tilde{P}_{BE3}) \otimes (\tilde{1} \ominus \tilde{P}_{BE4}) \otimes (\tilde{1} \ominus \tilde{P}_{BE5}) \otimes (\tilde{1} \ominus \tilde{P}_{BE6}) \otimes (\tilde{1} \ominus \tilde{P}_{BE7}) \otimes (\tilde{1} \ominus \tilde{P}_{BE8}) \otimes (\tilde{1} \ominus \tilde{P}_{BE9})]$ = (0.419, 0.875, 0.997) = 0.767 i.e. defuzzified failure possibility or FPS for R_{61}.

All formulas and methodologies used for the bow-tie method, FTA and ETA can be found in the work of Ferdous (2006) and Ferdous et al. (2009). All equations and methodologies for experts' judgements, FST, AHP method and calculations for the Fuzzy AHP technique are as per Chang (1996) extent analysis which also can be found in work of Mokhtari and Amani (2019).

Analyzing and interpreting the results:

The calculated FPS of the top event i.e. $\tilde{P}_{TE(R61)}$ is found to be 0.767. After that, by the elimination of every event, new FPSs will be obtained for the top event (P_{TEi}) correspondingly as depicted in Table 2. Consequently the amount for every deviation i.e. $(P_{TE(R61)} - P_{TEi})$ has been declared in the deviation index column shown in Table 2. The more significant number for deviation index means having higher importance on the failure possibility of the top event. That means the elimination of any basic even, which can lead to a higher deviation index will decrease the failure possibility of the top event (R_{421}) more than in the case of other eliminations. As it is illustrated in Table 2basic event number four, i.e. BE_4, has the maximum importance among others. In $[\tilde{P}_{TE(R61)} \ominus \tilde{P}_{TEi}]$; *TE* ($R_{421}$) denotes top event of R_{61}, i.e. "people's safety in the area" of marine ports and offshore terminals and *TEi* denotes the top event which its *i*th basic event is eliminated.

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

Elimination of Basic Events	Possibility Approach					
	Fuzzy number			Occurrence possibility(P_{TEi})	Deviation index ($P_{TE(R61)} - P_{TEi}$)	Ranking
	l	*m*	*u*			
BE 1	0.419	0.875	0.995	0.763	0.004	6
BE 2	0.419	0.863	0.994	0.759	0.008	5
BE 3	0.419	0.875	0.995	0.763	0.004	6
BE 4	0.303	0.828	0.992	0.708	0.059	2
BE 5	0.419	0.875	0.995	0.763	0.004	6
BE 6	0.366	0.847	0.993	0.736	0.031	4
BE 7	0.300	0.804	0.990	0.698	0.069	1
BE 8	0.419	0.875	0.995	0.763	0.004	6
BE 9	0.366	0.828	0.992	0.729	0.038	3

Figure 8 demonstrates the sensitivity analysis performed for the risk factor R_{61}, as per the results depicted in Table 2. It illustrates that via elimination of anyone of the events how the failure possibility for the top event will be decreased gradually.

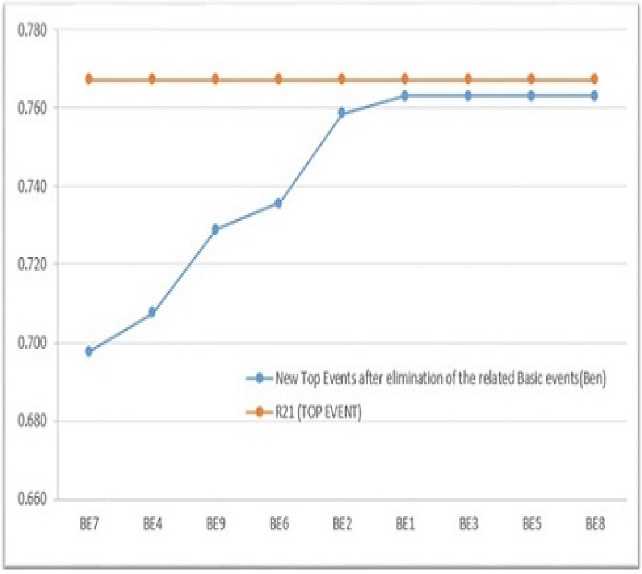

Figure 8: Sensitivity analysis of the top event or risk factor R_{61}

As NE P&I Club (2018) explains consequences which can contribute to the risk factor, R_{61} are loss of life, severe and minor injuries respectively. Figure 9 illustrates the ETA of the R_{61}, along with fuzzy linguistic variables.

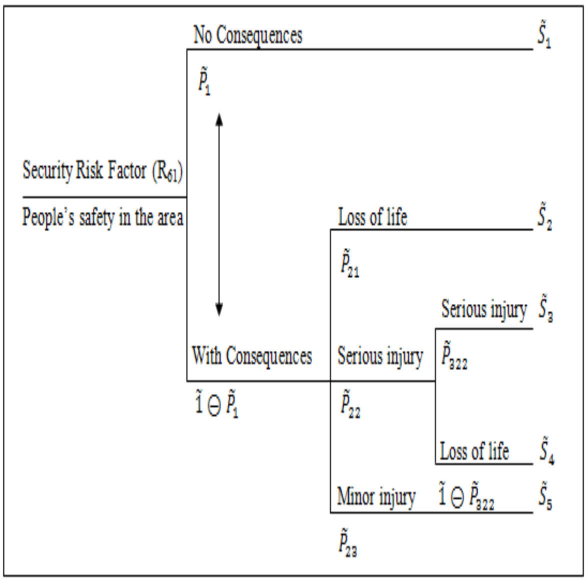

Figure 9: Event tree analysis for hazard number R_{61}
Source: Expressed consequences are as per ISPS (2011) and NE P&I (2018)

In order to determine the occurrence possibility scores of the consequences started from the appointed risk factor R_{61}, it has been preferred to perform the assessment using the experts' judgements. The same professionals performed the experts' judgements for FFTA have been invited for the assessment here. By using the mentioned Equations in Section 4, the final results can be

obtained as follows:
$\tilde{S}_1 = \tilde{P}_1$= W1 ⊗ L ⊕ W2 ⊗ L ⊕ W3 ⊗ L = (0.00, 0.25, 0.5) = 0.25

$\tilde{S}_2 = (\tilde{1} \ominus \tilde{P}_1) \otimes \tilde{P}_{21}$= (0.5, 0.75, 1.00) ⊗ (W1 ⊗ L ⊕ W2 ⊗ H ⊕ W3 ⊗ H) =
(0.5, 0.75, 1.00) ⊗ (0.33, 0.58, 0.83) = (0167, 0.438, 0.833) = 0.479

$\tilde{S}_3 = (\tilde{1} \ominus \tilde{P}_1) \otimes \tilde{P}_{22} \otimes \tilde{P}_{322}$= (0.5, 0.75, 1.00) ⊗ (W1 ⊗ VH ⊕ W2 ⊗ VH ⊕ W3 ⊗ H) ⊗
(W1 ⊗ M ⊕ W2 ⊗ M ⊕ W3 ⊗ M) = (0.5, 0.75, 1.00) ⊗ (0.67, 0.92, 1.00) ⊗ (0.25, 0.50, 0.75) = (0.08, 0.34, 0.75) = 0.392

$\tilde{S}_4 = (\tilde{1} \ominus \tilde{P}_1) \otimes \tilde{P}_{22} \otimes (\tilde{1} \ominus \tilde{P}_{322})$ = (0.5, 0.75, 1.00) ⊗ (W1 ⊗ VH ⊕ W2 ⊗ VH ⊕ W3 ⊗ H) ⊗ (0.25, 0.50, 0.75) = (0.5, 0.75, 1.00) ⊗ (0.67, 0.92, 1.00) ⊗ (0.25,0.50, 0.75)= (0.08, 0.34, 0.75) = 0.392

$\tilde{S}_5 = (\tilde{1} \ominus \tilde{P}_1) \otimes \tilde{P}_{23}$= (0.5, 0.75, 1.00) ⊗ (W1 ⊗ VH ⊕ W2 ⊗ VH ⊕ W3 ⊗ H) =
(0.5, 0.75, 1.00) ⊗ (0.67, 0.92, 1.00) = (0.333, 0.688, 1.00) = 0.674

The final results are listed in Table 3, along with rankings for different consequences. As it can be seen consequence S_5, i.e., loss of life as a result of an attack to the mentioned LNG Export Terminals and Marine Port of Qalhat in Sultanate of Oman will affect the safety of the people within the addressed area more than other consequences. As terrorist attacks are intentional acts carried out deliberately to make destructions and/or harming people (mainly physically) therefore the most significant consequence, i.e. S_5found in this case study justifies the nature of the risk factor (i.e. hazard) R_{61}.

Table 3: Occurrence possibility scores for different consequences

Consequences	Occurrence possibility scores	Rankings
No Consequences	0.250	4
Minor injury	0.479	2
Serious injury	0.392	3
Loss of life as a result of serious injury	0.392	3
Direct loss of life	0.674	1

All formulas and methodologies used for the bow-tie method, FTA and ETA can be found in the work of Ferdous (2006) and Ferdous et al. (2009). All equations and methodologies for experts' judgements, FST, AHP method and calculations for the Fuzzy AHP technique are as per Chang (1996) extent analysis.

To accomplish the third and last phase (i.e. Risk mitigation) of the QRM methodology in Figure 1 and to control the identified hazards demonstrated in Figure 3 for this paper it is decided to use a Fuzzy TOPSIS method. Concerning Figure 2, TOPSIS method is one of the best decision-making tools used in many applications, as explained earlier.

Based on the reviewed literature and referred references in Table 4, there are different strategies and alternatives to mitigate and control the addressed identified risk factors for marine ports and offshore terminals. Ultimately the best alternatives after using experts' judgements and using of the mentioned equations in Section 2 of this paper about TOPSIS method under fuzzy environment are ranked as per their priorities shown in Table 4.

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

Alternativ	Names of	CC_i	Rankin
A2	IMS (ISO:	0.153	1
A4	QHSES - Risk	0.153	1
A6	VTMS	0.152	2
A7	ISPS Code	0.136	3
A10	Performance	0.102	4
A9	Plan	0.087	5
A3	Safety Cases and	0.087	6
A8	Port State	0.072	7
A1	Privatisation	0.032	8
A5	Internal Audits	0.018	9

Sources for mitigation factors: Chang et al. (2019); Makofske (2019); Chen et al. (2017); IMO (2019); Baraforta et al. (2018); Sui et al. (2018); Acheamponga and Akumperigyab (2018);
Mouet al. (2019) and Lia et al. (2019).

4. Conclusion and further suggestions

Marine ports and offshore terminals are critical infrastructures for the 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 marine and offshore industry, all of which necessitate for being concerned their identification, evaluation and mitigation with the help of a proper QRM methodological approach, if this industry is going to be responsive to the strategic requirements and future challenges. To achieve this first, it is essential an appropriate QRM methodology be incorporated into all of the functions and processes, e.g. management within the marine and offshore industry and secondly decision-makers to have strategic management approach during the implementation of the addressed QRM methodology. However, there is a need to become conversant with the methodology of QRM in the marine and offshore industry at a holistic level in order to achieve this initially. For these reasons, a generic QRM methodology for marine and offshore industry applications was presented in this paper. The proposed QRM methodology in this paper can cause seaports' and offshore terminals' 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 accurately analyze the risk of potential hazards in marine ports and offshore terminals and help them during their decision making processes. Moreover, the addressed professionals can use the addressed QRM methodology in conjunction with their related software-based decision-making programmes to determine the 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 ones that can suit their QRM decision making processes. This will depend on the type, nature and 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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