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RISK ASSESSMENT METHODS IN SEAPORTS

A Literature Review

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ABSTRACT

Seaports are centres of trade which contribute significantly to sustaining growth and development of the economy. They generate business activity through their operations and are critical interfaces between sea and land supply infrastructures. Due to their complex operations, the heterogeneity of stakeholders and critical location, seaports are exposed to a wide range of developing and changing risks. Unforeseen or underestimated hazards can lead to complications that will most likely result in human, environmental, material or economic damages. This research work aims to identify suitable risk assessment methods that can be applied in seaports. The methodology for the literature review involves the consultation of two databases in an evaluation period from 1980 to 2017. The exploration is based on a set of keywords and phrases to extract significant data. After the data screening, refinement process and evaluation of the information, 58 research articles are acquired for the analysis. This study helps to summarize the hazard sources which are classified into: natural and man-made; factors of risk which are enlisted in different categories: climate, operational, safety, technical, organizational, environmental, socio-economic and political. Moreover, a review of the different qualitative, semi-quantitative and quantitative approaches to assess risks in port areas is presented in order to suggest a particular set of suitable methods that could be used by the different stakeholders at seaports. In addition, based on the results of the analysis, future research areas are recommended with a focus on an empirical study.

Keywords: risk; hazard; seaport; port; risk assessment

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LIST OF ABBREVIATIONS

AFRV	Average Fuzzy Resulting Values
AHP	Analytical Hierarchical Process
BBN	Bayesian Belief Networks
BT	Bow-Tie
BWTS	Ballast Water Treatment System
CPT	Conditional Probability Table
DAG	Directed Acyclic Graph
DoB	Degrees of Belief
DPSIR	Driver, Pressure, State, Impact, Respond
D-S	Dampster-Shafer
ER	Evidential Reasoning
ERA	Environmental Risk Assessment
ET	Event Tree
ETA	Event Tree Analysis
EU	European Union
FAHP	Fuzzy Analytical Hierarchical Process
FMEA	Failure Mode Effect Analysis
FRB	Fuzzy Rule-based
FRBER	Fuzzy Rule-based Evidential Reasoning
FRBN	Fuzzy Rule-Based Bayesian Networks
FRF	Fuzzy Risk Frequency
FRI	Fuzzy Risk Index
FRS	Fuzzy Risk Severity
FRV	Fuzzy Resulting Values
FST	Fuzzy Set Theory
FTA	Fault-Tree Analysis
FTN	Fuzzy Triangular Number
FuRBaR	Fuzzy Rule-based Bayesian Reasoning
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
GIS	Geographical Information System
GNOME	General NOAA Operational Modelling Environment
HAZOP	Hazard and Operability study
HE	Hazardous Event
HIRA	Hazard Identification and Risk Assessment
IDS	Intelligent Decision System
IEC	International Electro-technical Commission
IR	Index of Risk
LOPA	Layers of Protection Analysis
mERMq	Mean Effects Range-Median quotient

MESA	Maritime Environment for Simulation Analysis
MSA	Maritime Safety Bureau
PAH	Polycyclic Aromatic Hydrocarbons
PEC	Predicted Environmental Concentration
PIS	Port Infrastructure System
PNEC	Predicted No Effect Concentration
PORMAT	Port Risk Management
PRA	Probabilistic Risk Assessment
PTOM	Sea ports and Offshore Terminal Operations and Management
RA	Risk Assessment
RC	Relevant Chemical
RE	Risk Estimation
RM	Risk Management
RMDA	Risk-Management-based Decision Analysis
RMM	Risk Matrix Model
RPN	Risk Priority Number
SD	Science Direct
SE	Security Estimate
SM	Similarity Measure
SPR	Source-Pathway-Receptor
SPRC	Source-Pathway-Receptor-Consequence
SRA	Seismic Risk Assessment
WoS	Web of Science

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1 MOTIVATION AND INTRODUCTION

Seaports are an important aspect in modern international transportation networks and systems. they play an important role in global production and distribution systems being responsible for more than 80% of international trade (Branch, 2012; Hall, 2007). Also, they have a high impact on the economy of the area where they are found (Ramani, 2016; Repetto et al. 2017) and are considered to act as a link in transport chains (Branch, 2012).

Based on these characteristics, it has become critical to effectively and efficiently evaluate and manage their risks in order to protect the people and the environment along with maintaining the quality and performance. Singh (2013) suggested that after identifying the threats, it is imperative to evaluate them and determine which security measures are required to manage risks. Therefore, a risk assessment approach needs to be conducted involving every aspect related to this industry; such as ships, facilities and other objects.

The objective with the most priority for the risk assessment is to analyse threats taking into account their consequences and probabilities in order to define the risk. Particularly, seaports possess an extraordinary amount of hazards, which will lead to different types of risks that can be categorized into: environmental, natural, operational, security, technical and organizational (John et al., 2014; Arisha and Mahfouz, 2009).For instance, it has been demonstrated that ports are vulnerable to seismic motion and other natural disasters (Arisha and Mahfouz, 2009). After the latest terrorist attacks, concern has arisen regarding potential harms in ports (Bier, Haphuriwat, 2011; Rosoff, Winterfeldt, 2007). Moreover, employees in some seaports have expressed that they feel less prepared for rare events and organized crime (Quigley and Mills, 2014).

In order to evaluate the different risks that disrupt operations in seaports and to reduce the economic loss and harm to people, different authors (e.g. Alyami et al., 2014; Alyami et al. 2016; Chlomoudis et al. 2016; Ding and Tseng, 2012; Grifoll et al. 2010; John et al., 2014; John et al. 2016; Mokhtari et al. 2011; Pallis, 2017; Rømer et al. 1993; Rosoff and Winterfeldt, 2007; Sánchez-Rodríguez et al. 2011; Trbojevic and Carr, 2000; Zhang et al., 2014) have investigated the diverse approaches of risk assessment that will help to identify the security measures required. Furthermore, these investigators have also discussed which method is, in their opinion, the most adequate for the source of risk.

In the next pages of this research work, qualitative, quantitative and semi-quantitative risk assessment approaches will be reviewed. Qualitative approaches are normally used as a preliminary risk management activity that can help assess whether or not a risk requires further investigation; quantitative methods are often characterized by the use of probabilistic information in regards of potential events and their consequences and semi-quantitative methods are a combination of the two previous methods. The main difference among the different methods is the technique used to create and share the information in order to reach a conclusion (Coleman and Marks, 1999; Wooldridge, 2008).

Over the years, the reduction of potential hazards has been an important aspect in different industries. In order to successfully decrease their risks, a clear assessment strategy needs to be followed. The objective of this work is to analyse the existing literature with regards to the different qualitative, quantitative and semi-quantitative risk assessments approaches implemented in seaports. This will support the identification of the most suitable methods that can be potentially implemented in this sector.

Based on the literature available, this research will focus on answering the next questions:

- What are the main hazard sources and their possible consequences on seaports?
- Which risk factors affect the operations and safety of seaports?
- Which methods and approaches for risk assessment from the literature can be used to identify, analyse and/or evaluate risks in seaports?

In order to answer the previously mentioned interrogations, a deep and robust literature review will be executed. The structure of the work is as follows: section 1 gives a basic explanation of the importance of risk assessment in seaports and provides an introduction to the inquiries to be explored in this work. Section 2 establishes a theoretical description of seaports, including their significance in the economy and stakeholders. Similarly, it highlights important terminology related to risks and describes the different approaches for assessing them. Section 3 presents the methodology used to extract the information from the literature with regards to hazards sources, factors of risk and risk assessment methods. Section 4 provides the different outcomes of the analysis. Lastly, section 5 summarizes the work performed, identifies limitations of the study and offers future research areas.

2 THEORETHICAL FOUNDATION

This section provides an overview of the operations and characteristics of seaports. It also describes important terminology related to risks and provides an overview of the different types of risk assessment methods.

2.1 Seaports

Ports are distribution facilities where commercial maritime operations take place; these vary in assets, roles, functions and organization. Moreover, ports differ in size and can range from small quays for berthing a ship to large centres with terminals. Ports usually have an optimal critical location in order to have access to transportation links via sea, river, canal, road, rail and air routes. Some other attributes that port hold are waterfronts, maritime and estuary bases, logistic centres, trade centres, corridors and gateways as well as warehouses (Bichou and Gray, 2005).

Seaports are crucial systems for coastal cities and for the worldwide mobility chain of goods and people. They are an attractive part of a city that facilitates imports, exports and transportation of goods. More specifically, one can argue that a seaport system is a link needed to carry goods or people from one destination to another, including also the necessary infrastructure, such as containers, cranes and ships (Nevins et al. 1998).

Important to mention is that, seaports are considered a critical factor for the economy of seaside cities and maritime countries (Repetto et al., 2017). Mokhtari et al. (2012) claimed that these infrastructure systems are fundamental elements that can affect a country's cost structure, industry competitiveness and living standards. Seaports are equally important for trade networks where channel control and ownership can be identified or traded. Furthermore, they also serve as a link for process flows and create new patterns of working by helping in the performance improvement of the supply chain (Bichou and Gray, 2005).

As it can be observed, seaports play an important role in different commercial activities, however, these are also extremely complex systems where the labour required is considered to be high, because of the widespread use of personnel and technological equipment (Nevins et al., 1998). Additionally, seaports are particularly exposed to extreme threats that can cause numerous types of risks, which can be categorized into operational, environmental or natural, security, technical and organizational (John et al., 2014; Arisha and Mahfouz, 2009). These different types of risks will lead to unexpected disruptions that can cause harm or damage.

Another important aspect related to the complexity of seaports is the fact that these systems have a wide range of stakeholders. Based on Notteboom and Winkelmans (2002), the authors Becker et al. (2015) as well as Denktas-Sakar and Karatas-Cetin (2012) suggested to categorize stakeholders in two groups: *internal and external* (Figure 1).

The *internal stakeholders* include port authorities, managers, employees, board members, shareholders and unions. *External stakeholders* are subcategorized depending on their interest, objectives and influence. *Economic direct* stakeholders included logistic services (e.g. shipping agencies), supporting industries (e.g. ship repairers) and industrial companies (e.g. insurers). *Economic indirect* investors refer to port customers, trading companies and importers/exporters. *Legislation and public* parties involve all-level government departments involving transport and economic affairs. Lastly, *academic and community* stakeholders included civil organizations, general public, press, universities, and environmental non-profit organizations (based on Notteboom, and inkelmans, 2002 as presented in Becker et al., 2015; Denktas-Sakar and Karatas-Cetin, 2012).

Because of the high importance and complexity of seaports, adequate methods are needed to enhance their security and competiveness. Seaports need to take into account their complex environment, daily operations, climate conditions and stakeholders to carry out risk assessments in order to implement and follow a well-established risk management (RM) process. However, port managers are facing issues regarding the lack of appropriate methodology and evaluation techniques to identify and assess risks and take good decisions (Mokhtari et al., 2012).

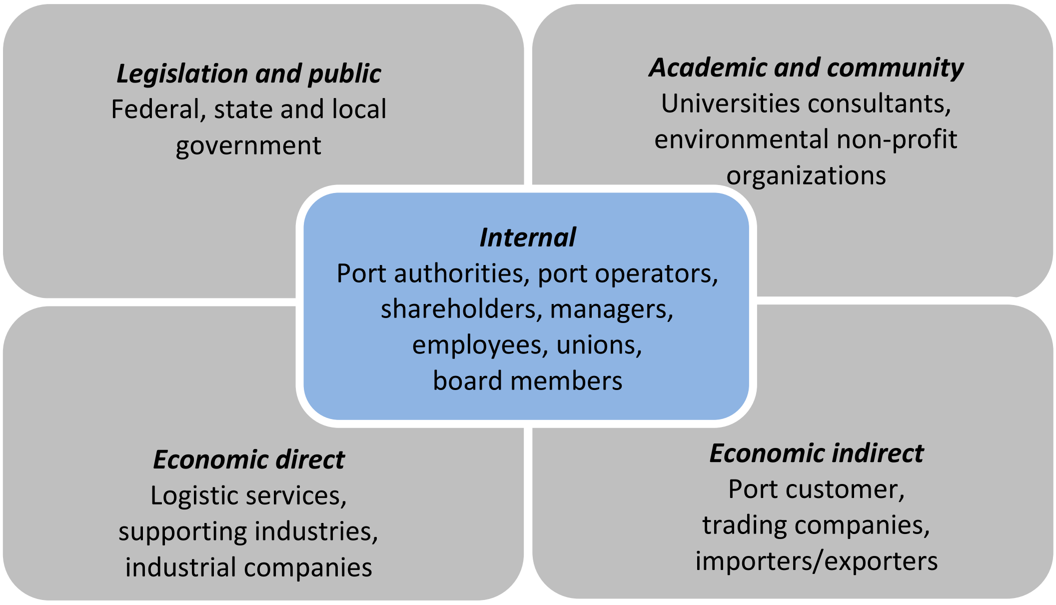

Figure 1: Stakeholder categorization of ports
(own illustration based on Notteboom / Winkelmans, 2002)

2.2 Risk and its related notions

It is important to consider the fact that the term "risk" is used in the day-to-day life, and that not everybody has the same conception of its meaning. Normally, the terms hazard, threat and risk are confused in their use, and people might think that these can be used in the same context.

Aiming to provide a clear understanding of the discussion, overall definitions of important terminology in risk assessment methods will be defined. These descriptions are carefully selected by reviewing previous studies.

First of all, a *hazard* is a condition, characteristic or situation which exists and has the potential to cause harm. This state might also potentially lead to an undesirable event generating risks to people, environment or corporations (Aven, 2016; Cameron et al., 2017; Kwesi-Buor et al. 2016; Singh, 2013; Sullivan-Wiley and Short Gianotti, 2017). In other words it is the "potential" or "possibility" to cause damage to individuals, environment and infrastructure.

Threats are situations that can trigger a hazardous source and raise the risk probability in a system or infrastructure (Singh, 2013). An *event* is an occurrence that has an associated causes and consequences. Events depend on other conditions and therefore, comprise different potential outcomes which vary in severity (Aven, 2016). *Accidents* are unplanned and unintended events which can cause damage to people or entities (Kwesi-Buor et al., 2016). In order to avoid accidents, hazards, threats and risks need to be acknowledged and evaluated.

After the previous explanation of significant terminology, it becomes easier to define the term "risk". *Risks* are unwanted, negative probabilities of occurrence of an event that can cause an accident, loss or damage (Aven, 2016; Mannan, 2012; Singh, 2013; Sullivan-Wiley and Short Gianotti, 2017). An easier view of this definition was given by Singh (2017) and supported by Sullivan-Wiley and Short Gianotti (2017) who represented the relationship of the probability and the consequence of a risk with the following formula:

$$R = P\ x\ C$$

where R = risk; P = probability; and C = consequence

The *probability* is the likelihood of occurrence or existence of a potential risk and the *consequence* is the severity, damage or loss given by the risks (Dong and Cooper, 2016). Some risk assessment techniques begin the process of analysis with a well-defined *undesirable or top event*; for instance, the total failure of a system and inability to perform its functions (Apostolakis and Lee, 1977).

2.3 Risk assessment

People argue everyday whether or not an action is safe (Denning and Budnitz, 2017); this is a clear example of an everyday risk assessment approach. However, individuals should comprehend the risks that are associated with the hazard sources in order to have the possibility to take an action or decision and be able to apply protective measures (Sullivan-Wiley and Short Gianotti, 2017).

As previously mentioned, managers in seaports are required to assess and manage risks in the different maritime operations. A risk management (RM) process aims to help in addressing these issues based on a structured approach to aid the decision-making process. Typically, this RM framework has four main phases; hazard identification, risk assessment, risk mitigation and risk monitoring as shown in Figure 2 (Mokhtari et al., 2012).

The first step, hazard identification is an essential and fundamental step to successfully assess and manage risks (Cameron et al., 2017). However, this research will focus specifically in the second phase; the risk assessment, which is basically the measuring process of potential risks (Singh, 2017).

In a risk assessment the objective is to analyse threats that will lead to a hazardous event. Thereafter, the potential risks and their consequences and probabilities need to be evaluated. Moreover, it is essential to identify a strategy to determine whether a risk is acceptable or what should be done to make it acceptable, taking into account the different uncertainties or assumptions. Furthermore, this process should help identify known, unknown and surprising events; and assess their probability of happening as well as their consequences (Aven, 2017). In its most basic approach a risk assessment method should answer the next questions: “what can go wrong?”; “how likely is it?”; and “what are the consequences and their severity?” (Apostolakis, 2004; Pasman et al. 2017).

Risk assessment as a scientific field is considered to be not more than 40 years old (Aven, 2016). The American Bureau of Shipping (2000) suggested that the insurance industry was one of the first ones to develop these methods or techniques in order to be able to calculate and assess customers risks. Pasman et al. (2017) also argued that because of the harmful accidents in the oil-based industry, studies or methodologies that could judge risks were urgently needed.

For these reasons, governments started requiring corporations to implement measures to reduce risks and also demonstrate operation at a feasible level of risk (American Bureau of Shipping, 2000; Pasman et al., 2017; Silbergeld, 2017). Organizations such as the U.S. Environmental Protection Agency[1] (American Bureau of Shipping, 2000; Silbergeld, 2017), the EU Offshore Safety Directive[2] and the European Seveso Directive[3] (Pasman et al., 2017) have focused on prevention of current and future risks by requiring public and private companies to deliver safety reports containing detailed information of the evaluation, mitigation and prevention techniques for risks.

[1] https://www.epa.gov/
[2] https://ec.europa.eu/energy/en/topics/oil-gas-and-coal/offshore-oil-and-gas-safety
[3] http://ec.europa.eu/environment/seveso/

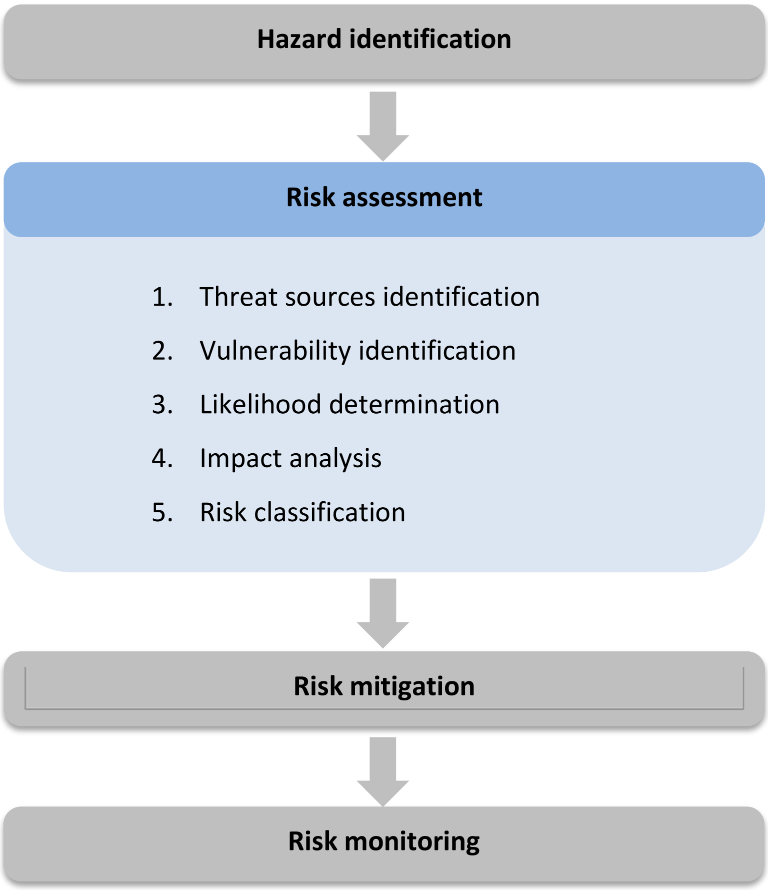

Figure 2: Risk Management (RM) process
(own illustration)

Based on Aven (2017), Singh (2017) and the American Bureau of Shipping (2000) a risk assessment comprises the following stages:

1. *Threats sources identification:* put together the necessary knowledge base in order to make a judgement of the potential threats that can raise a hazard and lead to a risk or top event; this includes also assumptions and beliefs made.
2. *Vulnerability identification:* identify who is at risk, synthetize available information to acknowledge people who might be harmed and anticipate threats.
3. *Likelihood determination*: calculate the probability of these threats to prioritize risks.
4. *Impact analysis:* critically analyse and record the corresponding level of risk and uncertainty.
5. *Risk classification*: different classes for the identified risks based on the conducted analysis.

One of the main objectives of the first step, threats and source identification, is to analyse hazards originating from the internal and external characteristics of a particular system. All sources of information can be used, for instance historical data, theoretical analysis, informed opinions and concerns of stakeholders.

This will help create a database of the potential risk scenarios. As it can be observed, the main question that need to be answered during this stage is “what can go wrong?” In addition, there are methods that can support in this analysis such as the hazard and operability study (HAZOP) and the failure mode and effect analysis (FMEA) (Kasai et al. 2016).

This leads us into the risk evaluation step, where the associated risks need to be analysed and evaluated taking into account the perception of both stakeholders and decision makers (Clarke, Obrien, 2016). The decision-makers or risk managers have to take all evidence into account to reach a decision with the help of the risk assessment method to inform the relevant stakeholders about the choice made (American Bureau of Shipping, 2000; Aven, 2016; Sumner and Ross, 2002).

Managers in every industry have always had the responsibility to make good decisions in order to achieve the established goals (Abukabar et al. 2017). Even though individuals tend to make intuitive decisions; based on patterns, feelings or objects; a more rational or analytical style is needed in order to make wise judgments that will bring better benefits. The decision-making process requires methodical approaches to identify all potential choices and be able to take risk-informed judgments. These processes and every other activity in an organization involves managing the potential risks (IEC 31010, 2009).

Abukabar et al. (2017) and American Bureau of Shipping (2000) suggested that a good decision-making process should help establish a varied set of alternatives, identify relevant decision conditions and consequences. Moreover, it should also support in providing fitting approaches for review and communication. This is the reason why a well-stablished risk assessment is needed to support the decision process. Through the years, private and public institutions in different industries have become more and more familiar with the different risk assessment techniques. This has helped in increasing their implementation in decision-making processes as well as in the evaluation of different categories of risks.

As aforesaid, a risk assessment approach typically answers three main questions and the process to follow involves the steps elaborated in Figure 2. Basically, once the hazard sources have been identified, the overall risks can be assessed. The risk assessment process can be carried out using different *qualitative*, *quantitative* or *semi-quantitative* techniques. The approach chosen depends on the information available, degree of quantifications desired and the complexity of the situation (Pasman et al., 2017).

A qualitative risk assessment was one of the first approaches used. This technique tends to be used in a wide majority of industries because of its easiness and comparative characteristics which can help in ranking the identified risks (Pasman et al., 2017). This approach is a simple rapid assessment, where even a single person can gather the necessary information to conclude the analysis. Moreover, this type of method is used whenever there is a lack of adequate information, resources and/or time.

When using this method, the overall risks are assessed as a function of exposure regarding the probability and severity. The probabilities are the potential scenarios that could lead to an event and the severity is the magnitude of the consequences of the risk. These characteristics of a potential accident are evaluated or ranked using non-numerical descriptors (Department for Environment Food; Rural Affairs, 2016; Jori et al., 2009).

Qualitative methods include, for instance, influence diagrams, surveys, and checklists (Pallis, 2017). The first step of a qualitative approach should be to define the scale that will be consistently used to evaluate the risks. For instance, in order to evaluate the probability of an accident, the terms shown in Table 1 can be used. Moreover, the severity should be ranked according to a criterion that expresses the consequences or damages that might lead to an accident.

Table 1: Terms which can be used to evaluate probability of accidents

Term	**Description**
Negligible	rare event, it does not need to be considered
Very low	rare event, however, cannot be excluded
Low	rare event but can occur
Medium	event occurs on a regular basis
High	event occurs often
Very high	occurrence of event is certain

In a qualitative approach, risks are usually categorized into “high”, “medium” and “low”, and are represented in a risk matrix (see Table 2). This matrix will represent the previously mentioned characteristics, probability of occurrence and severity, and will also integrate the potential accident scenarios that were identified in the threat identification stage (Kasai et al., 2016). Within the matrix, the criticality of a risk can be denoted through the use of colours as explained in Table 3 (Pasman et al., 2017). The results provided by this matrix can be used to compare risks and identify suitable mitigation measures.

Table 2: Example of a risk matrix (own illustration based on Gravey, Lansdowne 1998)

Severity / **Probability**	Negligible	Minor	Moderate	Serious	Critical
Very likely to occur	Medium	Medium	High	High	High
Likely to occur	Low	Medium	Medium	High	High
May occur about half of the time	Low	Low	Medium	Medium	High
Unlikely to occur	Low	Low	Low	Medium	Medium
Very unlikely to occur	Low	Low	Low	Medium	Medium

Table 3: Colour code in the risk matrix

Colour	**Description**
Yellow (Light grey)	safe or risk is acceptable
Orange (Medium grey)	may be unsafe or risk needs to be reduced
Red (Dark grey)	unsafe or risk is unacceptable

In the context of more complicated or high-technology industries, applications or systems, a more adequate quantitative approach is required to effectively evaluate risks. A quantitative risk assessment is a technique that requires intense analysis and therefore includes more detailed information and results (Pasman et al., 2017).

Similar to the qualitative approach, a quantitative approach the threats sources need to be identified as well as potential event scenarios. Then, the evaluation relies on numerical values which are assigned to the probability of damage, harm or loss. The result will indicate likelihood of risk, and can be ranked using a numerical scale; for instance, from 0 to 1, where 1 demonstrates the highest risk probability.

This analysis is based on objective, high-quality data and well-developed project or simulation models. The main difference between a qualitative and quantitative approach relies on the fact that in a quantitative risk assessment, mathematical and simulation tools are used to assess possible outcomes and calculate their probability.

The next approach, the semi-quantitative method, provides an intermediary technique between the “word-based” evaluation of qualitative risk assessment and the “numerical” evaluation of quantitative risk assessment. It is a method that offers a more consistent and rigorous approach to evaluate and compare risks than what a qualitative process does, but it does not reach the outcome levels of a quantitative method. This method also helps to elude ambiguities or uncertainties regarding the estimation and magnitude of the risks.

A semi-quantitative risk assessment can incorporate, for instance, a qualitative evaluation of the risk frequency and a quantitative assessment of the severity or vice versa. The risk score will then be represented as a product of risk frequency and the severity of the consequences (Moonis et al. 2010). A risk matrix can also be used in a semi-quantitative method. The main difference to a qualitative one is that instead of using linguistic labels (low, medium, high) to assess the severity and probability, established numerical values are used. For instance, the rows could represent the increasing likelihood of consequences, and the columns the increasing severity of the correspondent consequences. After that, the quantification of the risk is performed, by multiplying the probability of occurrence and severity.

During every type of assessment, qualitative, quantitative or semi-quantitative; people need to take into account what is known and what it is not. With these assessments, managers and decision makers can evaluate strengths and weaknesses and use resources in an effective way. In conclusion, a *qualitative risk assessment* is a subjective evaluation of the probability and severity; a *quantitative risk assessment* is a probabilistic approach to rank and appraise risks; and a *semi-quantitative risk assessment* is an “intermediary” approach which uses both qualitative and quantitative techniques to judge risks.

3 METHODOLOGY

In order to guarantee the quality and consistency of the work, the presented project performs a comprehensive literature review using a systematic research methodology based on Tranfield, Denyer and Smart (2003) as well as Soni and Kodali (2011). The methodology used provides a new space to obtain and analyse the information available and a suitable examination of judgements or decisions, procedures and conclusions.

The research methodology followed is designed along five steps as shown in Figure 3. The preliminary phase includes the identification of relevant information which is the basis for the better understanding of the project. The main objective of the first phase is to delimit the search string which will be used; here it is important to define the time horizon, select the databases and define the keywords and phrases. The second phase involves the data screening and selection of potential papers as well as the data refinement in order to collect relevant articles. The third phase contains the categorization of the relevant articles and the data synthesis. Lastly, the findings are documented while addressing the research questions.

During the preliminary phase, the global tasks to perform and the expected outcomes are clearly clarified. Moreover, the necessary important terms and definitions are emphasized aiming to provide an equivalent knowledge that will act as a background.

A systematic search begins with the identification of the time horizon. The definition of the time period was linked to the objective of the project. In this case, it was important to consider as many risk assessment approaches or techniques related to seaports as possible. Therefore, a period that considered at least the last three decades was necessary; the evaluation period of the articles is between 1980 and 2017. Moreover, this year frame can effectively support the identification of up-to-date hazards sources with their associated risks that affect seaports. Aiming to cover most of the major journals in management, logistics, supply chain and operations management, the following library databases were used: *Science direct* and *Web of science.*

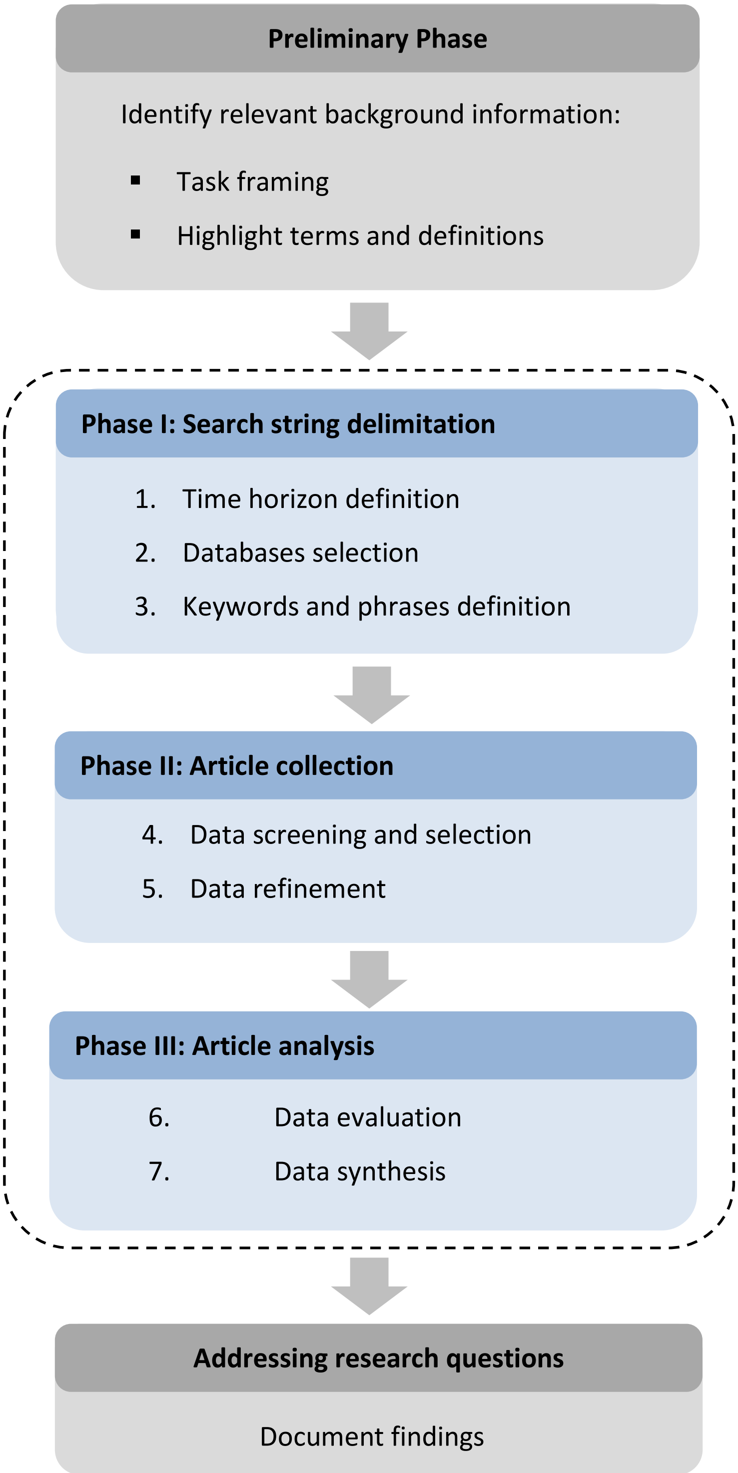

Figure 3: Systematic literature review phases
(own illustration based on Tranfield et al., 2003 & Soni and Kodali, 2011)

The next step is to define the keywords that were used to search in the different databases. Based on the final outcomes of the project, a specific set of keywords was carefully selected. These terms needed to be broad enough to capture and at the same time provide an acceptable set of papers. The main keywords used were: *risk, hazard, threat, port, container terminal, seaport and harbour.* Boolean operators, such as *"AND" and "OR"* were used in order to combine them and obtain better results. The search string was defined as followed: Title: (risk OR threat OR hazard) AND (port OR container terminal OR seaport OR harbour) OR Abstract: (risk OR threat OR hazard) AND (port OR container terminal OR seaport OR harbour) OR Keywords: (risk OR threat Or hazard) AND (port OR container terminal OR seaport OR harbour).

Nevertheless, using this search string returned many articles that focused on other different topics. This forced the creation and use of different phrases related to the research topic. The objective here was to obtain narrower correlated results and avoid spending unnecessary time and effort evaluating irrelevant articles. Consequently, the search included the phrases "*risk assessment", "risk management", "risk analysis"* and *"port safety"* which were used as an exact expression to look for in the databases. The Boolean operator "OR" was used to separate these phrases instead of an "AND" aiming to find as many articles as possible that encompassed these similar expressions.

Additionally, after including the key phrases, it was observed that the databases still pitched articles which were not completely related to the topic in discussion. After a careful revision, it was observed that several results were associated with the road transportation and bank industry; and also to some derivative words related to "port". This is the reason why an exclusion criterion was prepared, which included the terms: *airport, portfolio, road, rail and bank.*

An overview of the search criteria established to find relevant results for the study is presented in Table 4. The search protocol also included the selection of particular disciplines in which relevant results could be found; this characteristic was also specific for each database and included sciences or research areas, and categories related to topics such as: Engineering, Mathematics, Operations Research Management, Decision Sciences and Environmental disciplines. The specifics disciplines or categories selected per database can be found in Table 5.

Furthermore, Table 5 also shows the final search strings used in each database; as one can observe, there are only minor alterations that were necessary because, as mentioned before, each database has its own search characteristics or mechanisms. With the use of the search string, a vast amount of potential articles was obtained. In *Science Direct*, 371 results were found and in *Web of Science,* 338.

Having obtained more than 700 results from the databases inquiries, the next step; data screening and selection was performed. Here, the main objective was to assess the different papers regarding their connotation and relevance to the research topic. First, the titles of the articles were evaluated resulting in the extraction of 42 papers from Science direct and 65 from Web of Science for further analysis. Afterwards, the selected and collected information was refined in order to compare and remove duplicated articles; this resulted in 93 potential publications.

Table 4: Search criteria used

Item	Description
Time horizon	1980-2017
Databases	Science Direct, Web of Science
Keywords	risk; hazard; threat; port; container terminal; seaport; harbour
Key phrases	risk assessment; risk management; risk analysis; port safety
Excluding	airport; portfolio; road; rail; bank
Boolean Operators	AND; OR; NOT
Search fields	Title; abstract; keywords
Language	English

Table 5: Final search string used per each database

Database	Search string	Discipline or category
Science Direct	Topic: (risk OR hazard* OR threat*) and (port* OR "container terminal" OR seaport OR harbour) and ("risk assessment" OR "risk analysis" OR "port safety" OR "risk management") and not (airport OR road* OR rail* OR portfolio OR bank*)	Chemical Engineering, Decision Sciences, Engineering, Environmental Science, Mathematics
Web of Science	Topic: (risk OR hazard* OR threat*) AND (port* OR "container terminal" OR seaport OR harbour) AND ("risk assessment" OR "risk analysis" OR "port safety" OR "risk management") NOT (airport OR portfolio OR road* OR rail* OR bank*)	Engineering Chemical, Operations Research Management, Science, Transportation, Engineering Environmental, Engineering Industrial, Engineering Marine, Engineering Ocean, Environmental Studies, Mathematics Interdisciplinary Applications

During the third phase; the abstracts of the 93 different articles were carefully examined and analysed. The different publications were assessed based on their applicability and quality; at least one of the following conditions should be fulfilled in the abstracts in order to consider the associated paper: Highlight the different sources of hazards in seaports or similar infrastructures; Presentation of qualitative, quantitative or semi-quantitative models and methods for risk assessment in seaports or similar infrastructures; Provide an overview or explanation of mayor risk factors in seaports or similar infrastructures; Include safety or risks analysis, as well as potential accidents in seaport or similar infrastructures.

4 RESULTS

The outcomes of the literature review previously described are explained in this section. First, an overview of the sources of hazards as well as the diverse factors of risks and their consequences are presented. Secondly, the different procedures or methods used to assess risks within ports are elaborated. Lastly, suggestions regarding the best suitable methods for seaports are given.

4.1 Hazard sources and factors of risk in seaports

Hazard sources identification is one important step that must be followed in order to effectively assess vulnerabilities, threats and the potential risks in seaports. If a hazard is somehow missed, overlooked or underestimated, it might likely produce an inadequate expected top event. This is a reason why, it is extremely important to create a comprehensive list of foreseeable hazard sources. Particularly regarding seaports or similar infrastructures, because these are important systems where a series of accidents or catastrophic events could endanger the life and operations of people and organizations respectively.

In port facilities, there are many known and unknown hazard sources; aiming to classify them in an effective and understandable manner, two terms were selected: *natural or man-made hazards* as shown in Figure *4* (Birkmann, 2011; John et al., 2016; Kaundinya et al., 2016; Schmidt et al., 2011; Zhang and Lam, 2016; Zhou et al. 2010). Important to mention is that these terms have been successfully used in other transport infrastructures.

Natural hazards are ordinary occurring processes which exist in the natural environment (Kaundinya et al., 2016; Schmidt et al., 2011). These hazards possess a threat to societies and organizations because they occur due to uncontrollable changes in the physiognomies of the planet such as hydrological, meteorological, seismic, geologic, volcanic or mass movement variations (Kaundinya et al., 2016). For instance, in the past years, the world has experienced extremely dangerous natural disasters, including tsunamis, hurricanes and earthquakes (Zhou et al., 2010). Seaports or similar organizations are extremely vulnerable to these hazards because of their critical location (Yang et al., 2010); these environmental or climate changes have a great potential to cause a negative impact on humans working in ports, on the community and on the related operational activities.

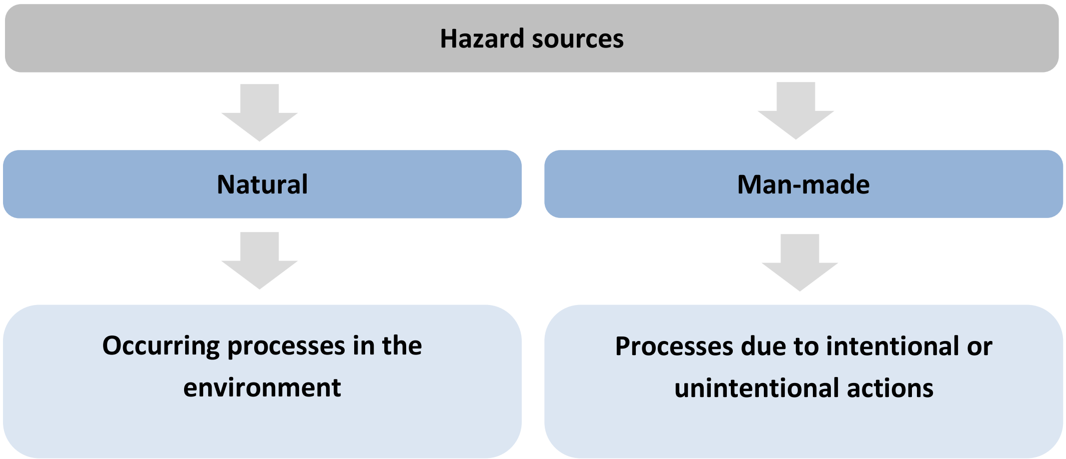

Figure *4*: Types of hazard sources

There are different studies conducted which mention natural hazard sources related to seaports. John et al. (2016) mentioned that floods, snowstorms, hurricanes or earthquakes represent dangerous natural hazard sources in seaports. The authors Trbojevic and Carr (2000) enumerated specific and related natural hazard sources in ports; they included all types of extreme weather events or conditions. For instance, they also described the potential accidents or harmful events that might happen when weather exceeds the ship or vessel design conditions as well as the seaport operations standards.

Moreover Mansouri et al. (2010) listed as well the different types of climate conditions which can be a source of hazard to ports and create severe incidents. For instance, geologic and seismic hazard sources, such as earthquakes, tsunamis, hurricanes and cyclones. They analysed the port of Boston and found out that category 3 and 4 hurricanes along with snowstorms could generate severe economic and social consequences.

Jin Na and Shinozuka (2009) particularly examined the impact related to seismic events. In this case, seaports could have damages that could degrade their normal operations. In specific cases, the quay, piers, cranes or warehouses could be severely disrupted, thus having an undesirable effect. For instance, the authors mentioned that in 1995 the Kobe port in Japan received direct physical damage due to an earthquake, which was amounted to more than $9 billion within the first 9 months of the event.

Unlike natural hazards, man-made or human hazard sources are intentional or unintentional actions that have a potential to cause harm to people, environment or organizations (Kaundinya et al., 2016). In other words, a man-made hazard source derives mainly from one or more deliberate or negligent human actions.

Grifoll et al. (2010) discussed the different activities associated with the potential contamination of water in the premises of the Barcelona harbour; these included, bunkering activities from vessels, oil spills from boats, and pollutants from shipyard and construction activities.

Mansouri et al. (2010) enlisted as well hazard sources in the port of Boston that are related to transportation of dangerous goods (chemical spills) and failures of information systems. Moreover, John et al. (2014) also discussed some of the hazard sources related to these type of top events. For instance, they mentioned that the handling of hazardous cargo or petroleum products could lead to cargo spillages. Additionally, interferences such as IT outbreaks and port control systems or databases could potentially lead to cyber- or terrorism attacks (John et al., 2014; Polatidis et al., 2018). Table 6 summarized the hazard sources with associated examples.

Table 6: Categorization of hazard sources and examples

Type of hazard source	**Hazard source category**	**Examples of hazards sources**
Natural	Hydrological	Floods
	Geophysical	Earthquake, tsunami
	Metrological	Extreme wind, snowstorm
Man-made	Operational	Loading/unloading activities Movement of containers, usage of cranes/carriers Reversing vehicles Storage and transportation of dangerous goods Lifting, carrying or manoeuvring activities Container dimensions or weight (excessive) Dredging activities
	Safety	Spills/leakage of materials Working on heights or dock edges Unguarded machinery or cargo Electrical installations (malfunctions) Unknown traffic of illegal goods Unauthorized access to online databases
	Technical	Complex automated systems Failure of digital navigation or IT systems
	Organisational	Improper hierarchical/unclear organization Excessive workload Lack of know-how, training, communication Incompatible goals among employees Poor management procedures
	Environmental	Use of corrosive chemicals, oil spills Transportation of toxic materials

Alyami et al. (2014) and Alyami et al. (2016) mentioned specific hazardous events related to different sources: transportation circumstances, including collisions, for instance due to break down of cranes or rail-mounted cranes and trailers; storage conditions, such as potential leakage of substances and ignition due to the transportation of dangerous goods; handling situations, including situations such as uneven surfaces or contaminated premises and falling objects; transportation problems, mobile equipment on the quay and stacked or suspended containers.

Elsayed (2009) described and evaluated six different dangerous scenarios considered during the loading and unloading operations at terminals. The different descriptions included leakages on the cargo system, release of liquid nitrogen and bunker oil, fire in the engine room and on open deck. Sunaryo and Hamka (2017) also mentioned hazard sources such as bad weather, unclear regulations, corroded floors and unfit working conditions.

Fabiano et al. (2010) as well as Rao and Raghavan (1996) elaborated the different types of hazards related to chemical handling at ports. Among these, the authors included accidents during ship-to-shore transfer of chemicals and during berthing; disasters at cargo shed leading to explosions and toxic gas discharges; misfortune events during transportation and lifting of hazardous cargo. These hazards are extremely problematic because seaport authorities need to believe on the documentation provided by the ship owners, thus they do not have full control of the containerized hazardous chemical cargo found in the premises of the port.

Barbosa-Póvoa et al. Carvalho (2017), Fabiano et al. (2010) and Ronza, Lázaro-Touza, Carol, Casal (2009) suggested that the transportation or storage of dangerous goods is one of the major hazard sources in port areas. These activities could cause several accidents and have economic and environmental impacts. Valdor et al. (2016) developed a map showing the environmental impact caused by different hazardous sources, such as chemical substances, eutrophication processes and bacteriological contamination. Moreover, Sánchez-Rodríguez et al. (2011) performed an analysis of the environmental risk factor caused by hazardous chemicals.

The authors Trbojevic and Carr (2000) also included man-made hazards, such as impact and collision events, comprising vessel collisions or berthing impacts; ship-related hazards, containing flooding and loading/unloading; navigation hazards, such as pilotage errors and command errors; manoeuvring-related accidents, including berthing/unberthing errors; fire/explosions, involving fires in engines; loss of containment, such as release of flammables or toxic materials; and pollution, including oil spills. They also stated that hazard can be represented by different threats which have the potential to create a top event.

Table 7 gives an overview of the different categories of hazard sources that could potentially create a top event. Important to mention is that a phenomenon can have both man-made and natural hazards at the same time (Kaundinya et al., 2016).

The performed literature review revealed that the risk factors associated with seaport operations are extremely challenging, due to the evolution of maritime systems and the complexity of the interrelated structures and stakeholders. Based on the research, a risk factor is an attribute, characteristic or exposure that can increase the likelihood of having a top event or risk. The selection and exemplification of the risk factors in seaports were based mainly on the work performed by John et al. (2014), Mali et al. (2017) and Mokhtari et al. (2011).

John et al. (2014) described and categorized the significant risk factors that disrupt seaports processes. The authors included factors related to operations, which materialize due to machinery and equipment failures, ship/vessels accident/grounding, and cargo spillage; security, including risks associated with terrorism attacks, sabotage and surveillance system failure; technical, including maintenance of different equipment and systems used in ports; organizational, including labour unrest, berth and gate congestion; and natural, including environmental phenomena.

Mokhtari et al. (2012) and Mokhtari et al. (2011) evaluated operational risk factors in seaports and offshore terminals, including safety conditions, such as traffic, navigational and waterway structures; security factors, including people's safety and port assets; pollution situations, due to ship activities, garbage and dredging; legal circumstances, such as decisions of public authorities or approval of contracts; human factors, including worker's errors; and technical aspects, comprising maintenance of equipment and machinery.

Pallis (2017) gave an illustration of the taxonomy of risk in container terminals. He categorized the risk in five different types: human, including collisions and human errors; machinery, comprising damage to equipment or system failures; environment, such as ballast water and chemical contaminants; security, containing terrorist attacks or theft; and natural, such as earthquakes or floods.

Jin Na and Shinozuka (2009) studied the consequences of a climate risk factor. They mentioned in their paper that port facilities experience a high degree of damage, such as the disruption of seaports' operations because of seismic activities. Moreover, Mutombo and Ölçer (2017) identified climate variables that can affect seaports performance, among these are sea level rises, rainfall, wave, wind, salinity and humidity.

In their research, Mali et al. (2017) assessed the pollution risk in four ports due to heavy metal contamination. They reached to a conclusion that human factors are one of the main sources of contamination in coastal areas. Moreover, Pearson et al. (2016), Valdor, Gómez, Velarde, Puente (2016) and Valdor et al. (2016) mentioned the increased environmental risk related to oil spills in ports, which could cause ecological and public damage. Furthermore, Belamarić et al. (2016), Rømer et al. (1993) and Zhang, Teixeira, Guedes Soares, Yan, Liu (2016) evaluated the type of accidents that can lead to oil spillage including collisions, groundings, structural damage and fires or explosions.

Likewise, Bouda et al. (2016) and Zhang et al. (2014) evaluated the environmental risk associated with ballast waters carried by ships originating mainly from loading activities at ports. Also, on one hand Bedell et al. (2014), Carić e tal. (2016) and Perrodin et al. (2012) evaluated how sediments of polluted seaports create a high risk factor for the environment and the economy. On the other, Ondiviela et al. (2012) studied the operational risk factors of port contaminant discharges with regards to water quality.

Ronza et al. (2009) mentioned as well that the loss of containment of dangerous substances are related to risk factors such as failure of equipment or human errors. Besides, Zheng et al. (2011) identified a potential top event related to the construction of a port, such leakage of ship oil. This could be caused by collision or grounding accidents, fire or explosion, human errors, ballast waters or emergency discharge. Also, Chin and Debnath (2009), Debnath and Chin (2016), Debnath, Chin (2010), Debnath et al. (2011), Rao and Raghavan (1996) as well as Vidmar and Perkovič (2015) mentioned the potential operational and safety risk factors related to collisions between vessels or other vehicles in the seaport premises.

Moreover, Ding and Tseng (2012) identified four different dimensions related to safety factors and their associated risk. These included man category, such as operator's mistakes or human carelessness and omissions; machine type, such as mistakes in the safety protection selection or maintenance failures; media set, including illuminations improvement or automation operations; and management classification, such as training or lack of safety auditing.

Polatidis et al. (2018) discussed the safety risk factor associated to cyber-attacks in maritime supply chains, including unauthorized access to the networks. Also, Yang et al. (2010) gave an overview of the factors associated with terrorist attacks in ports; these could happen by attacking the entry channels or bombing the facilities at the terminals.

Table 7: Factors of risk

Risk factor	**Cause**
Climate	Geologic/seismic Hydrologic Atmospheric
Operational	Port equipment/machinery failures Vessel accident/grounding Cargo spillage Human related errors
Safety	Sabotage Terrorist/cyber attack Surveillance system failures Arson
Technical	Lack of equipment maintenance Lack of aids for navigation Lack of IT system maintenance
Organisational	Organizational structure Human resources (ethics, behaviour) Regulatory changes or delays in contracts
Environmental	Pollution Foreign species
Socio-economic and political	Social and political systems Economic status, changes in industry/market Customer and market characteristics (change)

Additionally, in their study, Rosoff and Winterfeldt (2007) analysed the possibility and probability of bomb attacks on the Long Beach and Los Angeles ports, reaching the conclusion that these types of attacks are likely to occur. However, not many lives will be lost; instead the consequences will be economical and psychological. They also listed three different categories of consequences: immediate fatalities and injuries, medium and long-term health effects and economic impacts. Important to mention is that, terrorist attacks in ports have mainly other hazard sources such as the unauthorized access to port premises

Chlomoudis et al. (2016), Pallis (2017), Pearson et al. (2016) and Ronza et al. (2009) stated that political instability, wars or social characteristics of the country could potentially be a risk factor affecting port activities. Besides, Mokhtari et al. (2012) and Pearson et al. (2016) argued that business or trade related factors could also disturb these systems.

Based on the research performed, the different factors of risk can be divided into seven categories depending on the cause and consequence that these will devise as shown in Table 7. All of these will eventually result in the disruption of seaports.

Important to mention is that after the extensive literature review, one can recognize that the human element plays one of the major roles in most hazard sources and risk factors related to seaports. The disruptions created in ports by these alterations have a high potential to create different type of damages.

In this context, the consequences are considered to derive from risk factors having a negative influence on the hazard sources. More specifically, Valdor et al. (2016) defined a consequence as a cumulative effect that arises from all hazards. These consequences can affect the people, equipment, environment, and economy (Greenberg, 2011; Grifoll et al., 2010; Mokhtari et al., 2011; Ronza et al., 2009; Thekdi and Santos, 2016; Zhang et al., 2016).

Ronza et al. (2009) presented a review of the damages derived from accidents as a consequence of hazard and risk underestimation (see Table 8). Human damages referred to loss of human life or injuries and also the evaluation costs needed to contain the effect of events. Environmental damage concerns natural resources or areas as well as the social aspect affected by the accidents. Material damage includes replacement or repairs costs. Also, the economic damage comprises loss of profit.

Table 8: Damages related to accidents in ports

Type of damage	**Damage**
Human life/health	Deaths, injuries, evacuation costs
Environmental	Biosphere, air, water, soil
Material	Equipment replacement
Economic	Loss of profit

As aforementioned, Rosoff and Winterfeldt (2007) categorized the effects of a dirty bomb attack into: injuries and instant loss of life due to blast effects and acute radiation exposure; health effects, including both mid- and long-term caused by airborne dispersal of radioactive material; and economic impacts resulting in evacuations, profit and property losses and decontamination costs.

Moreover, Rømer et al. (1993) mentioned that the hazard or transporting dangerous goods can cause different risks and accidents, he concluded that these can have a direct consequence of humans and the environment. Also, suggests that long-term port closure due accidents, can threaten local, regional, national and international economies.

Due to the fact that ports are such complex systems, the potential accident scenarios are limitless. The estimation of the consequences of hazards and risks is extremely important. There should be a system or process which allows the effective capacity to manage and prevent top events and therefore the consequences. A successful risk assessment technique needs to be carried out to avoid consequences in seaports from minor equipment damage to port closure.

4.2 Risk assessment methods used in seaports

The occurrence of disruptions related to different types of hazard sources and factors of risks are imprecise and challenging. As mentioned before, an effective and successful risk assessment method should provide a view of the possible hazard sources, the possible threats and the magnitude of risks along with their consequences.

Risk assessment methods have become an important part of the decision making process. For instance, it can be the case that managers or authorities cannot approve and execute a resolution until a risk evaluation has been performed. This is why it is essential to focus on achieving the adequate performance and eluding undesirable top-events.

Evaluation of risks in ports is a complex task due to the different aforementioned hazard sources and factors of risk. In order to have a better understanding of the risk assessment methods employed in seaports, it is imperative to give a short overview of the approaches normally used as the analysis "foundation" or "basis". These are: Failure mode and effects analysis (FMEA), fault tree analysis (FTA), event tree analysis (ETA), scenario analysis, bow-tie method, Bayesian belief networks and decision trees (see Table 9).

FMEA method has been employed in different industries for hazard identification and risk analysis. It is a traditional approach where three attributes are used to evaluate the safety level as follows: probability of occurrence (O), severity of consequences (S) and probability of failures being undetected (D). One of the main objectives of this method is to calculate the risk priority numbers (RPNs) based on the multiplication of the aforementioned three attributes (Alyami et al., 2016).

FTA constitutes a coherent analysis method to illustrate the causes of an undesirable outcome. This top-event is evaluated using Boolean logic (event, gate, transfer symbols) to explore the interrelationships between the critical event and the causes of incidence. This method can help in identifying weaknesses and effects, provide an assessment for reliability, and quantify failure probability (Mokhtari et al., 2012, 2011; Sunaryo and Hamka, 2017).

ETA has been effectively implemented to analyse the causes of accidents and to identify the hazard sources for a top-event. It is also a logical model which starts by representing an initiating top-event (initial horizontal branch) and then models the potential "pathways" (vertical branches with binary information, either success or failure). This method can be carried out qualitatively by obtaining the possible outcomes and quantitatively by evaluating the probability of occurrence (Mokhtari et al., 2012, 2011).

Decision Trees use attributes of elements for categorization and decision which are used to improve the decision-making process. These trees are visual and analytical tools where expected values/utilities of the alternatives are calculated (Shang, Hossen, 2013). Scenario analyses are descriptive models of future situations which can be used to identify risks. These explorations can include "best case", "worst case" and "expected case" and are used to analyse consequences and probabilities (Rosoff et al. 2007). Risk maps are often represented as risk matrices. These involve the creation of severity and frequency indexes to evaluate risks (Belamarić et al. 2016; Carić et al. 2016). Cause-consequence analysis is a combination of ETA and FTA where the consequences of an event are analysed based on logic gates (Mokhtari et al. 2011).

A Bow-tie method allows people to visualize the components and attributes of a top-event in a straightforward manner. The analysis starts with the identification of potential threats that could trigger a hazardous source and cause a top event. Threats and consequences are consequently analysed in order to have a full picture of the overall occurrence probability and severity of the top-event. Moreover, this type of analysis also allows analysing the potential entry and recovery barriers which can be applied to prevent the occurrence of the top event and minimize the severity of the consequences respectively (Mokhtari et al., 20112 2011; Trbojevic, Carr, 2000).

Bayesian Belief Network (BBN) uses a set of nodes or variables with their dependencies (correlated nodes) to represent interconnected functions. Expressed by directed acyclic graph (DAG), each variable has mutually exclusive states where the probabilities of the parent nodes are expressed by prior knowledge. The relationship between the dependencies is represented by conditional probability tables (CPTs) which are generated either using statistical or computational methods (Ben-Gal et al. 2007).

Table 9: Foundation methods for risk assessment

Method	Risk assessment approach
Even tree analysis	Qualitative or quantitative
Failure mode and effects analysis	Qualitative or Semi-quantitative
Fault tree analysis	Qualitative, quantitative
Risk maps	Qualitative, quantitative, semi-quantitative
Scenario analysis	Qualitative or quantitative
Bayesian belief networks	Quantitative
Decision tree	Qualitative
Bow-tie analysis	Qualitative or quantitative
Cause-consequence analysis	Qualitative or quantitative

In addition, there are also “supportive” methods which are implemented to improve the risk assessment approach (as seen in Table 10). These include Analytical Hierarchy Process (AHP), fuzzy theory, evidential reasoning (ER) and simulation methods. AHP helps in analysing complex decisions by finding the one that best suits objectives by analysing criteria, attributes or alternatives; the evaluation are done with numerical values which allow for better processing and comparison.

Fuzzy logic provides a framework in which experts’ input and experience information can evaluate uncertainty in an explicit manner by considering information described in linguistic variables (because these can model the human knowledge) and reducing the bias introduced by specialists’ judgements. These can also help to categorize attributes or elements in more than one set (different levels of truth/confidence); and recognize the absence of knowledge or rough data.

Evidential Reasoning (ER) is based on the Dempster-Shafer (D-S) theory and can deal with both quantitative and qualitative data. It is used to associate evidence obtained from two or more sources. Similar to fuzzy logic, ER can cope with uncertainty by using belief structures to represent an assessment as distribution instead of as single numerical score. It allows decision-makers to represent judgements with degrees of belief lower than 1 (Mokhtari et al., 2012).

Table 10: Supportive methods for risk assessment

Method	Risk assessment approach
Analytical Hierarchy Process	Qualitative or quantitative
Evidential Reasoning	Qualitative or quantitative
Fuzzy theory	Quantitative or semi-quantitative
Simulation methods	Quantitative

Based on the literature review performed, an overview of the quantitative and semi-quantitative risk assessment methods implemented in seaports is shown in Tables 11 & 12 . The objectives, characteristics and methodology applied in these methods fluctuate depending on the type of hazards and risks identified.

Alises et al. (2014) discussed the overtopping hazards in port infrastructures. The authors developed a methodology to help port authorities assess overtopping risks and establish preventive and corrective actions. The established model took into account the probability, consequences (cost) and vulnerability. The probability of occurrence involved the combinations of climate values which could release an overtopping risk. Thereafter, the variables were established using mathematical formulations (propagation and prediction models) and climate analysis tools. The vulnerability evaluation was defined as the exposure which may lead to a catastrophic event; this attribute was measured by a non-dimensional index which expressed potential losses (0= no possible losses, 1= destruction of the element). The overtopping cost consequences were later evaluated through weighted sets (linguistic variables) of material good or activity. Lastly, the authors mentioned that the PORMAT (Port Risk Management) software can be used to assess the risks by performing all the previously mentioned evaluation of risk attributes.

Alyami et al. (2014) believed that the traditional quantitative risk assessment could not manage uncertainty in seaports; because of this, they established an advanced Failure Mode and Effects Analysis (FMEA) which integrated fuzzy logic. The method comprised four steps: 1) Fuzzy rule based FRB formation: involved the use of IF-THEN instructions and belief structures. The risk parameters (likelihood, consequence, severity and impact) assessed with linguistic variables were in the IF part. The risk levels were rationalized and distributed with the use of Degrees of Belief (DoB) and were recorded in the THEN part of the rule; 2) HEs identification: the associated hazardous events (HEs) in container ports were identified through literature reviews. Then, a "What-If Analysis" technique was performed using experts' judgements and the major threats and impacts related to risk factors and hazards were recognized; 3) Prioritization of HEs: a BBN technique was used to represent the fuzzy rules – established in step 1 – into conditional probabilities. Then, a utility function was performed to prioritize the potential failures; 4) Validation of method: with the use of sensitivity analysis, the accuracy of results was evaluated based on different parameter values.

Moreover, Alyami et al. (2016) proposed again the use of a FMEA method based on a Bayesian Network (BN) mechanism to conduct FRB risk inference; the aim was to prioritize failure values in a more sensitive manner. First, the hazardous events (HE) were prioritized using the Fuzzy Rule-Based Bayesian Networks (FRBN) approach; this helped provide a flexible realistic data (failures) which could be updated through a Risk Estimation (RE).

Belamarić et al. (2016) analysed the pollution risk of the Port of Šibenik due to oil spill scenarios because of collision, impact and grounding. The assessment of the impact and probability of risks was performed using a risk matrix with numerical and linguistic elements. Also, the consequences of weather conditions in ships operations were quantified and the risk indicators were established to indicate the level of acceptability. In addition, the authors considered that it was necessary to simulate the scenarios to have an overview of the potential consequences of the risks using the GNOME[4] pollution spread simulation software. The data introduced in the program included oil type, properties and currents of sea water, wind and wave conditions, leaking information and clean-up operations. This semi-quantitative approach allowed the better understanding of environmental impact of oil spills in ports' premises.

Bruzzone et al. (2000) provided a synopsis of the Maritime Environment for Simulation Analysis[5] (MESA) which is a tool that can simulate various accidents or hazardous events, such as oil or other hazardous materials spills, fires, explosion. It was an interesting development which can serve as quantitative approach to evaluate risks in ports and improve safety policies and regulations.

Carić et al. (2016) proposed a method for Environmental Risk Assessment (ERA); they identified the hazards using the concept Source-Pathway-Receptor (SPR). After that, potential consequences or effects were explored using literature reviews and historical data. The impact was estimated though contamination rates and pollution costs and the risks were assessed using linguistic variables integrated in a risk matrix. The ERA provided a simple approach to calculate ecological risk levels; also, the usage of emission rates and pollution costs, conveyed logical and reliable results.

Chlomoudis et al. (2016) suggested the use of a risk matrix adapted from the IMO Formal Safety Assessment (FSA[6]) as a semi-quantitative approach. In there, the columns represented the increasing likelihood of consequences and the rows the severity. After that, the authors used frequency and severity indices to express the different level of significance (included both linguistic and numerical values). Finally, they tested the technique analysing the container terminal of the Greek port of Thessalonica. In their study, the authors used historical accidents data to estimate the occurrence and impact on human and environmental resources.

Ding and Tseng (2012) proposed a fuzzy risk assessment method which included three steps. First, the risk identification was based on literature review and comprehensive interviews to senior managers working at the port. Then, the analysis and evaluation of fuzzy risks were carried out. The authors employed linguistic variables and a risk matrix model (RMM) which was further extended to a fuzzy risk matrix to deal with vague information. This second stage of the method included the assessment of the linguistic sets of fuzzy risk frequency (FRF) and fuzzy risk severity (FRS) for each risk factor. After that, the fuzzy RVs (fuzzy values resulting from the multiplication of FRF and FRS) were evaluated; and the average FRV (AFRV) of the risk factors was calculated. Lastly, the Similarity Measure (SM) method was used to integrate the RVs into

[4] https://response.restoration.noaa.gov/gnome
[5] http://www.liophant.org/projects/mesa.html
[6] http://www.imo.org/en/OurWork/safety/safetytopics/pages/formalsafetyassessment.aspx

the risk areas in the risk matrix. The main advantage of this semi-quantitative risk assessment method can be represented by its help in expressing ambiguous information and rough terms.

Elsayed (2009) based his research on fuzzy inference; where the Mamdani and the Sugeno fuzzy inference methods were implemented. The author used these methods to assess the potential risks of loading and unloading activities at terminals. The first step involved obtaining fuzzy sets of the probabilities and consequences of accident scenarios; then, the symmetric Gaussian membership function approach was used to obtain membership functions; which provided input values to the fuzzy sets. Afterwards, probabilities, consequences and risks were mapped using IF-THEN rules. Weighting factors and Fuzzy Risk Index (FRI) were used to combine consequences and obtain a risk measure and results were presented in a qualitative/fuzzy risk matrix, which included both Mamdani's and Sugeno's inference. This semi-quantitative method was able to cope with imprecise data and provided more information than a qualitative assessment. It also delivered two different methods to compare results; the Mandani method was suited to manage human input and produced fuzzy sets under membership functions; while Sugeno was more efficient and stable, providing either linear or constant results (Soares and Santos, 2016).

Grifoll et al. (2010) used a decision making process to assess the risk of water degradation in harbour domains. The method included a branch-decision scheme of decision making theories, such as decision trees, Source-Pathway-Receptor-Consequence (SPRC) model and indexes of probability, severity and vulnerability (numerical and linguistic values). Also, in order to take into account the economic loss, the authors decided to implement an Index of Risk (risk/value), which was the risk of water degradation due to pollution events. Moreover, a comparison of the mean of water quality was performed considering also the physical behaviour of the port Integrated Index of Risk. This is considered a semi-quantitative risk assessment approach which provides an overview of the consequences about a specific pollution activity in the port.

Jin Na and Shinozuka (2009) evaluated the potential damages and disruptions in ports due to earthquakes; a computerized simulation model was developed to determine the economic loss. The model took into account studies performed on Seismic Risk Assessment (SRA), including probabilities regarding the nature and damage of this phenomenon. Flow-charts were also used to illustrate the potential loss estimation process and fragility curves were made using the Monte-Carlo method. The ARENA[7] simulation model was then used to obtain final operational data.

In their work, John et al. (2014) suggested a semi-quantitative risk assessment technique based on a novel fuzzy approach. The risk management process included first, the identification of risk factors and vulnerabilities and their presentation in a hierarchical structure; this allowed having a clear overview of the issues. Subsequently, a fuzzy analytical hierarchical process (FAHP) was implemented to obtain the weight of each parameter in the hierarchical model and arrange the risks in a top-down style. At this point, the usage of experts' opinions in the form of a linguistic

[7] https://www.arenasimulation.com/

scheme was needed (forming a pair-wise comparison matrix for severity and likelihood); the results were fuzzy triangular numbers (FTNs) representing the risk levels. After that, it was necessary to transform the fuzzy rankings into belief parameters; the authors believed that it is better to use linguistic terms rather than numerical values at the moment of assessing risks, because analysts or experts cannot always provide an "exact" estimate of them. This is the reason why the authors employed a fuzzy IF-THEN rule to describe risk attributes, transform FTNs to linguistic variables and measure risks of seaports. Next, the evidential reasoning (ER) algorithm was executed to synthetize results and a utility approach was applied to identify the "crisp" results. In addition, a sensitivity analysis was employed to corroborate the results of the model. This flexible and robust method can provide coherent insights of complex systems to managers and can be computerised to perform an advance risk-assessment.

John et al. (2016) presented a semi-quantitative logical approach where new information can be updated easily. The model implemented is a Bayesian Belief Network (BBN) which allows influencing variables to be presented in a hierarchical structure. Thereafter, a Fuzzy Analytical Hierarchy Process (FAHP) is used to assess the relative importance of each node or variable. In addition, a sensitivity analysis was introduced to validate the results.

Mabrouki et al. (2014), used a semi-quantitative risk assessment approach based on a multi-criteria method to evaluate operational risks in port terminals. First, the authors identified hazards and risks based on experience and brainstorming. They determined the risks based on a qualitative description of the probability and then, they extracted the most meaningful risks in terms of impact and occurrence. After that, it was decided to reassess the risk using a survey provided to the affected people. The results provided an overview of severity or impact (critical, major and low) and the level of mastery (excellent, good and poor). With this, they were able to perform a comparison of the risks' location zone in a risk classification matrix. Also, in order to be more precise, they defined numerical descriptive severity values in a risk judgement matrix. Moreover, the AHP method was used to assess major risks to support decision making.

Mali et al. (2017) analysed the pollution risk of ports in the Apulia region in Italy. The method included the collection of sediment samples which were then stored, classified and further examined A software was used to perform statistical analyses to evaluate geochemical associations, relationship between contaminants and potential sources. At the end, the pollution risk was calculated using the mean Effects Range-Median quotient (mERMq). This is a quantitative method which usage is limited to the evaluation of pollution risks.

Mansouri et al. (2010) proposed a Risk Management-based Decision Analysis (RMDA) framework which can help decision makers to identify, evaluate and prioritize risks in port infrastructure systems (PIS). The method used a cause-and-effect diagram to identify factors of risk in ports and their effects. The risks were evaluated using a scale of likelihood and impact, which, according to the authors, could be done with surveys or questionnaires. Thereafter, decision trees and real options analysis were used to evaluate strategies for the system. This is a systematic semi-quantitative process that has a main objective in the provision of a base for the development of prevention strategies.

Mokhtari et al. (2011) suggested that fuzzy analytical hierarchy process (FAHP) hazard identification methods can be used to identify and rank the factors of operational risk of a seaports and offshore terminals operations and management (PTOM). By means of a cause-consequence diagram method the author identified the top event; and used fuzzy set theory (FST) to deal with linguistic frameworks as part of the human/experts' judgements in the evaluation of causes and consequences of risk factors (FTNs). Then, these were transformed to membership functions in order to represent fuzzy numbers (fuzzy risks). Afterwards, a fault-tree analysis (FTA) was used to describe the causes of the undesired event; and an event-tree analysis (ETA) for showing the consequences that might lead to damage or complete shutdown of activities. This semi-quantitative method is called bow-tie framework and is a valuable prediction tool which demonstrates how important is to analyse previous accidents to avoid potential future undesired events. It provided a simplified linked overview of the causes and consequences of dangerous scenarios.

Mokhtari et al. (2012) proposed a fuzzy set theory (FST) method to provide a risk control technique to managers or other authorities. Its usage also helps to analyse the source of uncertainties. The technique included a HAZID cycle to identify risk factors; then, a generic hierarchical structure model needed to be developed based on these factors. After that, using the FAHP methods, the global weights were obtained. Additionally, qualitative linguistic variables during experts' judgements are used to find FTNs. These fuzzy numbers need to be transformed to belief structures by applying the same set of linguistic variables. Lastly, using the ER approach the results were synthetized and with the IDS software these were aggregated. This model provided an approach to support decisions under uncertainties which can be implemented in any port.

Liwång et al. (2013) performed a study which focused in threat assessment in ship operations and was based in the identification of potential dangerous scenarios or incidents and their evaluation in terms of probability and consequences. The necessary information was collected from surveys and interviews with experts in "piracy operations" in Somalia during 2010 and 2011. An event-tree was used to illustrate and evaluate the potential consequences and likelihood of an outbreak. The influence diagrams were used to model each important aspect of the scenarios. Using a semi-quantitative method, this research helped in recognizing and understanding security risks, along with their impact, in a logical manner.

Ondiviela et al. (2012) implemented a tool called ROM 5.1[8] which is a procedure based on the Driver, Pressure, State, Impact, Respond (DPSIR) system. This tool integrates four programmes: 1) classification of water bodies using a hierarchical base system that provides information on the types of contaminant. 2) Environmental risk assessment which calculates a multi-metric index based on three characteristics: probability, consequences and vulnerability. 3) Environmental monitoring delivers information on the disruptions' sources. 4) Management of

[8] Environmental Management Standard designed by the Spanish National Ports Administration

contaminant episodes provides detection, controlling, monitoring and management procedures of disturbances.

In their work, Pak et al. (2015) performed a quantitative analysis to collect data about the factors influencing navigational risks in ports including literature review, interviews and experts' judgements. A fuzzy analytical hierarchy process (AHP) was implemented to evaluate the importance of risk factors and classify security ranks of the seaports; involving as well linguistic scales and Triangular Fuzzy Numbers (TFNs). This method provided the opportunity to use pairwise comparisons which can provide accurate options for decisions makers.

Pallis (2017) performed a Port Risk Assessment to two Greek ports. Accidental historical data (2008-2011) involving human and environmental attributes was obtained. The authors used qualitative frequency and severity indexes to scale and find fatality rates. An important drawback of the method is the fact that it did not consider all environmental risks, for instance chemical contaminant, transportation of toxic goods, etcetera. Thus, the results cannot be completely reliable.

Perrodin et al. (2012) provided a method to measure the ecological damage of dredged sediments in port proximities. They started by collecting data/samples and finding techniques to measure levels of pollutant substances. Then, the authors analysed the sources of these pollutants as well as the transfer and distribution characteristics. Thereafter, they identified the consequences of exposure to contaminating substances using complementary approaches such as the "substances approach" which involved the inquiry of the risk elements in worldwide databases. Lastly, these substances were prioritized and the results were obtained which can help in understanding the process and effects of ecological risk to take decisions.

Polatidis et al. (2018) suggested the use of tool called MITIGATE[9] to deal with risks, threats and vulnerabilities of IT systems in marine infrastructures. This technique provided a general overview of cyber-threats and risks; it included an "attack path discovery method" where vulnerabilities, which could be employed by invaders, were identified. Also, the path included the identification of capability and location of attackers through qualitative values, propagation length, in addition to entry and target assets. This tool can be categorized as a semi-quantitative method because it used subjective and real data; also it is a reliable option to evaluate and report cyber maritime security.

Rømer et al. (1993) performed an investigation of accidents related to the transportation of dangerous goods in maritime transportation. The authors used databases, such as DAMA, to collect annual reports of accidental information for a period of five years. Afterwards, they evaluated the data found based on event trees (ET). In this ET model, the accident frequencies were estimated as quantity of observed events in terms of the number of ships. The probabilities were the number of total observations per box in the event tree. This methodology employed

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[9] Multidimensional, integrated, risk assessment framework and dynamic, collaborative Risk Management tools for critical information infrastructures, https://www.mitigateproject.eu/

information which can bring quantitative results to review statistics or analyse the conditions of calamities in ports. Nevertheless, it is believed that a more detailed collection strategy can bring better results to take actions against these events.

Rosoff and Winterfeldt (2007) used a semi-quantitative judgement to analyse feasible and likely terrorist attacks on the ports of Los Angeles and Long Beach. This framework is a theoretical exploratory investigation where the threats and vulnerabilities were developed by literature reviews, experts' ideas and information on databases. The consequences of this type of attacks were evaluated taking into account the human health (hundreds of latent deceases) and economic impact (billions of dollars).

Sánchez-Rodríguez et al. (2011) presented a Probabilistic Risk Assessment (PRA) to evaluate the ecological damage which resulted from the presence of biocides in the water premises of ports. The authors monitored different ports in Spain and collected different samples; pollutant substances were identified and quantified. The probabilistic analysis was then performed using statistical software. This quantitative approach provided a straight-forward and reliable base on realistic data and computational tools.

Sunaryo and Hamka (2017) suggested the use of Hazard Identification and Risk Assessment (HIRA) and Fault-Tree Analysis (FTA) methodology to evaluate safety regarding loading and unloading activities in container terminals. Data was collected through observation of operations at quays, interviews and accident statistics of three ports. The sources were evaluated using fault-tree analysis and the risk was assessed by using linguistic and numerical values in a risk matrix.

Trbojevic and Carr (2000) implemented a quantitative assessment method to evaluate risks in ports. The methodology included the use of a fault-tree to measure the frequency and event-trees for likelihood and severity calculation. The authors mentioned that the use of boolean logic to combines the series of events and a bottom-up logical model that explores reactions to events can help to easily and reliably understand systems, identify the best decision options and measures.

Valdor et al. (2016) proposed the usage of prioritization maps to analyse risks. The method includes four steps: the identification of environmental hazards, the estimation of cost consequences, vulnerability, and the integration of environmental risks into prioritizations maps. During the first stage, databases were necessary to gather all the information possible which were then analysed using linguistic criteria. The consequences or cumulative effects in the environment were assessed using a "mess grid" or effect matrix by obtaining spatial variations (using also linguistic and numerical variables). Moreover, the vulnerability was expressed through functional relations (qualitative features) of exposure, disruption and safety aspects related to each risk factor. Furthermore, the prioritization maps were obtained by combining the consequences and vulnerabilities using five different levels in the assessment criteria. This type of semi-quantitative model can help port authorities to explore the variability of risks by obtaining a consistent and understandable overview of these; also, it can help in identifying key improvement aspects and precautionary actions.

Valdor et al. (2016) presented a computational tool which can evaluate the oil spills risk in harbours. this SPILL Tool used a Geographical Information System (GIS) to deliver immediate results. The oil facilities at the Tarragona Harbour in Spain were validated using this software. It provides a probabilistic output of the affected areas based on the spill initial area, the spreading process, the transport and fate of the oil and the displacement of the oil.

Yang et al. (2010) considered that the lack of information regarding potential terrorist attacks proved that evaluations of these events can be challenging. This is why the authors suggested using an analysis based on fuzzy logic to cope with unavailable or incomplete data. In this approach, the first stage involved the definition of risk parameters with linguistic variables (including consequence or "security estimate" (SE), and antecedents; such as likelihood, destructive force/execution of certain action, resilience and probability). Fuzzy logic was used to accommodate these variables through fuzzy memberships. Fuzzy IF-THEN rules and belief structures were introduced to correlate the antecedents and consequences; this provided a functional uncertain mapping among antecedents and conclusions. Consequently, an activating rule weight method was presented to describe the relationship between risk input transformed from observations and rules in the system. The rules obtained were then associated with the ER method and Intrusion Detection System (IDS) software to find security parameters. Lastly, utility values were assigned to the security estimates to be able to rank them and reach a conclusion. This semi-quantitative risk assessment approach was called Fuzzy Rule-Based Evidential Reasoning (FRBER).

Moreover, Yang et al. (2010) also proposed a Fuzzy Rule-based Bayesian Reasoning (FuRBaR) method where all relevant fuzzy rules (IF-THEN) were accommodated with the belief structures by the implementation of BBN. Afterwards, the utility functions and vulnerability values were obtained. The main difference among the two methods is the technique used to calculate and configure failure probabilities. FRBER can effectively cope with incomplete information; and FuRBaR successfully simplifies risk calculations and describes dependency between risk factors.

Table 11: Analysis of the semi-quantitative risk assessment methods

Method	**Authors**	**Short description**
Advanced Failure Mode and Effects Analysis	Alyami et al. (2014)	Evaluation of hazardous events in CTs, applying FRB approach, IF-THEN rules, DoB, BN, expected utility and sensitivity analysis
Advanced uncertainty model	Alyami et al. (2016)	Approach implemented to evaluate safety performance of CTOS by the application of FRBN and ER into a FMEA

Method	Authors	Short description
Bayesian Belief Network	John et al. (2016)	Approach used to improve resilience of ports using FAHP and literature reviews
Bayesian Belief Network	Zhang et al. (2016)	Analysis of consequences of accidents in ports by means of usage of historical data, logical models and experts' judgements
Generic bow-tie risk analysis framework	Mokhtari et al. (2011)	Bow-tie technique with use of FTA, ETA and FST, linguistic risk levels/belief parameters
Fuzzy Rule-base Bayesian Reasoning	Yang et al. (2010)	Method which aims to deal with uncertainty in ports using fuzzy logic, IF-THEN rules and BBN
Fuzzy Rule-based evidential reasoning	Yang et al. (2010)	Method which aims to deal with uncertainty in ports using fuzzy logic, IF-THEN rules and ER method
Fuzzy inference system	Elsayed (2009)	Adaptation of Mandami and Sugeno fuzzy inference methods to assess the risks loading/unloading activities at CTs
Fuzzy risk assessment	Ding and Tseng (2012)	Evaluation of safety risk factors in ports using fuzzy logic, fuzzy RMM and SM method
Fuzzy set theory	Mokhtari et al. (2012)	The aim is to help in decision making and risk management, by means of FAHP, FST, ER, linguistic variables and belief parameters
Hazard Identification and Risk Assessment	Sunaryo and Hamka (2017)	Assessment of accidents related to loading and unloading activities in CTs using risk matrix (linguistic and numerical values. Sources were analysed by a FTA
Index of Risk	Grifoll et al. (2010)	Method use of IIR maps, decision trees and SPRC model to assess risk of water degradation in harbours
MITIGATE	Polatidis et al. (2018)	Assessment of cyber-attacks risk using attacks graphs and paths

Method	Authors	Short description
Multi-criteria analytical hierarchy process	Mabrouki et al. (2014)	Method proposed to evaluate operational risks in ports using AHP, surveys, risk matrix and judgement matrices
Novel fuzzy risk assessment	John et al. (2014)	Introduced to simplify uncertainties management in ports by means of FAHP, ER, FST and expected utility, linguistic risk levels/belief parameters
Overtopping risk assessment	Alises et al. (2014)	Methodology established to evaluate overtopping risks using linguistic variables, mathematical models and computational tools
Port Risk Assessment	Pallis (2017)	Assessment of environmental risk in CTs based on risk matrices and risk index to support decision making procedures
Prioritization maps	Valdor et al. (2016)	Method to evaluate environmental risk using linguistic criteria, effect matrix and mathematical functions
Port risk assessment approach	Chlomoudis et al. (2016)	Method used to assess CT risks by means of port experts judgements, severity and frequency indices
Risk assessment-based threat ranking	Belamarić et al. (2016)	Method used to evaluate pollution risk due to oil spills, performed through the use of risk matrix and simulations to observe consequences
Scales evaluation	Mansouri et al. (2010)	Method used to define the nature of resilience in PIS; guided by RMDA framework and with the use of cause-effect diagrams and decision making trees
Scenario analysis	Rosoff et al. (2007)	Analysis of potential terrorist attacks on ports generating scenarios, using direct consequence modelling and indirect economic impact

Table 12: Analysis of the quantitative risk assessment methods

Method	Authors	Short description
Eco-toxicological risk assessment	Perrodin et al. (2012)	Evaluation of pollution risk through collection and analysis of samples

Method	**Authors**	**Short description**
Effects-Range-Median quotient	Mali et al. (2017)	Evaluation of pollution risk through sample collection and examination of hazard degree
Environmental Risk Assessment	Carić et al. (2016)	Evaluation of pollution risk through hazard identification using SPR, contamination rates and risk matrix
Environmental Risk Assessment	Zhang et al. (2014)	Methodology proposed to evaluate ecological damage of BW discharges, involving sample collection and emission modelling software
Event tree analysis	Liwång et al. (2013)	Research focused on assessment of security risks using event trees and influence diagrams
Event tree analysis	Rømer et al. (1993)	Analysis of accidents related to transportation of dangerous goods using data collection procedures through databases and event trees
Fuzzy Analytical Hierarchical Process	Pak et al. (2015)	Evaluation of safety related risk factors using experts' judgements, linguistic variables and TFNs
Integrated Safety management system	Trbojevic, Carr (2000)	Valuation of risk in ports to support decision making. Frequency of risks is evaluated using fault trees. Likelihood and severity are appraised by the use of event trees
Probabilistic Risk Assessment	Sánchez-Rodríguez et al. (2011)	Evaluation of ecological damage in harbours through sample collection and statistical software
Risk simulation	Bruzzone et al. (2000)	Introduction of MESA software to simulate different types of risks in maritime infrastructures
ROM 5.1	Ondiviela et al. (2012)	Systematic procedure to assess quality of water in ports by collecting processing and classifying data
Simulation-based seismic loss estimation	Jin Na and Shinozuka (2009)	Evaluation of earthquake's impact on seaports, using SRA method, flow-charts, fragility curves, statistical information and the ARENA software
SPILL Tool	Valdor et al. (2016)	Software to evaluate oil spill risk in harbours

4.3 Suggested risk assessment methods for seaports

Currently, there is a strong requirement for risk assessment methods that are capable to take into account multiple criteria, qualities, stakeholders and characteristics of ports. The risk assessment process needs to incorporate phases that may be iterative and understandable to participants performing and/or involved in the assessment process. Moreover, stakeholder identification and analysis should be conducted to provide information on: internal or external individuals that will be affected by and can benefit from the risk assessment; and those who can influence, contribute or be experts in the process.

There is no “ideal” risk assessment that will suit all seaports; as the investigation revealed, most of the time, the selected method depends on the information available, the people involved, the degree of knowledge/expertise and the type of risks that will be assessed. For instance, there were authors concentrating on assessing operational or security risks whereas other focused on natural disaster threats, pollution risk or cyber-attacks.

A multidisciplinary team is normally required to take part in the risk assessment; the people designated to undertake this evaluation should be competent and have an understanding of the general approach to be used. The employers participating in the risk assessment process should cooperate with other stakeholders in the identification, analysis and evaluation of risks. The stakeholder engagement and understanding during this process is imperative. Therefore, it is recommended to choose the best suitable methods that comply with the characteristics of the risk assessment team involved.

In general, suitable methods should exhibit certain characteristics: they should be justifiable and appropriate to the type of risks being assessed; provide results in a form that enriches the understanding of the nature of the risk; and also be easy to track, repeat and verify. Moreover, one should take into account certain factors when selecting the methods, such as the complexity of the risks, the nature and degree of uncertainty, the resources available (expertise, information, time, cost, etc.) and the type of output needed.

Lichtenstein (1996) suggested a set of recommended factors or requirements that should be taken into account before selecting a risk assessment method for the required application. These factors comprise budget (cost of method), external influence (approval parties), agreement among parties, organizational structure and size, adaptability to stakeholders’ requirements, complexity and completeness and lastly understandability, feasibility and reliability.

Table 13: Risk assessment methods using fuzzy theory and ER

Authors	Method
Alyami et al. (2014)	Advanced Failure Mode and Effects Analysis
Alyami et al. (2016)	Advanced Uncertainty Model
Ding, Tseng (2012)	Fuzzy Risk Assessment
Elsayed (2009)	Fuzzy Inference System
John et al. (2014)	Novel Fuzzy Risk Assessment
John et al. (2016)	Bayesian Belief Network
Mokhtari et al. (2011)	Generic Bow-tie Risk Analysis Framework
Mokhtari et al. (2012)	Fuzzy Set Theory
Pak et al. (2015)	Fuzzy Analytical Hierarchical Process
Yang et al. (2010)	Fuzzy Rule-based Evidential Reasoning
Yang et al. (2010)	Fuzzy Rule-based Bayesian Reasoning

More sophisticated methodologies are based on modelling and simulation techniques. If a profounder and improved analysis is required, and the risk assessment team has access to people with precise mathematical expertise, they can implement fuzzy theory and/or ER as supportive methods. Table 13 shows the authors who applied these approaches to further evaluate risks of collision, leakage, accidents while loading and unloading activities, pollution, sabotage, and terrorist attacks. These are considered complex, challenging and advanced mathematical methodologies, which provide precise outcomes.

Table 14: Risk assessment methods using computational tools

Author	Method & computational tool
Bruzzone et al. (2000)	Risk simulation (MESA software)
Jin Na, Shinozuka (2009)	Simulation-based seismic loss estimation (ARENA software, Monte Carlo simulation)
Polatidis et al. (2018)	MITIGATE (Depth-first search)
Sánchez-Rodríguez et al. (2011)	Probabilistic Risk Assessment (Statistical package R)
Valdor et al. (2016)	Oil spill pollution assessment (SPILL tool, Monte Carlo simulation)
Zhang et al. (2014)	Environmental Risk Assessment (MAMPEC model)

Simulation tools were also often used by diverse authors in the literature review. These were employed to evaluate specific types of risks, such as pollution risk as consequence of oil spills; seismic loss; and the risk of cyber-attacks (see Table 14). These might be costly and demanding alternatives; however, the results are highly reliable. The data required for the simulation is historical and this will enable to assure authentic results. Moreover, simulation tools can show possible outcomes of decisions and assess the impact of risk, which at the end can enhance the decision making and risk management process.

In order to perform an understandable risk assessment by the stakeholders in seaports, the methods should implement deductive approaches to identify, analyse and evaluate risks. Table 15 shows a suitable set of risk assessment methods from the literature review. These risk assessment methods are based on probability analysis and have been the base of decision making in different industries. Moreover, they can be considered easy and simple representations of experiences, feelings or opinions from workers, experts and other internal and external stakeholders. The deductive methods can create accurate data which can be further expressed in management terminology. Moreover, they also take into account human experience in the specific attributes being evaluated; and are adaptable and reliable methods. These procedures provide visual comparison and most importantly the risk assessment team does not require deep scientific knowledge. Additionally, they are not time consuming methods and do not require supplementary expenses.

Table 15: Risk assessment methods for seaports

Authors	Method	Risk assessment approach
Belamarić et al. (2016) Carić et al. (2016) Chlomoudis et al. (2016) Mabrouki et al. (2014) Pallis (2017) Sunaryo, Hamka (2017) Valdor et al. (2016)	Risk map analysis	qualitative, semi-quantitative or quantitative
Liwång et al. (2013) Rømer et al. (1993) Trbojevic, Carr (2000) Mokhtari et al. (2011)	Event-tree analysis	Qualitative or quantitative
Trbojevic, Carr (2000) Sunaryo, Hamka (2017) Mokhtari et al. (2011)	Fault-tree analysis	Qualitative or quantitative
Mokhtari et al. (2011)	Bow-tie analysis	Qualitative or quantitative
Mokhtari et al. (2011) Rao, Raghavan (1996)	Cause-consequence analysis	Qualitative or quantitative

Alyami et al. (2014) Alyami et al. (2016)	FMEA analysis	Semi-quantitative or quantitative
Rosoff et al. (2007) Zhang, Lam (2016)	Scenario analysis	Qualitative or quantitative

The risk maps or matrices were used to assess environmental and operational risks due to oil spills, transportation of chemical substances, human errors and loading/unloading activities. Event-trees were developed either qualitatively or quantitatively to evaluate safety and operational risks, due to human activities, transportation of dangerous goods and lack of equipment maintenance. Fault-tree analysis was performed to give an overview of the consequences that operational and safety risks can bring. Scenario analyses were also employed to assess safety risks related to dirty bombs attacks and to analyse economical losses due to port disruptions. FMEA analysis was utilised as a base to evaluate safety risks and hazardous events due to transportation, storage and handling of dangerous substances. Cause-consequence analysis was implemented to evaluate operational risks such as chemical handling activities and human errors.

Depending on the time and resources, the risk assessment teams can use qualitative or quantitative methods for evaluating the diverse risks. While the qualitative approach is easy and fast to use, the quantitative will produce more accurate results. However, it is advisable to balance the use of the two approaches for the risk assessment process in seaports. This means that a semi-quantitative approach can be used to take into account interrelationships or dependencies of risks and all the potential consequences.

Nonetheless, the authors also identified limitations in the previous mentioned methods. These might lack the capability to process diverse and more complex information as well as analyse the interdependence among different risk factors. Moreover, it is mentioned that several of these methods might not cope with high level of uncertainty when using linguistic variables in experts' judgements.

In order to obtain the best possible results from the risk assessment, it is imperative to approach the people who are experienced in applying several risk assessment methods and have deep understanding in port operations in order to provide suggestions to select the suitable applicable methods.

Risk assessment in seaports is a significant and time consuming process. Selecting the adequate risk assessment methods are crucial in order to define the rules and tactics by which the team will perform the risk assessment. The methods implemented should provide assurance that all the relevant hazards and risks are identified, analysed and evaluated. These activities will provide a basis for decision making processes and will help in developing effective control and mitigation measures.

5 CONCLUSION

Risk assessment is an important step to ensure a safe work environment in seaports. Every stakeholder in port areas needs to be aware of hazard sources and factors of risk which could potentially cause harm. The objective of this research project was to review the available literature on risk assessment methods in seaports, aiming to identify the best suitable ones for these systems. Based on a theoretical foundation, the importance of seaports in the economy and in the maritime supply chains was emphasised.

The methodology implemented in this study was developed based on a systematic literature review with two databases selected to search for relevant material: Science Direct and Web of Science. The search string included an extensive time horizon (1980-2017) and logical combinations of keywords and phrases in order to narrow and enhance the quality of results. The data collected was then screened and selected for refinement and evaluation; and 58 research articles were synthesized.

The analysis of the extracted articles helped in the categorization of the sources for hazards in natural and man-made as well as the factors of risks in climate, operational, safety, technical, organisational, environmental, socio-economic and political areas. Moreover, a profound breakdown of the methodologies used in ports to assess risks was elaborated. Based on different criteria, such as adaptability for different stakeholders, complexity of method, extent of resources, reliability, quality and overview of results, a recommended set of risk assessment methods was provided.

Additional information can be incorporated into these models; however, there is a danger that these become excessively complex such that they fail to engage all stakeholders. It is imperative to guarantee a trade-off between difficulty to describe and evaluate risks effectively, while remaining interpretable, engaging, and supporting decision-making. This should be the primary element while developing a risk assessment tool.

Limitations in this study are related to the methodology implemented to perform the literature review and extract the required information. The review was restricted to two databases which are considered to be reliable sources; nevertheless, there is a possibility that potential significant articles could have been found in other databanks. The retrieval results were based on the selection of keywords and phrases; this might have affected the amount of results extracted, thus slowing down the data screening and selection phase.

Future research areas should consider interviews, surveys and/or workshops with the different authorities or managers in the diverse subdivisions of seaports to support the information found in this project. It will be motivating to observe which methods and approaches are currently being used in seaports. Moreover, an analysis of how the different divisions in ports perform risk assessment should be reflected. It is also advisable to analyse how seaports cover specific stakeholders who are involved in the risk assessment process and to review the level of engagement and expertise they bring.

Besides, a historical exploration of accidents in seaports could be employed in order to analyse the impacts, consequences and mitigation strategies. Additionally, it is suggested to investigate which type of awareness campaigns or mitigation strategies are focused on targeting human related errors in seaports, which is an aspect that is repeatedly mentioned in the literature as a significant factor of risk. Lastly, it is also suggested to investigate further in supplementary disciplines as there are risk assessment methods implemented in other fields which could be altered to fit seaports' requirements.

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APPENDIX

#	Data-base	Title	Year	Journal	Authors	Keywords
1	WoS	A decision support methodology for risk management within a port terminal	2014	SAFETY SCIENCE	Mabrouki, C; Bentaleb, F; Mousrij, A	AHP; Multicriteria approach; Decision making; Risk engineering; Risk analysis
2	SD	A Multi-Tree Committee to assist port-of-entry inspection decisions	2016	European Journal of Operational Research	Pablo Romero, Jorge Graneri, Omar Viera, Sandro Moscatelli, Libertad Tansini	Risk analysis; Port-of-entry; Inspection policy; Binary decision tree; Multi-Tree Committee
3	SD	A new risk assessment method for water quality degradation in harbour domains, using hydrodynamic models	2010	Marine Pollution Bulletin	Manel Grifoll, Gabriel Jordà, Ángel Borja, Manuel Espino	Risk analysis; Decision-making; Hydrodynamic modelling; Residence times; Water quality; Barcelona harbour
4	SD	A policy making framework for resilient port infrastructure systems	2010	Marine Policy	Mo Mansouri, Roshanak Nilchiani, Ali Mostashari	Risk management; Decision analysis; Resilience; Port infrastructure systems
5	WoS	A risk and economic analysis of dirty bomb attacks on the ports of Los Angeles and long beach	2007	RISK ANALYSIS	Rosoff, H; von Winterfeldt, D	dirty bomb; economic impact analysis; project risk analysis; terrorism
6	SD	A risk assessment approach to improve the resilience of a seaport system using Bayesian networks	2016	Ocean Engineering	Andrew John, Zaili Yang, Ramin Riahi, Jin Wang	Seaport systems; Decision support model; Bayesian belief network; Fuzzy set theory; Resilience; Sensitivity analysis
7	SD	A Risk Assessment Methodology in Container Terminals: The Case Study of the Port Container Terminal of Thessalonica, Greece	2016	Journal of Traffic and Transportatio n Engineering	Constantinos I. Chlomoudis, Petros L. Pallis and Ernestos S. Tzannatos	Ports, risk assessment, container terminals, case study, Greece

8	SD	Advanced uncertainty modelling for container port risk analysis	2016	Accident Analysis; Prevention	Hani Alyami, Zaili Yang, Ramin Riahi, Stephen Bonsall, Jin Wang	FMEA; Port safety; Maritime risk; Maritime safety; Maritime transport; Sensitivity analysis
9	SD	All-hazard Guide for Transport Infrastructure	2016	Transportatio n Research Procedia	Kaundinya, Ingo; Nisancioglu, Selcuk; Kammerer, Harald; Oliva, Rita	hazards; natural; man-made; transport infrastructure; assessment; AllTraIn-Tool; CIPS program
10	WoS	An advanced risk analysis approach for container port safety evaluation	2014	MARITIME POLICY; MANAGEMEN T	Alyami, H; Lee, PTW; Yang, ZL; Riahi, R; Bonsall, S; Wang, J	
11	SD	An integrated fuzzy risk assessment for seaport operations	2014	Safety Science	Andrew John, Dimitrios Paraskevadaki s, Alan Bury, Zaili Yang, Ramin Riahi, Jin Wang	Seaport operations; Evidential reasoning approach; Fuzzy set theory; Fuzzy analytical hierarchy process
12	SD	Analysis of vulnerabilities in maritime supply chains	2017	Reliability Engineering; System Safety	Honglu Liu, Zhihong Tian, Anqiang Huang, Zaili Yang	Vulnerability; Maritime transport; Complex network; Network topology; Network robustness; Resilience; Maritime risk
13	SD	Application of a generic bow-tie based risk analysis framework on risk management of sea ports and offshore terminals	2011	Journal of Hazardous Materials	Kambiz Mokhtari, Jun Ren∗, Charles Roberts, Jin Wang	Bow-tie framework; Risk management (RM); Sea ports and offshore terminals operations and management (PTOM); Fuzzy Set Theory (FST); Fuzzy Possibility Score (FPS)

14	SD	Assessment and source identification of pollution risk for touristic ports: Heavy metals and polycyclic aromatic hydrocarbons in sediments of 4 marinas of the Apulia region (Italy)	2016	Marine Pollution Bulletin	Matilda Mali, Maria Michela Dell'Anna, Piero Mastrorilli, Leonardo Damiani, Alberto Ferruccio Piccinni	Hazard degree; Port sediment; Touristic port; Heavy metals; PAHs; Cumulative indices
15	SD	Can a GIS toolbox assess the environmental risk of oil spills? Implementation for oil facilities in harbors	2016	Journal of Environmental Management	Paloma F. Valdor, Aina G. Gómez, Víctor Velarde, Araceli Puente	Oil spill; Diffuse source; Environmental risk analysis; Affected areas; Geographical Information System; Tarragona harbor
16	WoS	Conflicts in some of the World harbours: what needs to happen next?	2016	MARITIME STUDIES	Pearson, S; Windupranata , W; Pranowo, SW; Putri, A; Ma, YJ; Vila-Concejo, A; Fernandez, E; Mendez, G; etcetera	
17	SD	Cyber-attack path discovery in a dynamic supply chain maritime risk management system	2017	Computer Standards; Interfaces	Nikolaos Polatidis and Michalis Pavlidis and Haralam bos Mouratidis	Cyber-security; Attack path discovery; Risk management system; Maritime supply chain; ISO standards; NIST SP 800-30
18	WoS	Decision support framework for risk management on sea ports and terminals using fuzzy set theory and evidential reasoning approach	2012	EXPERT SYSTEMS WITH APPLICATIONS	Mokhtari, K; Ren, J; Roberts, C; Wang, J	Decision support framework; Risk management (RM); Fuzzy set theory (FST); Evidential reasoning (ER); PTOM
19	WoS	Design of a risk assessment methodology for the introduction of invasive species from ship ballast waters The case of Arzew port	2015	MANAGEMEN T OF ENVIRONMEN TAL QUALITY	Bouda, A; Bachari, NE; Bahmed, L; Boubenia, R	Port of Arzew; Algerian ports; GIS.; Risk management; Invasive species; Water ballast; Ships

20	WoS	Economic valuation of damages originated by major accidents in port areas	2009	JOURNAL OF LOSS PREVENTION IN THE PROCESS INDUSTRIES	Ronza, A; Lazaro-Touza, L; Carol, S; Casal, J	Accident cost; Port; Major accident; Risk analysis; Social risk; Environmental impact
21	SD	Ecotoxicological risk assessment linked to infilling quarries with treated dredged seaport sediments	2012	Science of The Total Environment	Yves Perrodin, Gilles Donguy, Christine Bazin, Laurence Volatier, Claude Durrieu, etc.	Sediments; Seaports; Pollutants; Quarries; Aquatic ecosystems; Ecotoxicological risk assessment
22	SD	Ecotoxicological risk assessment of antifouling emissions in a cruise ship port	2014	Journal of Cleaner Production	Hrvoje Carić, Göran Klobučar, Anamaria Štambuk	Cruise tourism; Marine ecosystems; Biomonitoring; Pollution; Heavy metals; Dubrovnik Port
23	SD	Environmental Risk Identification of Port Construction Project	2011	Procedia Environmental Sciences	Lina Zheng, Baoxiu Zhao, Hong Wang, Hengming Liu	environmental risk assessment; process risk; risk identification; port project
24	WoS	Estimating economic losses of industry clusters due to port disruptions	2016	TRANSPORTA TION RESEARCH PART A-POLICY AND PRACTICE	Zhang, Y; Lam, JSL	Port disruption; Economic loss; Economic impact; Industry cluster; Risk assessment; Risk mitigation
25	SD	Evaluation of phytotoxicity of seaport sediments aged artificially by rotary leaching in the framework of a quarry deposit scenario	2014	Marine Pollution Bulletin	J.-P. Bedell, Y. Ferro, C. Bazin, Y. Perrodin	Ageing; Armeria maritima; Dredged seaport sediments; Lolium perenne; Leaching; Phytotoxicity
26	WoS	Facilitating uncertainty treatment in the risk assessment of container supply chains	2010	JOURNAL OF MARINE ENGINEERING AND TECHNOLOGY	Yang, ZL; Bonsall, S; Wang, J	

27	SD	Fuzzy inference system for the risk assessment of liquefied natural gas carriers during loading/offloading at terminals	2009	Applied Ocean Research	Elsayed, Tarek	Multiple attribute; Risk assessment; Fuzzy sets; Fuzzy inference system; LNG ships; LNG terminals
28	WoS	Fuzzy risk assessment on safety operations for exclusive container terminals at Kaohsiung port in Taiwan	2012	PROCEEDINGS OF THE INSTITUTION OF MECHANICAL ENGINEERS	Ding, JF; Tseng, WJ	Fuzzy risk assessment; safety operation; container terminal
29	WoS	Hazard and risk potential of chemical handling at ports	1995	JOURNAL OF LOSS PREVENTION IN THE PROCESS INDUSTRIES	Rao, PG; Raghavan, KV	port safety; risk at ports; cargo handling
30	SD	Integration of numerical modeling and Bayesian analysis for setting water quality criteria in Hamilton Harbour, Ontario, Canada	2010	Environmental Modelling; Software	Maryam Ramin, Serguei Stremilov, Tanya Labencki, Alexey Gudimov, Duncan Boyd, George B. Arhonditsis	Phosphorus loading; Eutrophication modeling; Risk assessment; Hamilton Harbour; Ecosystem restoration; Top–down control; Benthic–pelagic coupling
31	WoS	MARINE TRANSPORT OF DANGEROUS GOODS - RISK ASSESSMENT BASED ON HISTORICAL ACCIDENT DATA	1992	JOURNAL OF LOSS PREVENTION IN THE PROCESS INDUSTRIES	ROMER, H; BROCKHOFF, L; AASTRUP, P; ETERSEN, HJS	MARINE TRANSPORT; DANGEROUS GOODS; RISK ASSESSMENT
32	WoS	Maritime Transportation Risk Assessment of Tianjin Port with Bayesian Belief Networks	2016	RISK ANALYSIS	Zhang, JF; Teixeira, AP; Soares, CG; Yan, XP; Liu, KZ	Bayesian belief networks; maritime transportation; risk assessment; Tianjin port
33	SD	Methodological approach for safety assessment of cruise ship in port	2015	Safety Science	Peter Vidmar, Marko Perkovič	Accident analysis; Risk assessment; Cruise ships; Port safety

34	SD	Methodological procedure for water quality management in port areas at the EU level	2011	Ecological Indicators	Bárbara Ondiviela, José A. Juanes, Aina G. Gómez, María L. Sámano, José A. Revilla	Environmental management system; Port; Water quality management; Human pressure; Environmental monitoring; Risk assessment; Northern Spain; ROM 5.1
35	SD	Modeling perceived collision risk in port water navigation	2009	Safety Science	Hoong Chor Chin, Ashim Kumar Debnath	Ordered regression model; Collision risk perception; Port navigation safety; Automatic radar plotting aid; Harbor pilot
36	WoS	Modelling Collision Potentials in Port Anchorages: Application of the Navigational Traffic Conflict Technique (NTCT)	2016	JOURNAL OF NAVIGATION	Debnath, AK; Chin, HC	Port safety; Ship collision; Singapore port
37	WoS	Modelling Port Water Collision Risk Using Traffic Conflicts	2011	JOURNAL OF NAVIGATION	Debnath, AK; Chin, HC; Haque, MM	Navigational collision risk; Port fairways; Traffic conflicts; Binomial logistic model
38	WoS	Navigational Traffic Conflict Technique: A Proactive Approach to Quantitative Measurement of Collision Risks in Port Waters	2010	JOURNAL OF NAVIGATION	Debnath, AK; Chin, HC	Navigational collision risk; Traffic conflict technique; Port safety; Quantitative risk analysis
39	SD	Overtopping hazards to port activities: Application of a new methodology to risk management (POrt Risk MAnagement Tool)	2013	Reliability Engineering; System Safety	Ana Alises, Rafael Molina, Rebeca Gómez, Pascual Pery, Carmen Castillo	Overtopping; Hazard; Risk; Management; Probability
40	SD	Port Risk Management in Container Terminals	2016	Transportatio n Research Procedia	Petros L. Pallis	Risk, Management, Port, Greece

41	WoS	Port safety and the container revolution: A statistical study on human factor and occupational accidents over the long period	2009	SAFETY SCIENCE	Fabiano, B; Curro, F; Reverberi, AP; Pastorino, R	Accident; Container; Injury; Port safety; Response surface methodology
42	WoS	Port safety evaluation from a captain's perspective: The Korean experience	2014	SAFETY SCIENCE	Pak, JY; Yeo, GT; Oh, SW; Yang, ZL	Port safety factors; Maritime transport; Fuzzy AHP; Safety evaluation; Maritime risk; Maritime safety; Expert knowledge
43	WoS	Port traffic risks - A study of accidents in Hong Kong waters	2006	TRANSPORTATION RESEARCH PART E-LOGISTICS	Yip, TL	transport risk; port safety; marine traffic; maritime transportation; navigational accidents; regression model
44	WoS	Prioritising security vulnerabilities in ports	2013	INTERNATIONAL JOURNAL OF SHIPPING AND TRANSPORT LOGISTICS	Yang, ZL; Ng, AKY; Wang, J	port security; vulnerability analysis; risk assessment; fuzzy logic; Bayesian networks; analytical hierarchy process; AHP
45	SD	Prioritization maps: The integration of environmental risks to manage water quality in harbor areas	2016	Marine Pollution Bulletin	Paloma F. Valdor, Aina G. Gómez, Bárbara Ondiviela, Araceli Puente, José A. Juanes	Harbor areas; Risk maps; Cost-effective management; Multiple stressors; Integration
46	SD	Probabilistic risk assessment of common booster biocides in surface waters of the harbours of Gran Canaria (Spain)	2011	Marine Pollution Bulletin	Álvaro Sánchez-Rodríguez, Zoraida Sosa-Ferrera, Ángelo Santana-del Pino, José Juan Santana-Rodríguez	Probabilistic risk assessment; Irgarol 1051; Diuron; Antifouling paint; Canary Islands; Harbour

47	WoS	Quantitative maritime security assessment: a 2020 vision	2016	IMA JOURNAL OF MANAGEMENT MATHEMATICS	Yang, ZL; Qu, Z	quantitative security assessment; maritime risk; risk quantification; port security; maritime transport; maritime security
48	WoS	Quantitative risk analysis - Ship security analysis for effective risk control options	2013	SAFETY SCIENCE	Liwang, H; Ringsberg, JW; Norsell, M	Control option; Influence diagram; Piracy; Quantified risk management; Ship security analysis
49	WoS	Risk analysis and port security: some contextual observations and considerations	2009	ANNALS OF OPERATIONS RESEARCH	Greenberg, MR	Ports; Risk assessment; Risk management
50	SD	Risk analysis in harbor environments using simulation	2000	Safety Science	A.G Bruzzone, R Mosca, R Revetria, S Rapallo	Simulation; Harbors; Emergency management; Risk analysis
51	WoS	Risk analysis in port competition for containerized imports	2015	EUROPEAN JOURNAL OF OPERATIONAL RESEARCH	Fan, L; Wilson, WW; Dahl, B	Logistics; Stochastic model; Container
52	SD	Risk assessment of marine environments from ballast water discharges with laboratory-scale hydroxyl radicals treatment in Tianjin Harbor, China	2014	Journal of Environmental Management	Nahui Zhang, Yubo Zhang, Mindong Bai, Zhitao Zhang, Cao Chen, Xiangying Meng	Marine environmental risk assessment; Ballast water treatment; Tianjin harbor; Predicted environmental concentrations; Predicted no effect concentrations
53	SD	Risk based methodology for safety improvements in ports	2000	Journal of Hazardous Materials	Vladimir M Trbojevic, Barry J Carr	Risk; Safety; Ports
54	SD	Safety Risks Assessment on Container Terminal Using Hazard Identification and Risk Assessment and Fault Tree Analysis Methods	2017	Procedia Engineering	Sunaryo, Mochamad Aditya Hamka	container terminal; loading unloading; risks assessment; safety

55	WoS	Simulation Method - Based Oil Spill Pollution Risk Analysis for the Port of Sibenik	2016	TRANSACTIONS ON MARITIME SCIENCE-TOMS	Belamaric, G; Kurtela, Z; Bosnjak, R	Risk; Oil spill pollution; Simulation; Sea environment
56	WoS	Simulation-based seismic loss estimation of seaport transportation system	2008	RELIABILITY ENGINEERING ; SYSTEM SAFETY	Na, UJ; Shinozuka, M	Seaport; Simulation; Seismic loss; Container throughput; Revenue; Fragility curves; System analysis; Risk assessment
57	WoS	Supply Chain Vulnerability Analysis Using Scenario-Based Input-Output Modeling: Application to Port Operations	2016	RISK ANALYSIS	Thekdi, SA; Santos, JR	Input-output modeling; maritime port disruptions; operations management; resilience; uncertainty analysis
58	WoS	Towards port infrastructure adaptation: a global port climate risk analysis	2016	WMU JOURNAL OF MARITIME AFFAIRS	Mutombo, K; Olcer, A	Port infrastructure; Adaptation; Risk; climate change

HAZARD project has 15 full Partners and a total budget of 4.3 million euros. It is executed from spring 2016 till spring 2019, and is part-funded by EU's Baltic Sea Region Interreg programme.

HAZARD aims at mitigating the effects of major accidents and emergencies in major multimodal seaports in the Baltic Sea Region, all handling large volumes of cargo and/or passengers.

Port facilities are often located close to residential areas, thus potentially exposing a large number of people to the consequences of accidents. The HAZARD project deals with these concerns by bringing together Rescue Services, other authorities, logistics operators and established knowledge partners.

HAZARD enables better preparedness, coordination and communication, more efficient actions to reduce damages and loss of life in emergencies, and handling of post-emergency situations by making a number of improvements.

These include harmonization and implementation of safety and security standards and regulations, communication between key actors, the use of risk analysis methods and adoption of new technologies.

See more at: http://blogit.utu.fi/hazard/