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Comprehensive review on risk assessment methodologies for HAZMAT transportation between 1995-2015

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ABSTRACT

Issue related to safety, health and environmental has become major priority to be concerned of in the transportation of hazardous materials (HAZMAT) worldwide. Due to the high risk that entailed in the operation of HAZMAT transportation, many accidents in this industry have been reported which include chemicals spillage, fire and explosion. In order to quantify the degree of hazards and risks of these accidents, various assessment methods have been introduced either by the academia, the industry as well as the authority. The methods present various approaches for the assessment, ranging from a simple to highly complicated ones depending on the purpose of the assessment and the available resources and constraints. To date there is yet any study conducted to review those available methods. This paper intends to present a comprehensive review of the existing methods for hazards and risks assessment of HAZMAT transportation between years 1995-2015 which considers road, marine, railway, air and pipeline system. Based on careful screening of the abundance of methods available, 151 of them were selected – that is those specifically meant for hazards and risks assessment of HAZMAT transportation only. The methods are reviewed in terms of the types of assessment; either qualitative, quantitative or hybrid techniques, as well as their specific application in different mode of transportation. Also, statistical analysis was performed to determine the trend of past publications regarding on the type of journal, year of publication and also financial support received in the context of hazard and risk assessment of HAZMAT transportation.

Keywords:
Risk, Hazard, HAZMAT transportation, Review, Qualitative, Quantitative

1. Introduction

Managing hazard in modern technologies has become an attraction for researchers to contribute a new finding in improving the existence of risk assessment methods. Generally, many industries have been applied the appropriate risk assessment in order to perform excellent work

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performance and achieve huge business profits simultaneously. By upgrading the existing technologies into more pleasant and safe which are highly demanded by industries, a new framework or method is highly required for assessing the associated hazards and risks especially in the transportation system. The complexities of transportation system follow an upward trend which may create a new hazard that potentially to cause the problem especially on people and environment. Moreover, the bulk amount of hazardous materials (HAZMAT) transported in daily operation through all transport modes such as marine, roads, railways, air, and pipeline system have been reported drastically increase every year[1].Therefore, HAZMAT transportation may cause a lot of problems to the local government, NGO's, and also the industries to counter-balance the planning of suitable control plan without jeopardizing the demands of HAZMAT.

In general, HAZMAT transportation involves large shipments transported between two defined points, which is from the supplier location to other destinations, which known as the consumers. The increasing of the total number of shipment transported shows a good sign for the industries in terms of income's achievement. However, rapid industrialization has also resulted in a great increase in the number of HAZMAT transportation accidents over the years. Many accidents happen during the HAZMAT operation due to regular hazards exposure while the existing controls are not adequate to prevent those accidents. For this reason, people's health and the environment can be affected whether by direct or indirect exposure to the HAZMAT transportation risks. Although HAZMAT transportation can lead to many consequences as heavy as those created by the releases occurring at fixed plants[2-4], this mode of transportation is still highly needed in many industries. In fact, many of the industrialized countries have employed this facility to import and export goods in bulk quantity around the world. Additionally, this facility allows to reduce the transport cost and therefore has become the main choice by many industries to transport the shipment especially in transporting of HAZMAT. In order to overcome these difficulties, a proper risk assessment is considered as a great effort to improve the safety of HAZMAT transportation. Such effort is needed during the early phase of operation in order to identify, determine, and provide a comprehensive risk assessment without implying any difficulties in the method of implementation and consequently able to assist the industries to minimize HAZMAT transportation risks.

With regard to the methodological quality of risk assessment methods, a paper review is presented regarding the overview of risk assessment application for the past 20 years; from 1995 until 2015. The objective of this paper is to present a collective and a detailed review of a wide range of risk assessment methods applied to HAZMAT transportation including marine, roads, railways, air, and pipeline system. Practically, various methods that are suitable to assess hazards and risks of HAZMAT transportation are discussed, and the methods fully comply with the guidelines related to safety, health, and environment aspects as stated by US Department of Transportation (DOT).

Therefore, the rest of this paper is organised as follows. Section 2 gives a detailed description of the risk-related accidents in HAZMAT transportation including explosion, fire, and spillage happen in land, marine, or air transport. Section 3 reviews the existing methods for assessing hazards and risks in HAZMAT transportation. The methods are basically classified based on 3 different approaches; 1) qualitative approach, which is referred to the methods such as scoring method, profile and checklist method, and fuzzy method, 2) quantitative approach, which covers the methods that apply mathematical programming model and cost-benefit analysis, 3) hybrid techniques, which are the other methods that mixed up both qualitative and quantitative approaches. Next, section 4 covers various categories of methods application. Hence, this section is divided into 4 main categories, which are the review of accident occurrences, the assessment of

hazards and risks in HAZMAT transportation, the best practice sharing of existing methods, and lastly the prevention of HAZMAT transportation accidents. In section 5, statistical analysis is presented based on the collection of previous studies from 1995 until 2015 for supporting the additional information such as the types of journal, year of publication, and financial support. Finally, concluding remarks are given in section 6.

2.Risks in hazmattransportation

An increasing number of demands of HAZMAT transportation over the year consequently cause a direct impact on the growth of industries. Many products containing HAZMAT in various types such as chemicals, petrochemicals, and liquefied petroleum gases (LPG) are used and transported daily on the road, railway, sea, and pipelines. Recent statistics has showed that the number of HAZMAT transportation accidents, as a whole, is increasing. In particular, the vast majority of HAZMAT accident reported are disastrous and may result in death or injury to people, property or environmental damage due to the effects of fire, explosion, or toxicity. Due to the massive risks involved in HAZMAT transportation, this transportation has become one of the greatest concerns by the government, NGO, and industries in assessing and reducing the risks. Therefore, all possible risks associated with HAZMAT transportation are listed to be given precedence in the prevention action if these accidents occur in the future.

In this section, all modes of transport including marine, roads, railways, air, and pipeline system are discussed concerning the risks of HAZMAT transportation accident respectively. The low probability-high consequence nature of major HAZMAT transportation accidents attracts considerable public attention. An accident resulted from HAZMAT transportation will often have serious environmental and health consequences, not to mention considerable existing guidelines. According to [5],the main problem related to HAZMAT transportation has been identified which is due to the inappropriate guidelines and lack of supporting information to assist the local or international agencies to spell out those risks immediately compared to various guidelines that are easily available for fixed installation. Therefore, this issue should be given attention by the government, NGOs, and the industry to come out with better plan in order to overcome the effects of HAZMAT transportation accidents, in which suitable risk control are more difficult to be applied due to the moving activities of the transport.

In the context of land-based transportation of HAZMAT, whether via road or railway, both have faced a similar problem which is the risk effects arise from the location of developed routes. Most of the daily routine of HAZMAT transportation in bulk quantity from one location to other destination using nearby routes have raised the awareness among the adjacent community [6-8].Indirectly, many local residents become more worried because the number of routes constructed for both road or railways transportation is located near the area of their houses. Sometimes, the routes used to transport HAZMAT cross the area with high density of living population. Most people are worried when accidents involving toxic and inflammable materials on roads or railways happen near their residential areas, since it could cause-even worse-loss of properties and lives [3,9].This argument is supported by [10] in which they stated that the worst event could be induced by releasing a huge amount of HAZMAT as the impact of accidents occurrence. Such accidents have thepotential to cause various effects such as damaging the environment and killed many innocent people who live in the surrounding area. Meanwhile, [11]explained that the risks arise from road transport and rail transport are slightly different. The comparison is made based on the tutorial of risk assessment applied specifically in a case study of chlorine transport in England. The outcome

showed that rail transport is riskier than road transport since most of the rail yard are located nearby residential area instead of the main road or highway which is far away from residential area.

[12]revealed that the geographical sea is one of the important factors that tend to contribute to the existence of unforeseen hazards, which may have the potential in causing the occurrence of marine accidents such as collision, grounding, and flooding. These types of accident can be assessed by using suitable risk assessment methods, followed by calculating the level of severity and probability of occurrence in order to determine the total accident risks. A further study by [12,13]have agreed that sea is identified as a hazard-prone area with a high number of accidents happened regularly. In addition, the harsh marine environment and the remoteness of the accident locations provide many technical, logistic, and operational challenges. Due to that, these challenges may cause difficulties in providing proper emergency response and control plan in order to prevent similar accidents from happening. In fact, many accidental spillages of shiphave occurred along the shipping routes on the sea. To state the obvious, these spillage, especially in the form of chemical or oil, can be easily exposed to any existence of possible ignition sources and subsequently lead to worst accident cases such as fire and explosion. These accidents cause various effects either directly or indirectly on human health and environmental damage especially threatening the survival of floral and faunal species in the aquatic ecosystem. Moreover, [212] stated that the side effects of rapid development on marine industries involving HAZMAT transportation are very alarming and need to be carefully monitored by the authorities due to the high possibilities of unexpected events that might happen especially during the transportation of HAZMAT.

Similar to the pipeline system, the transportation of HAZMAT in the form of liquid or gas over long distance is also discussed in this section. The main focus is to identify and assess the risk especially the risk of pipeline accident through various approaches that have been developed. For example, [14]addressed different types of pipelines accidents such as toxic gas diffusion, jet flame, and fireball as the result of improper activities of pipelines transportation. By referring to the physical and chemical characteristics of the HAZMAT transported and the complexity of pipeline transmission topology, these identified factors are indicated as a major contribution to the occurrences of pipeline accident cases. For instance, the identified pipelines with small cracks have the potential to cause gas release during the transport operation. Therefore, if the gas is continuously released and being exposed to any ignition sources, it may lead to explosion events. In addition, gas release with high concentration especially toxic gas that dispersed in the workplace surrounding able to cause death among workers[15-17]. In other words, the impact of these types of accidents causes numerous fatalities and able to turn into domino effects which may progress into a more disastrous events if suitable control measures are not properly taken.

Last but not least, the discussion on air transportation especially the one related to accident risks is also included in this section. In fact, air transportation accidents have the potential to cause similar problems like other modes of transport. For example, the collision of aircraft during transporting HAZMAT may accidentally release a large quantity of materials with significant consequencesin the area of accident. These significant consequences impose a greater risk than ever thought and subsequently may cause a problem in preventing the damage to the environment and may also lead to other unexpected risks severe to the human population. Such accident risks have attracted the attention of responsible parties especially the commercial aviation community to manage a strategic plan to reduce the number of accidents reported from time to time. Most of the accidents reported happened due to the hull loss problems such as collisions with terrain, overrun or excursion, and runway undershoot [18].Even though air transport accidents are very rare as compared to other transport modes, it is not possible to happen with strong impacts involved. This argument is supported by [19]that air transport accidents have resulted in

devastating impacts due to a large number of fatalities per accident and a total destruction of aircraft is usually involved.

3. Assessment approaches (qualitative vs quantitative vs hybrid techniques)

Based on the extensive review of the existing 151 studies on various methods or techniques applied for assessing risks in different modes of HAZMAT transportation, the discussion from various angles regarding the assessment approaches is outlined in this part. Basically, these methods have been classified into 3 main categories which are (a) qualitative, (b) quantitative, and (c) hybrid technique (a combination of quantitative-qualitative techniques or semi-quantitative techniques). Detailed discussion on the following approaches are presented as below:

3.1.Qualitative method

There are various qualitative risk assessment methods widely available in transportation research. In qualitative approach, the existing methods do not use absolute variable value to determine the occurrence likelihood of the failure event and the severity of possible consequences. Generally, experience, expertise, and competence of many personnel (from engineers to safety managers) who have conducted risk assessment are highly required in order to determine the assessment results of the accident. The following are several methods that use qualitative approaches to assess and evaluate the risks in HAZMAT transportation. These approaches are divided into two sub-categories as follows:

3.1.1.Ranking method

In general, the main concerns regarding this kind of method are reliability, efficiency, and ability to produce a meaningful score. These include, for example, listing and describing, developing a matrix or impact statement, and calculating the weighted score for each variable. This method uses numerical values in a certain range, for example ranging from 0 (low value) to 4 (high value) to determine the resource value based on the expert judgments. These judgments should not be arbitrary or subjective, but should reflect expert views, and should be supported by objective information.For instance, [20]have conducted a study using questionnaires to identify the factors associated by determining the frequency of accidents and incidents happened on a ship. There were seven main factors considered in the study, namely 1) competence, 2) interpersonal, 3) management, 4) work practices, 5) feedback, 6) shore orientation, and 7) efficiency. The questionnaire consisted of ten sections including various questions to obtain the feedbacks from the respondents which are important for the study. These questions were assigned using the Likert scale which requires the respondents to select the answers from 1 (totally agree) until 5 (totally do not agree) for the corresponding questions. 1262 questionnaires were distributed to 76 ships from the year 2006 until 2010 and then were collected and analyzed using Statistical Package for the Social Sciences (SPSS) v.16.0 and STATA v.10.1.

Other than that, [21]have investigated the roles played by senior officers as the middlemen in measuring the level of involvement among workers in OSH management in shipping industry. The methods employed for data collection were semi-structured interviews and observations on 66 respondents which consisted of 16 senior officers and 50 junior officers from two different types of shipping company. Other than that, [22]conducted a study on the issue faced in the engine room (ER) and engine control room (ECR) such as thermal climate, noise, and awkward working postures.

Semi-structured interview employed in the study involved 20 engine officers who were selected using theoretical sampling method. The data from the interview were coded using MAXQDA software to allow comparison between the data based on certain categories.

Besides, index based methods are also categorized as qualitative method. The advantage of index method is that all information is aggregated into one final score. [23]studied the influence of methodological decisions, which were the selection of weighting method, the expert choice, and the set of indicators on the absolute average shift in countries' ranking in comparison with road fatality ranking. The final ranking was presented based on road safety index. In a study proposed by [23], the road safety data set including the underlying risk factors and road safety measures were taken into account to determine the index score. In order to construct a more robust index, the consideration of uncertainty and sensitivity analysis were preferred. Uncertainty analysis and sensitivity analysis were used in order to assess whether the selected indicators are successful in reducing the rank of uncertainty for the countries selected and to answer the question which of the uncertain input factors is the most influential, respectively. Due to that, Sobol method was used for generating the input sample after the values of each input factor has been converted to make clear either weighting method, expert selection or indicator set will be used in the construction of the index. As a result, the index scores of 18 countries were calculated and finally the relative ranking of each country known as road safety rank (RSR) was identified. Meanwhile, [24]also developed an airline safety index that can be used to indicate a comparative overall safety level among Taiwan's major airlines.

3.1.2.Fuzzy approaches

In a problem-solving process, data are highly required in order to come up with an accurate decision. However, there is an obvious difference in terms data usage, in which some data are usable while some others are not. To solve this problem, [25]has introduced a set of fuzzy theory. Data in the form of imaginary number can also be used in solving the problems. A fuzzy set allows incomplete data, information that cannot be counted, and information that cannot be collected to form a problem-solving model. In this part, an approach using fuzzy set theory (FST) to model the occurrence likelihood and the consequences of hazards is presented. For example, a study by [26]have found the suitable solution for transportation problems that essentially have fuzzy supply and demand, by introducing a new algorithm. Next, [27]introduced a novel approach named fuzzy compromise programming approach to solve multi-objective transportation problems. [28]used fuzzy set theory as the basis to form a method to select and arrange the ranking of transportation projects. [29]has introduced a simple adjustment method based on fuzzy linear programming in order to find the most appropriate set of crisp numbers. [30]have compared two methods namely fuzzy multi-attribute axiomatic design approach and crisp and fuzzy AHP approaches in selecting the best multi-attribute transportation company based on some criteria including cost, time, damage/loss, flexibility, and documentation ability.

Other than that, [31]has proposed a fuzzy logic approach to form a safety model for HAZMAT transportation in which fuzzy if-then rules were used as the main basis of the model. This model considered the qualitative aspects of human knowledge and reasoning processes without the need for accurate quantitative analysis. Other than that, [32]have used fuzzy evidential reasoning approach in forming subjective security-based assessment and management framework as proposed in the study. Not only that, [32]also selected a case study related to container transportation delay as an illustration to test the effectiveness of the technique proposed in the study, which was hybrid multiple uncertain attribute decision making in safety management. There

are also some studies that have combined fuzzy approach with Bayesian approach. For example, a study by [33]who have introduced fuzzy Bayesian network (FBN) in which the connector between probabilistic and possibilistic risk-based models were combined.

[34] have used fuzzy set and fuzzy logic as the method to assess system reliability in maritime transportation. Another study that has used fuzzy set applications in the marine sector has been performed by[35]. In the study, fuzzy approach for maritime risk assessment (MARISA) was applied to assess the safety aspects in maritime. The study developed a modular and hierarchical structure by using fuzzy logic in order to determine the fuzzy risk factor containing static risk factor and dynamic risk factor. A number of static data related to the ship were considered in the assessment to determine the static risk factors such as age, flag, gross tonnage, number of companies, and duration of detention. Other than that, dynamic risk factor was assessed by considering the factors such as moment of the day and meteorological conditions including sea state, wind speed, and visibility.

3.2.Quantitative method

Similar to qualitative method, this approach basically aims to determine the probability of occurrence of each system failure event and the magnitude of possible consequences based on the exact numerical values. In other words, each function variable has a precise value which is useful for quantifying risks by using appropriate mathematical equation especially for failure data of accident cases recorded in the workplace. The following sub-section discusses the quantitative approaches specifically for risk assessment applied in HAZMAT transportation:

3.2.1.Mathematical programming model

Mathematical programming refers to a class of analytical (algebraic) methods that prescribe the best way to achieve a given objective while complying with a set of constraints; linear or non-linear constraints. For example, a study by [36]has introduced a method based on a mathematical model to identify the types of ship accident that tend to increase the risks of nearest port by including the number of death recorded as the consequences of accidents. The model was programmed to calculate the rate of accident for each type of accident reported to be related to HAZMAT transportation. To assist the data collection, the study used the ship accident data from the year 2002 until 2007 which involved 12 domestic ports focusing on multi-criteria port risk problem that can be used as the constraints in goal programming formulation. As a result of such approach, the decision makers or port authorities can consider for port improvement especially in implementing port risk mitigation measures as well as designing better port construction in the future. In this sense, [37]described a mathematical model which incorporated linear programming into dynamic programming for identifying an optimal container port development plan and evaluating the alternative investments in Korea.

There are other studies that have discussed the use of integrated models on a software platform to systematically solve the problems related to risk assessment in HAZMAT transportation [38]. [39-41]have stated the calculation of containment loss frequency for railway transport based on a deductive model introduced earlier in the study. The model took into account the frequency of HAZMAT release from loss of containment accidents and the assessment of consequences by considering the damage impact mechanisms on the respective land and demographic environments. Due to that, the risk calculations could be carried out in a systematic manner. The risk-related results were integrated into a software supported with intelligent maps and a variety of

geographical information system (GIS) data processing procedures applicable to any type of railway transportation system.

[42]studied the uncertainties in risk and safe distances calculation which involved atmospheric parameters by improving a system called Stochastic Toxic Release Risk Assessment Package (STRRAP) for HAZMAT transport. This improved system allows the analysis of light and dense gas diffusion models and particulate matter dispersion models to be conducted compared to using the old version of the system. Therefore, this system is useful especially in the risk assessment or emergency planning of toxic substance release as the effect of transportation accidents or fixed installation, from many sources or one particular source only. Besides that, the studies by [43,44]have also adopted atmospheric parameters as the uncertain inputs in analysing truck road accidents cases which caused toxic substance release.

3.2.2. Cost-benefit analysis

This method basically focuses on identifying the advantage of comparing the costs and benefits of a project. The concept of cost-benefit analysis is quite simple, and does not necessarily involve complicated mathematical calculation. [45] has studied the method to determine and estimate the cost of substantial loss such as vessel destruction, oil cargo spillage, and other property damage costs as the results of tanker accidents. The method used in the study employed three-equation recursive model which can be used to estimate the costs of different types of accidents including collision, fire/explosion, material/equipment failure, and grounding accident that occurred not only in a single vessel, but also in many vessels (2 or 3 vessel). Due to that, the study has suggested a special implementation of tanker accident policies towards fire/explosion as well as grounding accidents that is required in order to plan the preventive action in reducing vessel damage costs and oil cargo spillage costs. Meanwhile, [46]studied the total estimated cost savings (TECS) of inspections in reducing the risk of total loss incidents for five different types of ship. Therefore, the combination of duration analysis and binary logistic regression was used to estimate the cost of incident. Basically, hazard rates, probability of total loss of an incident, and also the effect of safety inspections in each ship within one year are determined by calculating the survival gains based on hazard models. As a result, the incident risk of total loss with estimated hazard rates are translated into survival gains of inspections which are combined with total insured value (TIV) to determine the total estimated cost savings (TECS) of inspections.

In general, the accident costs are very difficult to be determined accurately due to insufficient information available. According to [47],four elements are required to be included in total marine incident costs which are lost assets, loss of cargo, loss of lives, and pollution. Each element contributes differently tothe calculation of total cost. Thus, referring to[45,48],the cost of total loss of each ship varied depends on the type of ship involved in the accidents. Furthermore, the cost of property damage due to tanker accident was also determined in the study. [49]have considered unclaimed compensation cost when marine accidents happen. However, the actual cost for the loss of life is different for each country as summarised in the study done by[50].

3.3.Hybrid technique

The final method is a hybrid method which is a combination of quantitative method and qualitative method or semi-quantitative method to form a new complex method that can only be utilised in some specific situations. This is with the purpose to avoid the widespread of risk in an

accident. Besides that, this method also enables a comprehensive analysis to be conducted to obtain a better result than the result gained by other methods.

An example of a study that employs this method has been done by [51], who proposed the use of a combination of two different methods, which were semi-quantitative and qualitative methods in the risk assessment of steel-blasting task in ship manufacturing industry. This study utilised a bow-tie diagram as the qualitative method in mapping the pertinent cause and consequence of the type of accident studied. The next step used semi-quantitative estimation of risk which was based on a five-level risk-matrix. Therefore, a scoring system that was based on specific subset of national accident statistics aligned with the ESAW harmonised variables [52]was used to connect the two methods to determine the level of risk for each accident. Other than that, [53]have introduced an integrated methodology based on the risk score (RRS) framework and fuzzy logic for assessing the risks in the pipeline system. This method, known as the fuzzy risk analysis method was a combination of qualitative (RRS) and quantitative (fuzzy inference system) method. By using the similar case study of natural gas pipeline as presented by[54], the comparison between the proposed method and traditional RRS was conducted. As a result, the proposed method gave much more comprehensive risk assessment and capable of removing the main shortcomings of the traditional RRS. This allowed the risks and hazards associated with the pipeline system to be controlled safely from any undesirable system failure.

Besides that, [55]studied the safety of metro train in order to determine the cause of potential accidents by proposing safety maturity model (SMM). This model is an upgrade version of previous safety culture maturity model (SCMM) presented by [56] which takes into account all technical, operational and methodological elements, not only the behavioural and/or attitudinal culture. Based on SMM, the study used a questionnaire consisted of 10 questions regarding the variables such as precursors, top events, injuries, and fatalities in order to test metro's safety maturity against their actual performance that was recorded from 2002 until 2009. The questionnaire was distributed to 11 metro organizations including 18 types of CoMET and Nova railways. In this questionnaire, 5 out of 10 questions were determined regarding the findings obtained from the previous studies on metro train [57,58].Meanwhile, the quantitative part calculated the safety maturity level based on the scores obtained. As a result, maturity score identified no correlation between the four variables due to non-normal distributed data. In other words, the data recorded for each variable was fewer and insufficient to provide a full set of data for maturity score calculation. However, this study has provided a major lesson in reducing the risks due to the improvement through technical design standards and investments in equipment and infrastructure for the safety of metro train.

Next, in the study by [59], an analytic hierarchy process (AHP) and fuzzy axiomatic design (FAD) were used to structure an integrated environmental management system (IEMS) that is suitable for shipping business. The AHP method was used to weight and prioritize the requirements of ISO 14001:2004 required in IEMS while FAD method was used to determine the conformity level between the clauses of ISM Code and ISO 14001:2004 standard utilized. Therefore, this study proposed a method useful in a pilot application for shipping management companies to contribute to the environment and to avoid any environmental damages in the maritime transportation industry. Other than that, [30]also used the same approach, i.e., using hybrid of FAD and AHP methodologies to solve the problems related to multiple criteria that need to be considered in selecting the appropriate model in different transportation company. [60]also introduced a hybrid approach by integrating business analysis, AHP[61], and a suitable technique in problem-solving i.e., TOPSIS [62] to solve ship evaluation and selecting problem.

4. Methods application

Based on the 151 previous studies in this review article, there are many types of risk assessment methods have been introduced and employed by researchers. Thus, the application of these methods has been categorized into four main categories as follows:

4.1.Accident review

This part is to highlight the discussion of accident cases for assessing the regional risks resulted from transportation by means of a different system as mentioned in previous sections. Referring to the study by [55], the precursors of railway accidents have been analyzed for 18 CoMET and Nova railways in the period 2002-2009. This approach allows a systematic analysis of the problem of the accidents and offers flexibility and efficiency in the improvement process by proposing the new SMM. The model takes into consideration the new aspects which are technical, operational and methodological elements, and actual achievements instead of behavioural and/or attitudinal culture solely. As a result of such approach, the improvements in technical design standards and investments in equipment and infrastructure are the most actions that take place to mitigate such risks especially for railway safety. As stated by [63],suitable prevention measures can be applied by monitoring the precursors that enable special emphasis to identify the areas or top events that are most likely to cause fatalities and injuries.

Besides that, [64]have presented a study of the trend of HAZMAT incidents from 1995 until 2004 with a total of 2145 cases reported in transportation of flammable/combustible liquids using roads in California, Texas, Illinois, New Jersey, and Iowa. Moreover, all the data were obtained from Hazardous Material Information Reporting System (HMIRS) database organized by United States Department of Transportation (USDOT). However, the main problem was the total distance of the incidents could not be defined because the lack of more details information on the transportation routes in the database. Therefore, the study used the approach to consider the distance through the great circle calculation between shipment origin and the incident location to overcome this problem. The study has revealed the correlation between the location of HAZMAT incident and the total distance of transportation i.e., from the shipment origin to the incident location. This finding has become the basic guideline to assist the authorities to prepare a safety plan to prevent the occurrence of the same incident in the future.

According to [65],the issues of HAZMAT transports are not only dealing with the type of substances being transported but also deal with the characteristics of road network chosen. Factors such as road condition, tolls, regulatory standards, and national regulations on the road transport of HAZMAT play roles in different countries. This is supported by the findings in a study done by [32]. The study revealed the increase in total number of accidents that happened from 2000 until 2008, with 322 accidents reported in China. The aim of the study was to analyse the accident trend to determine the causes, consequences, severity, and frequency of each of the accident cases. This study presented the findings of accident locations which mostly happened in the general road compared to other types of roads. Moreover, four categories of possible cause were determined as well as the type of accident and the population affected. Referring to that, human-related causes (driver error) are the most common causes of accident, the release cases represent the highest percentage and the population affected were expressed by four variables according to the scale of consequences. Therefore, the effective ways in organizing, planning, implementing, and monitoring HAZMAT road transport are very essential to avoid future undesirable accident cases from happening.

Next, [66]conducted a case study regarding the effects of fire on chemical storage container system in ships. The study analysed the probability of the formation of boiling liquid expanding vapour explosion (BLEVE), thermal radiation, and dispersion of smoke which are among the effects of such fire cases. These effects have been quantified to ensure that appropriate and accurate preventive measures are taken should such cases happen in the future. The most concern is to avoid the transmission of the accident from one container to the next container which led to a domino effect that could create the worst event to happen.

From the period 1993 to 2006, Hellenic Coast Guard investigation reports have recorded around 268 accidents involving Greek-flagged ships worldwide. As far as concern, [67]have proposed a study in analysing the occurrence of accidents in Greek shipping during the pre and post-International Safety Management Code (ISM Code). This analysis included the classification of dataset by referring to various accident factors that have been transformed and coded into dependent variables and predictors. In this respect, the tree analysis was performed to examine the variable, in which 'period of accident' was used as the significant predictor that contributed in distinguishing human or non-human element as the source of accident referred to dependent variable. As a result, human element was addressed as the main source of accident mainly in tankers and Ro-Pax vessels. The outcome showed that the ISM Code constituted an effective way in reducing human-induced accidents due to the respect by removing the influence of vessel type categories upon the source of accidents since the ISM code have been implemented. Another shipping accident due to human errors has been recognized as the significant cause with enormous challenges to control which consequently require an effective response towards the system safety. Thus, [68]proposedan analytical foundation for human factors analysis and classification system (HFACS) to quantitatively characterize the role of human errors. This study has extended the existing HFACS framework by integrating it withfuzzy analytic hierarchy process (FAHP) in order to quantify human error in shipping accidents. By using FAHP methodology, the problem to quantify the expert's judgments from HFACS methodology could be solved via pair-wise comparisons among the factors that contribute to the accidents. Therefore, the outcomes have shown the improvement of safety precautions in shipping companies regarding the consistency of findings and prevention of data manipulation in the shipping accident investigation process due to the advantages of FAHP integration.

4.2.Assessment of hazards and risks in HAZMAT transportation

In this category, the application of existing methods specifically for hazards and risks assessment in HAZMAT transportation is discussed. All types of transportation system including marine, roads, railways, air, and pipeline systems are covered in details as follows:

In railway transportation, [69]have presented a study related to HAZMAT transport and storage by using tank cars over yard expansion. The event tree analysis (ETA) was used to calculate the probability of occurrences and estimate the risk effects of the accident such as major spillage. In this study, six different chemicals were analyzed in order to determine the comparison results between the pre-expansion and post-expansion of yard. In particular, the average monthly volume and hazard for each chemical was taken into account for calculating the circular radius of impact areas of spillage especially involving a worst-case scenario for each chemical involved. With this approach, all possible scenarios which led to the accident risks involving different chemicals transported by tank cars can be evaluated properly.

The risk associated with accidental releases from pipeline transportation over long distances is extremely dangerous. Therefore, a proper risk assessment is required to address the risks that lead

to substantial risk reduction as presented in the previous study by [70]. By referring to quantitative risk analysis (QRA) method, a study for natural gas pipeline network has been presented. This integrated method consisted of three phases, which were probability assessment, the consequence analysis of the outside and inside pipelines, and the risk evaluation. To demonstrate this analysis, 20 pipelines were adopted in order to apply this assessment. Practically, for the consequence analysis of the outside pipelines, the parameters such as heat and overpressure were considered in order to calculate the individual risk and societal risk in different types of accident such as jet fire and unconfined vapour cloud explosion (UVCE). At the same time, economic risk was also calculated at the internal part of the pipeline system focusing on the risk of losing the source of production due to pressure re-distribution. By adopting QRA method, the pipeline comprehensive risk analysis (PCRA) has been developed in a study by [71].The analysis was applied to 60 feed and product pipelines of Mahshahr Petrochemical complexes. To estimate the risk and the probability of pipeline system damage due to active defect, a study by [72]has introduced a classification reliability procedure in risk assessment of pipeline system. This procedure consisted of minimax probability machine in reliability analysis and FORM/SORM methods. Moreover, pipeline system has been recognised as a facility that saves the cost of hydrogen transport especially when there is a high demand and it involves long distance transport. This is because there is only small energy loss during the transportation if appropriate type of pipeline and initial pressure are selected [16,73].

Generally, the quantitative studies related to marine transportation are low in the number of publication compared to qualitative studies [74]. Many of the quantitative studies published have been focusing on land transport such as road and railway instead of marine transportation. However, in the recent years, the increasing number of quantitative studies published especially in marine transportation showed a positive sign for new research field. For example, the studies by [75,76]have been focusing on the transport of HAZMAT through sea transport including the transport of petroleum products. Due to unexpected events like collision or grounding during marine transportation, the risk effects associated towards people and environment were assessed. Moreover, [77]have compared three models(neural network, multiple discriminant analysis, and logistic regression) to accurately estimate the type of vessel accidents despite the fact that there are various conditions in managing the vessels at lower Mississippi River. Meanwhile, [78]have conducted a study to assess the risk in marine transportation especially the risk related to the structural design of a ship. This study focused on the availability of formal safety assessment (FSA) to assist in the decision-making process. With that, the implementation of international regulations with the aim to enhance the marine safety was adopted. Another study conducted by[79]also applied the FSA method with an additional method known as safety-analysis-based decision-making framework. This framework is employed as the alternative way to the existing methods (i.e., FSA) especially when only non-numerical safety data with high uncertainty are involved. Based on the statistics of accidents involving containership, [80]have proposed a study using the FSA method to assess the occurrence of container ship accidents. As the result of assessment, several aspects can be improved in future such as the vessels' strength and stability, fire-fighting and life-saving equipment, human reliability and information availability, reliability and interchange related to the container ship safety. Besides that, [81]has also presented the situation in maritime safety assessment and the use of FSA method. The study revealed that the implementation of this method on ship operation system and design can reduce the maritime risks to a minimum level. On the other hand, [82]have proposed an integrated VAHP-ANP methodology as a useful tool for decision maker to make the decision in selecting the type of sea vessel for transporting passengers and goods in the current fleet of Bosphorus public transportation. The aspects such as economic view

and different transport distances were the main criteria considered in this study. Due to that, the short and medium distances for each sea vessel alternative was evaluated and compared to the result of VAHP and VAHP-ANP integrated method in order to determine the most suitable sea vessel type for efficient vessel fleet planning.

In air transportation, [83] have introduced two methods called launch area toxic analysis (LATRA) program and cold spill toxic risk analysis (COSTRA) program to estimate the probability risk of exposure to toxic materials. These programs combined the probabilistic models of an accident, the release cloud formation and dispersion, and the new exposure-functions (ERFs) for sensitive and normal exposed population. Other than that, [24]have introduced a new airline safety index based on the comparative safety performance and efforts of airlines which was applied to four major airlines in Taiwan. This index which included four safety dimensions; (a) management, (b) flight operations, (c) engineering and maintenance, and (d) fleet planning (finance and property) was able to assist the airlines management to identify the strengths and weaknesses related to safety management system in aviation. With this approach, the useful information in providing a guideline for the airline to maintain or improve their safety level in terms of both overall and individual safety dimensions. Other than that, [84]has established a quantitative model to assess the aviation safety risk factors. This model was developed by integrating fuzzy linguistic scale method, failure mode, effects and criticality analysis principle, and as low as reasonably practicable (ALARP) approach.

As there are issues in choosing the appropriate routes especially using road for transporting HAZMAT with minimum risks to the local population who lives near the selected road, it has become the "hot issue" focused by many researchers in various related publications. A study by [85], has introduced a new method based on the risk analysis to select the best route for transporting hazardous materials. This method adapted a computer code named OPTIPATH by introducing all risk indexes for linear risk sources. Next, [182]developed a novel model named reliability-based single-vehicle accident risk prediction model which has improved the existing model known as deterministic dynamic vehicle model. This model allows accident risk analysis to be conducted by considering realistic driving conditions in nature such as specific topography, wind, and road surface conditions as well as associated uncertainties. Other than that, [86]have introduced a model based on Bayesian hierarchical approach to estimate the total number of accidents causing injury or death to road users. This model is still usable although there are arising questions on the lack of data or information required for some specific road segments.

[87]have proposed a safety assessment method to analyse road tunnel problem. The method was demonstrated through a case study of a tunnel ventilation system which was based on the systems-theoretic accident model and processes (STAMP) model as the complementary support tool to overcome the insufficient information resulted from previous studies on road tunnel QRAs[88-91].These studies mainly focused on the technical and physical aspects of the system instead of other aspects such as human behaviour and the organization were not addressed sufficiently. By using the proposed method, decision-makers could consider other scenarios that are not mentioned in the traditional road tunnel QRAs and potential to assess the safety level of the tunnel and propose additional measures for improvement in order to avoid accidents. Such effort in obtaining accurate decisions, many researchers have emphasised the need to evaluate tunnel safety in a systemic perspective[92-94].

4.3.Preventionof HAZMAT transportation accidents

In this part, all the previous studies that are related in applying prevention approaches towards HAZMAT transportation are presented. However, there are some issues on the lack of data sources available which cause inaccurate result in the decision-making of conducting suitable prevention actions. On the other hand, many causal factors have been overlooked in the earlier identification phase in providing the important data required. In order to solve this problem, most studies are required to undergo specific analysis for all factors that have the potential in contributing to the sequence of events which lead to the occurrence of an accident. For instance, [41]have introduced a software that applies Hot Spot Approach to come out with a solution for these issues. The software analyzes various spatial data (railway infrastructure, land use, and population density) in rail transportation of HAZMAT by using hybrid method which involves several quantitative models and event tree analysis (ETA) method is used to collect the required data. This method is suitable to be applied to rail transport in which many aspects such as technical infrastructure, rolling stock, human actions, regulation, and management procedures are properly considered. Thus, a clear need for more comprehensive approaches does not only limit the insight to foresee the causes and sequences of the accident, but also allows in focusing other aspects that are indirectly related to particular studies.

There are many studies that specifically focus on avoiding disastrous effects of HAZMAT transportation accidents on people, property, and environment, especially involving railway transportation. For example, [95]have emphasised the safety design of a tank car using generalised tank car safety design optimisation model. This model uses a quantitative framework that assists the process of decision-making in deciding the tank car safety design for transporting HAZMAT. Moreover, [96] have discussed the improvement for safety in railway transportation of HAZMAT by applying an optimization model that considered the combination of two types of risk reduction strategies; broken rail prevention and tank car safety design enhancement. Meanwhile, [97]introduced a framework for airspace planning and design as the strategic planning to prevent aircraft conflicts and collisions. The framework consisted of a conflict risk assessment model which is able to compare different airspace designs and various organizational scenarios under different traffic flow levels.

Besides that, the occurrence of spillage event is getting more serious over the recent year which requires specific precaution action during the transportation of HAZMAT especially due to malfunction or collision of tanks. This problem has attracted the attention of many responsible parties to overcome the recurrence of these events. Therefore, a proper and systematic safety management plan is required to be established in the operation of HAZMAT transport. A previous study by [98]has introduced a fire-explosion-poisoning quantitative probability model (FEPQPM) to evaluate the risk of HAZMAT spillage via pipelines system. In this study, the derivative accident-events like jet fire, vapour cloud explosion, and poisoning were calculated based on the loss calculation which refers to material direct economic loss, personnel direct economic loss, direct economic loss, and total economic loss. As presented by Changing et al [199] a comprehensive systematic framework of emergency response rank mode of HAZMAT accidents by road especially related to spillage events was developed. By utilizing death toll, individual risk, and societal risk as the emergency rank criterion, a quick guide on the response during the initial phase of accident was outlined. This guide can be used as a reference to determine the emergency zone and response rank in the event of spillage. This means, the appropriate control measure must be taken drastically to avoid recurrence of this event in the future.

Next, [69] have estimated the cost-related and risk-related impact of chosen alternative routes instead of the existing routes for rail transportation of HAZMAT. The aim was to ensure that these routes are safer, cost-effective, and can avoid any risks that could happen such as spillage of hazardous materials that could harm the health of the population living near the rail yard. By combining a network computer model and a mathematical risk model, the estimated risk was evaluated for random sample of origin-destination (O-D) pairs on the U.S rail system. A few factors were addressed in this study. One of the important factors was commodity type, in which this factor could affect the conditional release probability and the impact radius of accident. In this model, the pair (O-D) of alternative routes was chosen after it underwent the analysis, resulted in a better estimation of relative routes length selected. The weightage for each route was calculated first by identifying the risk-related estimation with the purpose of generating better alternative routes instead of existing routes. According to [99],the gateway location problem (GLP) has been highlighted with the main concern to select the potential location of gateway that is able to minimize the total risk of HAZMAT transportation. Therefore, this study proposed a methodology to compute the best trade-off solutions easily between the risk and the cost when drivers travel along the shortest path of (O-D) pairs assigned with a gateway.

Other than that, [100] have proposed the appropriate routes for HAZMAT transportation that can minimize the harmful effects on the population if an accident occurs. This is similar to a study by [101]who focused on the suitable approach in overcoming the problems known as “minimum cost flow problem” when selecting the best route for HAZMAT transportation. Specifically, the aspects such as inexpensive distribution process and the huge total capacity from the production site to the destination of choice need to be considered [85]. According to [102], several factors such as road status, traffic density, and the condition of local population, if due attention in risk analysis is not given, will probably cause inaccurate results and the actual risk level cannot be determined. This is supported by[103]who stated that choosing the suitable routes is important in order to avoid the risk in land-based transportation of HAZMAT. The model is useful as a tool to estimate transport-related risks in which it is able to give an output to improve the decision on the selection of highway section, alternative routes, and emergency management. A further study by [104]has introduced a site-oriented framework for risk assessment based on a theoretical approach for emergency planning and optimisation. Many factors such as inherent factors (such as tunnels, bend radii, height gradient, and slope), meteorological factors, and traffic factors (traffic frequency of tank truck and dangerous good truck) were analyzed in order to modify the standard national accident frequency in the range of acceptable level. Moreover, [105] have proposed a Pareto-based bi-objective optimization of hazardous materials vehicle routing and scheduling problem with time windows (HVRPTW). Practically, Pareto optimal solutions can provide a significant base for decision-making process in HAZMAT transportation.

To achieve the objective of estimating crashes on digital or coded on urban transportation networks in the planning phase, a study by [106] has been published. The study focused on the use of safety performance functions (SPFs) or crash prediction models (CPMs) to relate number of crashes and the important of independent variables such as traffic flow or the number of lanes on a road segment.[8]also developed a road network for HAZMAT transportation. The road network was adopted based on a tree design problem as the basis for integer programme in minimizing the overall risk of transportation. This approach is similar to the procedure introduced by[107] in minimizing the risk in single HAZMAT shipment. Besides that,[108]have introduced the value-at-risk (VaR) framework for the routing problem of a single HAZMAT trip. Clearly, the VaR risk model was able to measure the risks brought by HAZMAT transport under uncertainties by embedding the

algorithm of a single HAZMAT trip problem into a Lagrangian relaxation framework to obtain an efficient solution.

4.4Best practice sharing

In the context of best practice sharing, all of the sharing derived from previous studies are discussed in more details in this part. As a matter of fact, the knowledge in risk assessment is one of the precious sharing that must be considered in the studies. For air transportation, all knowledge related to risk assessment are used by the pilot in making decisions to ensure the flight conducted is safe and sound. A study by [109] has adopted the concept of low-flying to enhance the capability of pilots to accurately make a decision based on the risk assessment during simulation training. The feedbacks from the pilots about the flight performance results were adopted as the basis for skill development to accurately assess the risks for amateur pilots. With this approach, the important point that could be highlighted here is the ability to modify pilot's behaviour in response to hazards during a similar flight after the following 1-week training. Due to that, the training has provided initiatives to the pilots to acquire safe and successful flight management when engaging potential hazardous events directly.

Next, [110] conducted a study on risk analysis of HAZMAT transport using roads in Singapore. The method used in this study was based on the method introduced by the Health and Safety Executive, UK [111] regarding the risk assessment of dangerous good transported by truck towards individuals and the community live nearby the routes. This issue has been given high attention by the Singapore authorities since most of the routes are located in the area with high-density population. A particular effort was dedicated to share the outcome of the studies applied in two selected routes for liquefied petroleum gas (LPG) transport. This study is important for solving the problem related to routing-location of routes. By using the software known as process hazard analysis software tools (PHAST), various hazard zones regarding the respective route were determined in terms of societal risk. As presented by [112], multi-criteria decision analysis was conducted in order to determine the alternative routes available around Mexico City especially during hard traffic congestion. This analysis has compared the transportation of two types of HAZMAT, chlorine and gasoline, by considering the ‘‘best” set of routes that can minimize the total daily exposure to the most dangerous accident. This is one of the examples for the problem in road transportation especially in transporting HAZMAT. These problems must be dealt with proactive action to ensure its safety in daily operation and also to avoid future undesirable accident cases from happening the same way.

Many studies have focused on sharing their best approaches in reducing the risks in HAZMAT transportation especially by using quantitative risk assessment (QRA) method. For example, [113] used the QRA method to compare the risk estimation for each route used for transporting HAZMAT. The main issue was highlighted for each route by considering the related risks especially towards people who are exposed such as road users and also the community who lives around the area where HAZMAT transportation accidents occur. In this assessment, two different types of routes were analysed; tunnel-type and normal road. From the conducted assessment, the comparison results between these types of routeshave been addressed as the basis reference to other researchers who are interested in assessing this matter in details in the future. Moreover, [114] have adopted the QRA method to analyze the transport of ethylene oxide by roads. The study shared how the analysis was conducted by dividing the routes of selected roads into small segments to facilitate the exact calculation ofthe individual risks and the societal risks by using a simple computer routine. The data collected from accident frequency, consequences of historical

accidents, meteorological conditions, and resident population were used in the analysis. On the other hand, [115] have developed a QRA software tool to assess the risks arise from road tunnel. This study specifically considered the unique characteristics of the road tunnel in Singapore such as the road tunnels that have many conjunctions in which the main tunnel and slip roads merge, and the road tunnels that have short distance between two consecutive conjunctions. The study is different from previous studies by[116] who applied QRAM software to analyze various risks of 13 selected Austrian tunnels and some road tunnels in UK, France, and US [213] This software is not suitable for evaluating the risks of road tunnels in Asian countries because it has been customized only for European road tunnels. It is well known that the comparison in terms of different risks between Asian and European road tunnels have been revealed.

There is also a study proposed by [43]who conducted the risk assessment of chlorine gas release caused by truck accidents around Rosario city. Due to that, the uncertainty problems identified in the accidents can be analyzed by using a computer-based system known as dense gas dispersion (DEGADIS) model. With the advantages of this model, the static emission points such as storage tank and stacks, as well as mobile sources like HAZMAT transportation can be analyzed by taking into account the stochastic nature of atmospheric variables and deterministic variables like gas properties, roughness surface characteristic, and population density. In that case, the chlorine concentration distributions and the risk-related to individual risk and societal risk in the affected zone can be estimated sufficiently. Therefore, the emergency plan can be proposed by the authorities to estimate the safe distance from the actual accident location. Besides that, [117]have analyzed the impact of hydrogen as a new source of energy in road transportation in Korea. The analysis was conducted using the energy economy model. Indirectly, the Korean Government started to show an effort to reduce the release of carbon dioxide through the introduction of alternative energy to replace petroleum as the main energy source applied for daily road transport. Moreover, a study by[118] has integrated the data from various sources which are mostly the databases on dangerous goods accidents, road accidents, and work accidents to analyze the accidents related to HAZMAT transportation using road in Quebec province, Canada. The major finding of the study had identified that many events related to HAZMAT were missing due to the improper record and also the use of different key attributes such as spatial location, time and date, and the presence of HAZMAT in each database. Therefore, the study has recommended the best practise to be applied by the authorities to ensure all information are standardized and recorded in the database, hence allows the better understanding in the future.

Besides that, environmental problems such as oil spillage and pollution have become the main concern among researchers to study the routes selection especially those that involve HAZMAT, crude oils, and petroleum products. For example, the study by [119]has introduced a multi-objective network flow model for risk analysis and risk routing with multiple commodities, modalities, and origin-destination pairs. With this model, the trade-offs between risk and transportation cost can be presented along with a web-based decision support module, IOTS. Each route was assigned an expected risk cost based on the history of spillage, which have been done in a previous risk assessment presented by [120,121].This method can also give the total loss cost based on the history of spillage happened at the port. On the other hand, materials such as irradiated nuclear fuel (INF), plutonium, and radioactive wastes have also been transported and possibly bring harmful effects if an accident takes place. Therefore, the authorities should take any preventive measures to avoid similar problems in the future. A study by [122]has illustrated the actions taken by the International Maritime Organisation (IMO) to ensure the ships used in such transport are in compliance with the highest possible standards such as INF Code.

Other than that, a study by [123] have proposed the development of strategic transportation model for the transport of oil on US waters. This model was developed based on the high-level strategic decision-making tool which has the ability to identify the "weak" links in the system and evaluate the alternative routing and shipping scenarios. Next, [124]has studied the risk management of liquefied petroleum gas (LPG) transport in Hong Kong. The study was constructed by considering the special features of Hong Kong such as high density of population and narrow streets. Based on the finding of the study, the authorities in Hong Kong have developed a comprehensive risk assessment with appropriate preventive measures which have the ability to reduce the possible risks arise during LPG transportation and also improve the existing risk management system in accordance with the new international codes and practices.

As discussed above, all the previous 151 studies included in this review paper are presented in Table 1. In order to facilitate the respective category, each of the categories based on the mode of transportation as mentioned in the previous section is summarized. As can be seen, the assessment category has the highest number of studies, followed by prevention category and best practice sharing category, and finally the accident review category. Due to that, the assessment category is identified as the main contribution among the researchers worldwide in order to improvise the application of risk assessment in HAZMAT transportation from year to year.

Table 1
Number of studies for each category based on the mode of transportation

		Assessment	Best Practice Sharing	Accident Review	Prevention
Marine		30	10	9	17
Road		11	11	2	11
Railway		3	1	1	4
Pipelines		6	-	-	1
Air		5	1	-	1
Others	All	12	2	-	1
	Intermodal	2	1	-	9
TOTAL		**69**	**26**	**12**	**44**

5. Statistical analysis

In this section, the analysis of previous 151 studies collected from online database available is discussed. The search mainly reviews the relevant literature in the area of risk assessment applied in HAZMAT transportation focusing on the statistical distribution of the studies over given topics. Several categories have been outlined as follows:

5.1 Statistical analysis based on type of journal publication

Various types of scientific journal publication have published many studies related to HAZMAT transportation. However, only 151 previous studies have been selected regarding the literature search of risk assessment methods in HAZMAT transportation. As mentioned previously, this review paper only discusses several key points regarding the risk assessment applied in HAZMAT transportation, whereby other points that are out of the scope are not discussed in further details. The following are the eight selected scientific journals which represent the highest number of studies recorded related to this area of study: (a) Journal of Loss Prevention in the Process Industries (JLPPI); (b) Reliability Engineering and System Safety (RESS); (c) Expert Systems with

Applications (ESA); (d) Safety Science (SC); (e) Journal of Hazardous Materials (JHM); (f) Accident Analysis and Prevention (AAP); (g) Transportation Research (TR); and (h) Marine Policy (MP).

Figure 1 shows the distribution of the total number of studies based on the types of journal published from the year 1995 until recent publications in 2015. Based on the analysis conducted, each journal indicates different number of publication in which 21 studies have been published in JHM, followed by SC with 19 studies, JLPPI with 16 studies, RESS (15), TR (13), APP (12), ESA (10), and last but not least is MP with 5 studies. Meanwhile, the other eight journals such as journal of safety research (JSR), European journal of operational research (EJOR), and marine structures (MS) have less than five studies published in the particular journals respectively. Lastly, the rest 21 studies are classified under OTHERS category which consists of a combination of various types of journal that record less than two studies.

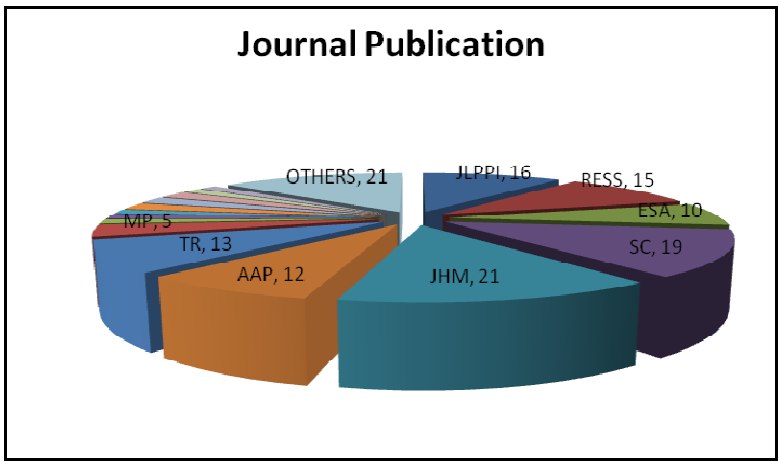

Fig. 1. Distribution by the type of journal publication

5.2 Statistical analysis based on year of publication

In this part, statistical distribution based on the year of publication has been analyzed in order to view the trend of studies published. This analysis is done based on the 151 studies selected from 1995 until 2015 i.e., within the period of 20 years. With that approach, any additional information which is relevant to the application of risk assessment methods could be outlined by researchers. In other words, the development of risk assessment methods become more applicable towards modern transportation. Only four studies were published in 1995. There is a significant difference between the number of studies published before 2000 and after 2000 in terms of 'publication progress'. As recorded from 1995 until 1999, the total number of related studies is only 13, which is only 9% out of the total number of studies from 1995 until 2015.

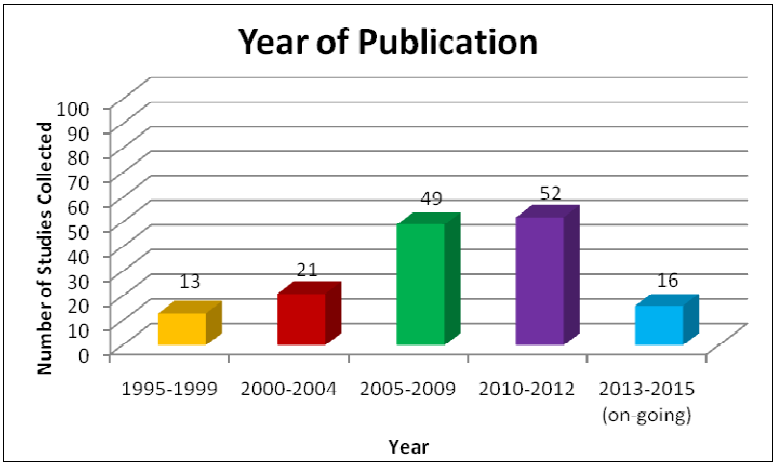

Fig. 2. Distribution by year of publication

However, starting from 2000, there is a rapid increase in the number of studies published in which 21 studies have been published within 2000 until 2004. Then, from the year 2005 until 2009, this kind of topic becomes a 'hot topic', thus there is a drastic increase in the number of studies i.e., twice of the previous period. 49 studies have been published within the year 2005-2009, which are 32% of the total number of studies from 1995 until 2015. This clearly shows that the topic of risk assessment in HAZMAT transportation is a wide area which requires more attention from worldwide researchers as the number of studies from 2010 until 2012 continues to increase up to 52 studies. Moreover, journal publication is well progressing as more than 16 studies have been published since 2013 until now (on-going).

5.3 Statistical analysis based on financial support on the studies conducted

The funding contributed to the success of each study is also discussed. The agencies that support the 151 studies financially have been identified. The analysis of the total number of agencies involved in HAZMAT transportation is illustrated in Fig. 3.

The result showed that many agencies have provided financial support for 57 studies (38%), meanwhile the rest 94 studies (62%) do not indicate whether any financial support has been provided. Among the agencies that have been actively funding the publication of studies related to HAZMAT transportation are Natural Sciences and Engineering Research Council of Canada and National Natural Science Foundation of China. Based on the analysis, China has the highest number of sponsors with 7 agencies, followed by Canada with 6 agencies, Italy and US with 5 and 4 agencies, respectively. Meanwhile, other countries such as Singapore, Argentina, Norway, and Taiwan also have been stated as the countries that provide funds for publishing a number of studies related to risk assessment in HAZMAT transportation.

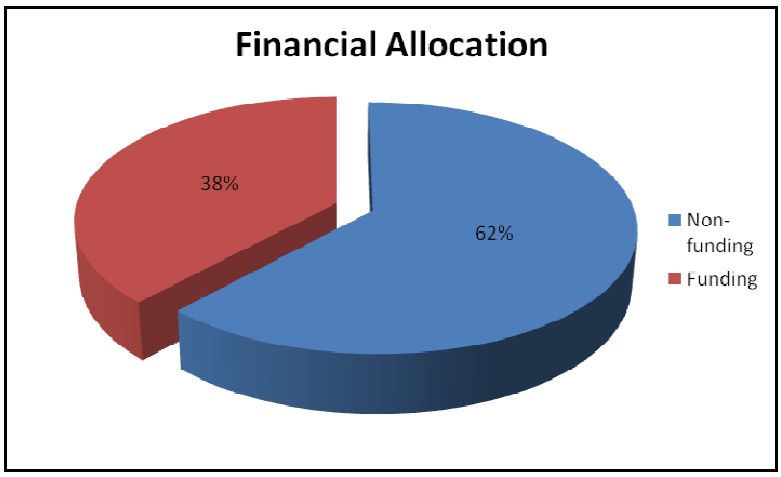

Fig. 3. Distribution by Financial Allocation

5.4 Statistical analysis based on the type of transportation system

As discussed in previous 151 studies, the main problem identified in a particular type of transportation system is related to safety, health, and environment. Therefore, these studies have been classified into 5 different types of transportation system; marine, roads, railways, air, and pipeline system. Figure 4 shows the distribution of published studies based on the type of transportation. The highest number of study collected is marine transportation with 66 studies, and followed by road transportation with 35 studies, and air and pipeline system with seven studies recorded each. Last but not least, the type of transportation with the least number of studies is railway transportation with only five studies.

However, the above numbers constitute 124 studies, which can be classified into specific categories, out of the overall number of studies, 151. The remaining 27 studies are those studies without specific discussion on a particular type of transportation system. 15 out of the 27 studies generally discuss the risk assessment in transportation system without specifying any type of transportation. Finally, the rest 12 out of the 27 studies have emphasized the risk assessment in HAZMAT transportation which combines road transportation and railway transportation, or more commonly known as intermodal.

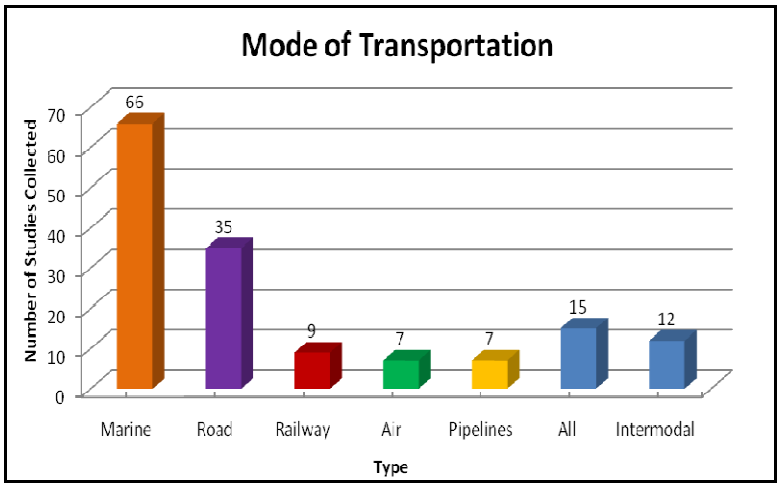

Fig. 4. Distribution by Mode of Transportation

For reference, all the 151 studies are summarized in the Appendix A. These studies are arranged into the following categories: (a) Title and paper citation; (b) Year of publication; (c) Technique's name; (d) Method's type; (e) Mode of transportation; (f) Scientific journal; and (g) Funding Agency.

6.Concluding remarks

In this paper, a scientific literature was outlined for a comprehensive review of the development of risk assessment applied in HAZMAT transportation. The outlined review consisted of 151 selected studies from 1995 until 2015 that were discussed in detail regarding 5 different modes of transportation system available in the industries, namely marine, roads, railways, air, and pipeline system. In the context of HAZMAT transportation, all methods that have been developed in the previous studies for assessing risk related HAZMAT transport were taken into account to utilize the strengths and weaknesses of each method specifically in different approaches such as quantitative, qualitative, and hybrid techniques respectively.

Referring to these studies, various key points were discussed in details especially the points related to the application of methods that have been developed. In order to make a better understanding, these methods were classified into 4 main categories;1) the review of accident occurrences, 2) transportation risk evaluation, 3) the best practice sharing of existing methods, and 4) the prevention of HAZMAT transportation accidents. Furthermore, a statistical analysis of 151 studies in this review was provided together with a presentation of the number and the type of scientific journal as well as the financial allocation for some of the selected studies.

Thus, this review paper provided the proper understanding on pros and cons of the existing risk assessment methods for enhancing the study of HAZMAT transportation. With this approach, it is believed that the way of this review was conducted will improve the effectiveness of control measures taken and reduce the transportation related risks simultaneously. Due to that, this review paper can be used as a suitable reference for government and industries that not only consider the potential severe consequence of a HAZMAT accidents, but also allows for developing the appropriate risk assessment methods that are able to improve the safety of HAZMAT transportation in the future.

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Appendix A

No	Paper Citation	Year of Publication	Technique	Method type	Main Point	Mode of transportation	Journal	Funding Agency
1	The ARIPAR project: analysis of the major accident risks connected with industrial and transportation activities in the Ravenna area [125]	1995		Quantitative	Assessment	Others (All)	RESS	NA
2	A Neural Network for Transportation Safety Modeling [77]	1995	Neural Network, Multiple Discriminant Analysis & Logistic Regression	Quantitative	Sharing	Marine	ESA	NA
3	Risk analysis for the road transportation of hazardous chemicals in Singapore- a methodology [110]	1995		Qualitative	Sharing	Road	JLPPI	NA
4	Optimal location of routes for vehicles transporting hazardous materials [100]	1995	Routing Model	Quantitative	Prevention	Road	EJOR	NA
5	Exposure-response functions in Air Force toxic risk modeling [83]	1996	Launch Area Toxic Analysis Program (LATRA) & Cold Spill Toxic Risk Analysis Program (COSTRA)	Quantitative	Assessment	Air	OTHERS	U.S. Air Force
6	Strategic Transportation Model for Oil in US Waters [123]	1996	Strategic Transportation Model	Quantitative	Sharing	Marine	OTHERS	NA
7	A scheme of hazardous chemical identification for transportation incidents [126]	1997	Scheme	Qualitative	Prevention	Others (Intermodal)	JHM	NA
8	Utilizing state hazardous materials transportation data in hazardous analysis [5]	1997	Survey	Qualitative	Assessment	Road	JHM	NA

9	Road transportation of dangerous goods: quantitative risk assessment and route comparison [113]	1998	Quantitative Risk Assessment (QRA)	Quantitative	Sharing	Road	JHM	NA
10	Risk analysis study of road transport of ethylene oxide [114]	1998	Quantitative Risk Assessment (QRA)	Quantitative	Sharing	Road	JLPPI	Italian National Group for Preventing Chemical, Technological and Ecological Risks
11	Effects of fire on a container storage system—A case study [127]	1998	Quantitative Risk Assessment (QRA)	Quantitative	Accident Review	Marine	JLPPI	NA
12	Determinants of the property damage costs of tanker accidents [45]	1999	Three-Equation Recursive Model	Quantitative	Accident Review	Marine	JLPPI	NA
13	New detailed numerical procedures for calculating risk measures in hazardous materials transportation [128]	1999	TransIn and TransSoc procedures	Quantitative	Assessment	Others (All)	JLPPI	GNDRCIE-CNR (Italy)
14	A subjective modeling tool applied to formal ship safety assessment [79]	2000	Safety-Analysis-Based Decision-Making Framework	Quantitative	Assessment	Marine	OE	NA
15	Marine transportation of irradiated nuclear fuel, plutonium and radioactive wastes: the continuing debate on regulatory measures [122]	2000	Questionnaire	Qualitative	Sharing	Marine	MP	NA
16	Risk management of LPG transport activities in Hong Kong [124]	2000	Quantitative Risk Assessment (QRA)	Quantitative	Sharing	Marine	JHM	NA
17	Hazardous materials transportation: A risk-analysis-	2000	Risk Indexes	Qualitative	Assessment	Road	JHM	NA

	based routing methodology [85]							
18	Using GIS to assess the risks of hazardous materials transport in Networks [129]	2000	GIS Technique	Quantitative	Assessment	Others (All)	EJOR	NA
19	Risk assessment in maritime transportation [78]	2001	Formal Safety Assessment	Quantitative	Assessment	Marine	RESS	European Union
20	Formal safety assessment of containerships [80]	2001	Formal Safety Assessment	Quantitative	Assessment	Marine	MP	NA
21	The current status and future aspects in formal ship safety assessment [81]	2001	Formal Safety Assessment	Quantitative	Assessment	Marine	SC	NA
22	An interactive multi objective model for the strategic maritime transportation of petroleum products: risk analysis and routing [119]	2001	Multi Objective Network Flow Model	Quantitative	Sharing	Marine	SC	NA
23	Assessment of a ship's performance in accidents [130]	2002	Survey	Qualitative	Accident Review	Marine	MS	NA
24	Offshore safety case approach and formal safety assessment of ships [131]	2002	Offshore Safety Assessment & Formal Safety Assessment	Quantitative	Assessment	Marine	JSR	UK Engineering and Physical Sciences Research Council
25	A framework for risk assessment and decision-making strategies in dangerous good transportation [103]	2002	Quantitative Risk Assessment (QRA)	Quantitative	Prevention	Road	JHM	Ministry of Instruction, University and Research, Rome, Italy
26	Statistics and damage assessment of ship grounding [132]	2002	Grounding Damage Assessment	Quantitative	Assessment	Marine	MS	NA
27	Risk analyses of transportation on road and railway from a	2002	Quantitative Risk Assessment (QRA)	Quantitative	Prevention	Others (Intermodal)	SC	NA

	European Perspective [133]							
28	Acute public health consequences associated with hazardous substances released during transit, 1993–2000 [134]	2003	Review Database	Qualitative	Sharing	Others (All)	JHM	NA
29	Risk analysis for road and rail transport of hazardous materials: A simplified approach [161]	2004	Transportation Risk Analysis (TRA)-Simplified Approach	Quantitative	Prevention	Others (Intermodal)	JLPPI	Italian Department of Civil Protection
30	Risk analysis for road and rail transport of hazardous materials: a GIS approach [114]	2004	Transportation Risk Analysis (TRA)-GIS Approach	Quantitative	Prevention	Others (Intermodal)	JLPPI	Italian Department of Civil Protection
31	A new airline safety index [24]	2004	Airline Safety Index	Qualitative	Assessment	Air	TR	National Science Council of Taiwan
32	Estimating the safety performance of urban road transportation networks [106]	2004	Safety Performance Functions (SPFS), Or Crash Prediction Models (CPMS)	Quantitative	Prevention	Road	AAP	Natural Sciences and Engineering Research Council of Canada
33	Qualification of Formal Safety Assessment: An exploratory study [135]	2004	Formal Safety Assessment	Quantitative	Assessment	Marine	SC	NA
34	Probabilistic modeling and evaluation of collision between shuttle tanker and FPSO in tandem offloading [136]	2004	Probabilistic Model of FPSO and Tanker Collision	Quantitative	Assessment	Marine	RESS	NA
35	Road risk analysis due to the transportation of chlorine in Rosario city [43]	2005	DEGADIS Model	Quantitative	Sharing	Road	RESS	Agencia Nacional de Promocio´n Cientı´fica y Tecnologica

36	Transport risk models for hazardous materials: revisited [137]	2005		Quantitative	Assessment	Road	OTHERS	NA
37	Safety-culture in a Norwegian shipping company [138]	2005	Questionnaire	Qualitative	Prevention	Marine	JSR	NA
38	Dangerous good transportation by road: from risk analysis to emergency planning [104]	2005	Transportation Risk Analysis (TRA)	Quantitative	Prevention	Road	JLPPI	NA
39	Comprehensive risk assessment for rail transportation of dangerous goods: A validated platform for decision support [41]	2005	Software (Hot Spots Approach)	Hybrid	Prevention	Railway	RESS	NA
40	Fuzzy multi-attribute selection among transportation companies using axiomatic design and analytic hierarchy process [30]	2005	Fuzzy Multi-Attribute Axiomatic Design Approach & Crisp and Fuzzy AHP Approaches	Qualitative	Sharing	Others (All)	IS	NA
41	Improving pilots' risk assessment skills in low-flying operations: The role of feedback and experience [109]	2006	Checklist of Pilot's Performance	Qualitative	Sharing	Air	AAP	NA
42	Risk management of road and rail transport of hazardous materials in Sicily [114]	2006	Transportation Risk Analysis (TRA)	Quantitative	Prevention	Others (Intermodal)	JLPPI	Italian Department of Civil Protection
43	Safety in shipping: The human element [139]	2006	Review Database	Qualitative	Prevention	Marine	JSR	NA
44	Risk assessment modeling in aviation safety management [84]	2006	Quantitative Model	Quantitative	Assessment	Air	JATM	National Science Council of the Republic of China and Taiwan
45	Application of the API/NPRA	2006	Security Vulnerability	Qualitative	Assessment	Others	JHM	NA

	SVA methodology to transportation security issues [140]		Analysis (SVA)			(All)		
46	Assessment of hazardous material risks for rail yard safety [141]	2007	Event Tree Analysis (ETA)	Qualitative	Assessment	Railway	SC	NA
47	Hazmat transport: A methodological framework for the risk analysis of marshalling yards [142]	2007	Transportation Risk Analysis (TRA)	Quantitative	Assessment	Marine	JHM	NA
48	STRRAP system—A software for hazardous materials risk assessment and safe distances calculation [42]	2007	STRRAP Software	Quantitative	Assessment	Others (All)	RESS	Agencia Nacional de Promocio´n Cientı´fica y Tecnologica
49	Formal safety assessment based on relative risks model in ship navigation [143]	2007	Formal Safety Assessment	Quantitative	Assessment	Marine	RESS	Shanghai International Port (GROUP) Co., Ltd
50	The cost and risk impacts of rerouting railroad shipments of hazardous materials [69]	2007	Network Model	Quantitative	Prevention	Railway	AAP	Natural Sciences and Engineering Research Council of Canada
51	Designing a road network for hazardous materials shipments [8]	2007		Quantitative	Prevention	Road	OTHERS	Natural Sciences and Engineering Research Council of Canada
52	Railroad transportation of dangerous goods: Population exposure to airborne toxins	2007	Quantitative Risk Assessment (QRA)	Quantitative	Assessment	Others (Intermodal)	OTHERS	Natural Sciences and Engineering

	[144]							Research Council of Canada
53	The role of hydrogen in the road transportation sector for a sustainable energy system: A case study of Korea [117]	2008	Energy Economy Model	Quantitative	Sharing	Road	IJHE	Ministry of Education of Korea
54	Results of the MITRA project: Monitoring and intervention for the transportation of dangerous goods [145]	2008		Qualitative	Prevention	Others (Intermodal)	JHM	NA
55	A review of research on risk and safety modeling in civil aviation [19]	2008	Safety Modeling in Civil Aviation	Quantitative	Assessment	Air	JATM	NA
56	SWOT analysis for safer carriage of bulk liquid chemicals in tankers [146]	2008	SWOT Analysis	Qualitative	Prevention	Marine	JHM	NA
57	The use of a bioassay based approach to the hazard/risk assessment of cargo derived toxicity during shipping accidents: A case study – The MSC Napoli [147]	2008		Qualitative	Assessment	Marine	OTHERS	NA
58	A Bayesian Belief Network modeling of organizational factors in risk analysis: A case study in maritime transportation [148]	2008	Bayesian Belief Network Model	Quantitative	Assessment	Marine	RESS	NA
59	The ship breaking industry in Turkey: environmental, safety and health issues [149]	2008		Qualitative	Prevention	Marine	JCP	NA
60	Safety of maritime transportation [150]	2008	Formal Safety Assessment	Quantitative	Assessment	Marine	RESS	NA
61	An evaluation of fuzzy transportation underwriting	2008	Fuzzy logic	Qualitative	Assessment	Others (All)	TR	NA

	systematic risk [151]							
62	Identifying geographically diverse routes for the transportation of hazardous materials [152]	2008	K shortest path algorithm	Quantitative	Assessment	Road	TR	NA
63	Quantitative evaluation of precautions on chemical tanker operations [153]	2009	Analytic Hierarchy Process (AHP)	Qualitative	Prevention	Marine	OTHERS	NA
64	Analysis of the marine traffic safety in the Gulf of Finland [154]	2009		Quantitative	Assessment	Marine	RESS	NA
65	Establishing an Integrated Process Management System (IPMS) in ship management companies [155]	2009	Fuzzy Axiomatic Design (FAD) & Analytic Network Process (ANP)	Qualitative	Prevention	Marine	ESA	NA
66	An expert system towards solving ship auxiliary machinery troubleshooting: SHIPAMT SOLVER [156]	2009	SHIPAMT SOLVER Software	Quantitative	Assessment	Marine	ESA	NA
67	Modeling perceived collision risk in port water navigation [157]	2009	Probabilistic Model	Quantitative	Assessment	Marine	SC	NA
68	Does ratification matter and do major conventions improve safety and decrease pollution in shipping? [158]	2009	Econometric Model	Quantitative	Sharing	Marine	MP	NA
69	Frequency analysis of hazardous material transportation incidents as a function of distance from origin to incident location [64]	2009	Scheme-Coding	Qualitative	Accident Review	Road	JLPPI	NA
70	Multi Criteria Decision on Selecting Optimal Ship Accident Rate for Port Risk Mitigation	2009	Mathematical Modeling	Quantitative	Assessment	Marine	OTHERS	NA

	[36]							
71	Cross-analysis of hazmat road accidents using multiple databases [118]	2009	Cross Analysis	Qualitative	Sharing	Road	AAP	NA
72	Uncertainty assessment of the road safety index [23]	2009	Road Safety Index	Qualitative	Assessment	Road	RESS	NA
73	Designing of integrated quality and safety management system (IQSMS) for shipping operations [159]	2009	Multi-Attribute Fuzzy Axiomatic Design (MAFAD)	Qualitative	Prevention	Marine	SC	NA
74	A hybrid design methodology for structuring an Integrated Environmental Management System (IEMS) for shipping business [59]	2009	Analytic Hierarchy Process (AHP) & Fuzzy Axiomatic Design (FAD)	Hybrid	Prevention	Marine	OTHERS	NA
75	Analysis of ship life cycles- The impact of economic cycles and ship inspections [160]	2009		Quantitative	Prevention	Marine	MP	NA
76	Analysis of accidents in Greek shipping during the pre- and post-ISM period [67]	2009		Qualitative	Accident review	Marine	MP	NA
77	Analytical HFACS for investigating human errors in shipping accidents [68]	2009	Fuzzy Analytical Hierarchy Process (FAHP)	Qualitative	Accident review	Marine	AAP	NA
78	Risk assessment for pipelines with active defects based on artificial intelligence methods [72]	2009	Classification Reliability Procedure	Qualitative	Assessment	Pipelines	OTHERS	NA
79	Preliminary risk analysis for LNG tankers approaching a maritime terminal [162]	2009	Quantitative Risk Assessment (QRA)	Quantitative	Assessment	Marine	JLPPI	NA
80	Comprehensive risk assessment and management of petrochemical feed and product transportation	2009	Probabilistic and Indexing Models	Hybrid	Assessment	Pipelines	JLPPI	NA

	pipelines [71]							
81	Application of axiomatic design and TOPSIS methodologies under fuzzy environment for proposing competitive strategies on Turkish container ports in maritime transportation network [163]	2009	Fuzzy Axiomatic Design (FAD)& Fuzzy TOPSIS	Qualitative	Prevention	Marine	ESA	NA
82	A fuzzy expert system for aviation risk assessment [164]	2009	Flight Operations Risk Assessment System (FORAS)	Quantitative	Assessment	Air	ESA	NA
83	Risk reduction in road and rail LPG transportation by passive fire protection [165]	2009		Quantitative	Prevention	Others (Intermodal)	JHM	NA
84	Enhancement of occupational health and safety requirements in chemical tanker operations: The case of cargo explosion [166]	2010	Analytic Hierarchy Process (AHP) & Fuzzy Axiomatic Design (FAD)	Qualitative	Sharing	Marine	SC	NA
85	Safety culture and safety management aboard tankers [167]	2010	Questionnaire	Qualitative	Prevention	Marine	RESS	NA
86	A semi-quantitative assessment of occupational risks using bow-tie representation [51]	2010	Bow-Tie Approach	Hybrid	Assessment	Marine	SC	NA
87	A lead-time based approach for planning rail–truck intermodal transportation of dangerous goods [168]	2010		Quantitative	Assessment	Others (Intermodal)	EJOR	National Sciences and Engineering Research Council of Canada
88	Structuring ship design project approval mechanism towards installation of operator–system interfaces via fuzzy axiomatic	2010	Fuzzy Axiomatic Design (FAD)	Qualitative	Assessment	Marine	IS	NA

	design principles [169]							
89	Under-reporting of maritime accidents [170]	2010	Cost Benefit Analysis	Quantitative	Accident review	Marine	AAP	European Commission
90	A survey on hazardous materials accidents during road transport in China from 2000 to 2008 [32]	2010	Survey	Qualitative	Accident Review	Road	JHM	National Natural Science Foundation of China
91	Sea vessel type selection via an integrated VAHP–ANP methodology for high-speed public transportation in Bosphorus [82]	2010	VAHP–ANP Methodology	Qualitative	Assessment	Marine	ESA	NA
92	An integrated quantitative risk analysis method for natural gas pipeline network [70]	2010	Quantitative Risk Assessment (QRA)	Quantitative	Assessment	Pipelines	JLPPI	National Natural Science Foundation of China
93	Review and application of ship collision and grounding analysis procedures [171]	2010	Formal Safety Assessment	Quantitative	Sharing	Marine	MS	NA
94	Transportation Risk ANalysis tool for hazardous Substances (TRANS) – A user-friendly, semi-quantitative multi-mode hazmat transport route safety risk estimation methodology for Flanders [172]	2010		Hybrid	Assessment	Others (All)	TR	Environment, Nature and Energy Department of the Flemish Government in Belgium
95	Working conditions in the engine department - A qualitative study among engine room personnel on board Swedish merchant ships [22]	2011	Semi structured interviews	Qualitative	Prevention	Marine	OTHERS	Swedish Mercantile Marine Foundation
96	Design and implementation of a quantitative risk assessment	2011	QRA Model for Road Tunnels	Quantitative	Sharing	Road	ESA	Land Transport

	software tool for Singapore road tunnels [115]							Authority of Singapore
97	A grounded theory model for analysis of marine accidents [173]	2011	Grounded Theory Model	Quantitative	Prevention	Marine	AAP	NA
98	Ship collision risk assessment for the Singapore Strait [174]	2011	Ship Collision Risk Assessment	Quantitative	Assessment	Marine	AAP	Maritime Innovation and Technology of Singapore
99	A novel approach for navigational guidance of ships using onboard monitoring systems [175]	2011		Quantitative	Sharing	Marine	OE	NA
100	Comparison study on qualitative and quantitative risk assessment methods for urban natural gas pipeline network [176]	2011		Quantitative & Qualitative	Assessment	Pipelines	JHM	National Natural Science Foundation of China
101	Formal Vulnerability Assessment of a maritime transportation system [177]	2011	Formal Vulnerability Assessment	Quantitative	Assessment	Marine	RESS	Norwegian Research Council
102	Middle managers' role in safeguarding OHS: The case of the shipping industry [21]	2011	Semi structured interviews & Observations	Qualitative	Prevention	Marine	SC	NA
103	Fuzzy multi-criteria selection among transportation companies with fuzzy linguistic preference relations [178]	2011	Fuzzy Logic	Qualitative	Assessment	Others (All)	ESA	National Science Council of the Republic of China
104	Under reporting of maritime accidents to vessel accident databases [179]	2011	Review Database	Qualitative	Accident review	Marine	AAP	Norwegian Research Council
105	Generalized railway tank car safety design optimization for	2011	Generalized Tank Car Safety Design	Quantitative	Prevention	Railway	JHM	Dow Chemical

	hazardous materials transport: Addressing the trade-off between transportation efficiency and safety [95]		Optimization Model					Company
106	Risk informed optimization of a hazardous material multi-periodic transportation model [180]	2011		Quantitative	Assessment	Others (All)	JLPPI	National Science Foundation of USA
107	Subjective operational reliability assessment of maritime transportation system [34]	2011	Fuzzy Set	Qualitative	Assessment	Marine	ESA	Singapore's Agency for Science, Technology and Research
108	Estimated incident cost savings in shipping due to inspections [46]	2011	Duration Analysis & Binary Logistic Regression	Quantitative	Prevention	Marine	AAP	NA
109	Ship inspection strategies: Effects on maritime safety and environmental protection [181]	2011	Review Database	Qualitative	Prevention	Marine	TR	NA
110	Reliability-based assessment of vehicle safety in adverse driving conditions [182]	2011	Reliability-Based Single-Vehicle Accident Risk Prediction Model	Quantitative	Assessment	Road	TR	National Science Foundation of U.S.
111	Reporting practices in merchant shipping, and the identification of influencing factors [20]	2011	Survey	Qualitative	Prevention	Marine	SC	NA
112	Hazardous materials transportation in Mexico City: Chlorine and gasoline cases [112]	2011	Multi-criteria decision analysis	Quantitative	Sharing	Road	TR	NA
113	Some technical aspects of spills in the transportation of petroleum materials by tankers [183]	2012	Review Database	Qualitative	Sharing	Marine	SC	NA

114	Performance of Safety Sea Transportation [184]	2012		Qualitative	Accident review	Marine	OTHERS	NA
115	Methodology for the sustainability assessment of marine technologies [185]	2014		Hybrid	Assessment	Marine	JCP	Department of Education, Universities and Research, of the Basque Government, Spain
116	Risk assessment of marine traffic safety at coastal water area [186]	2012	Formal Safety Assessment	Quantitative	Assessment	Marine	OTHERS	Shanghai Maritime University Research Fund
117	A multimodal location and routing model for hazardous materials transportation [187]	2012	Multimodal Location and Routing Model	Quantitative	Assessment	Others (All)	JHM	U.S. Department of Energy
118	A comprehensive risk assessment framework for offsite transportation of inflammable hazardous waste [188]	2012	Comprehensive Risk Assessment Framework	Quantitative	Assessment	Others (All)	JHM	NA
119	Safety in maritime oil sector: Content analysis of machinery space fire hazards [189]	2012	Content Analysis Methodology	Qualitative	Assessment	Marine	SC	NA
120	Intelligent decision support for effectively evaluating and selecting ships under uncertainty in marine transportation [190]	2012	Fuzzy Multi-criteria Analysis Algorithm	Quantitative	Assessment	Marine	ESA	NA
121	Quantitative risk assessment model of hazardous chemicals leakage and application [98]	2012	Fire-Explosion-Poisoning Quantitative Probability Model (FEPQPM)	Quantitative	Prevention	Pipelines	SC	National Science Foundation of China

122	Metro railway safety: An analysis of accident precursors [55]	2012	Questionnaire &New Safety Maturity Model (SMM)	Hybrid	Accident Review	Railway	SC	NA
123	Pareto frontier analyses based decision making tool for transportation of hazardous waste [191]	2012	Posteriori Method with Multi-Objective Approach	Quantitative	Prevention	Road	JHM	NA
124	A method to assess multi-modal Hazmat transport security vulnerabilities: Hazmat transport SVA [192]	2012	Multi-Modal Hazmat Transport Security Vulnerabilities	Qualitative	Assessment	Others (All)	OTHERS	NA
125	Tools for Assessing the Safety Impact of Interventions on Road Safety [193]	2012	Module RIA	Qualitative	Assessment	Road	OTHERS	NA
126	Shipyard fatalities in Turkey [194]	2012	Review Database	Qualitative	Accident Review	Marine	SC	Turkish Loyd Foundation
127	Introducing the STAMP method in road tunnel safety assessment [87]	2012	STAMP Model	Qualitative	Assessment	Road	SC	NA
128	Framework for airspace planning and design based on conflict risk assessment Part 1: Conflict risk assessment model for airspace strategic planning [97]	2012	Conflict Risk Assessment Model	Quantitative	Prevention	Air	TR	NA
129	Fuzzy-logic-based network for complex systems risk assessment: Application to ship performance analysis [195]	2012	Fuzzy-Logic-Based Network	Qualitative	Assessment	Marine	AAP	University of Minnesota, USA
130	Prediction of road accidents: A Bayesian hierarchical approach [86]	2012	Predictive Model	Quantitative	Assessment	Road	AAP	Austrian Road Safety Board
131	Multidimensional risk analysis of hydrogen pipelines [196]	2012	Multicriteria Decision Model	Quantitative	Assessment	Pipelines	IJHE	Brazilian Research

								Funding Bureau
132	Developing a new fuzzy inference system for pipeline risk assessment [53]	2012	Risk Score (RRS) Methodology with Fuzzy Logic	Hybrid	Assessment	Pipelines	JLPPI	University of Tehran
133	Influences of variables on ship collision probability in a Bayesian belief network model [197]	2012	Bayesian Belief Network Model	Quantitative	Assessment	Marine	RESS	European Union
134	A bi-objective model for planning and managing rail-truck intermodal transportation of hazardous materials [198]	2012	Bi-Objective Model	Quantitative	Prevention	Others (Intermodal)	TR	National Sciences and Engineering Research Council of Canada
135	Study on emergency response rank mode of flammable and explosive hazardous materials road transportation [199]	2012		Quantitative	Prevention	Road	OTHERS	Tianjin Science Foundation and National Key Technology R&D Program
136	Integrated risk reduction framework to improve railway hazardous materials transportation safety [96]	2013		Quantitative	Prevention	Railway	JHM	NEXTRANS University Transportation Center
137	Bi-objective decision support system for routing and scheduling of hazardous materials [105]	2014		Quantitative	Prevention	Road	OTHERS	NA
138	The Gateway Location Problem: a cost oriented analysis of a new risk mitigation strategy in Hazmat Transportation [99]	2014		Quantitative	Prevention	Road	OTHERS	NA
139	Generalized route planning	2014	VaR risk model	Quantitative	Prevention	Road	OTHERS	National

	model for hazardous material transportation with VaR and equity considerations [108]							Science Foundation
140	Study on route selection for hazardous chemicals transportation [200]	2014		Quantitative	Assessment	Road	OTHERS	NA
141	Models for the hazardous goods railway transportation in Spain considering the effect of the catchment area of the station [201]	2014		Quantitative	Sharing	Railway	TR	FEDER of European Union
142	A multimodal location and routing model for hazardous materials transportation based on multi-commodity flow model [202]	2014		Quantitative	Sharing	Others (Intermodal)	OTHERS	National Natural Science Foundation of China
143	Environmental risk analysis of hazardous material rail transportation [203]	2014	Hazardous Materials Transportation Environmental Consequence Model	Quantitative	Assessment	Railway	JHM	NA
144	Probability analysis of multiple-tank-car release incidents in railway hazardous materials transportation [204]	2014		Quantitative	Assessment	Railway	JHM	US DOT RITA University Transportation Center
145	MISTRAL: A game-theoretical model to allocate security measures in a multi-modal chemical transportation network with adaptive adversaries [205]	2015	MISTRAL model	Quantitative	Prevention	Others (All)	RESS	NA
146	Risk assessment of petroleum product transportation by road: A framework for regulatory improvement [206]	2015		Quantitative	Sharing	Road	SC	Petroleum Technology Development Fund
147	Modeling urban hazmat	2015	Bi-objective	Quantitative	Sharing	Road	TR	National

	transportation with road closure consideration [207]		programming model					Natural Science Foundation of China
148	Developing a chaotic pattern of dynamic risk definition for solving hazardous material routing-locating problem [208]	2015		Quantitative	Sharing	Road	JLPPI	NA
149	On the application of Valuation-Based Systems in the assessment of the probability bounds of Hazardous Material transportation accidents occurrence [209]	2015		Quantitative	Assessment	Road	SC	National Agency for Research
150	Planning and managing intermodal transportation of hazardousmaterials with capacity selection and congestion [210]	2015		Quantitative	Prevention	Others (Intermodal)	TR	National Sciences and Engineering Research Council of Canada
151	Time-dependent fuzzy random location-scheduling programming for hazardous materials transportation [211]	2015		Quantitative	Assessment	Road	TR	National Natural Science Foundation of China