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Risk Analysis of Container Ship Accidents and Risk Mitigation Measures

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Abstract : *The study performs a risk analysis on container ship accidents using accident data collected over the six years from 2006 to 2011, presents the resulting risk level, and suggests three risk mitigation measures to reduce the overall risk, for the safer operation of container ships. More specifically, starting from the initial accident of collision, we developed 13 different accident scenarios using event tree analysis based on which the overall risk level was obtained and presented as a FN curve. Since diverse human factors are the main cause of most of the ship accidents, our study focuses on the effect of reducing human causes on the resulting risk level. For the research we considered the injuries for the calculation of fatality with the help of MAIS. The results show that collision was the main type of accident, accounting for 62 % of all accidents, and the measures employed were proven to be effective in the sense that the risk level was much lowered and the average number of fatalities was also reduced. With more data accumulated, more precise risk level will be calculated with which the practical risk mitigating measures will be also developed. For future study, economic loss and environmental damage as consequences need to be considered.*

Key Words : *Risk analysis, Ship accidents, Risk mitigation measures, Event tree analysis, FN curve, MAIS*

1. Introduction

A quantitative risk analysis, which is a method of quantifying risk in a probabilistic way, has mainly been used in industrial areas such as chemical and nuclear plants, the transport of hazardous materials and other dangerous substance-handling industries to calculate the potential risk. The result of a risk analysis shows the risk level of the system in operation when an accident happens. Although safety standards, policies, regulations, and technical developments have improved, major accidents occur continuously due to system failures, human errors, or other unexpected factors.

While this approach is now being applied to a wider range of risky operations, there has not been much in-depth research focusing on the shipping industry and maritime operations despite the growing importance of international sea transport. As the transport of goods by ship is increasing and will continue to increase, the safety of maritime operations needs to receive more attention than that of land transport because of the unpredictable and hostile environment. Maritime accidents pose considerable risk not only to the ships and their cargoes but also to the people on board. Today, mega-sized container ships handling enormous volume of goods are operating worldwide, and consequently the potential for catastrophic accidents, i.e., collision, explosion, capsize, fire, etc, is increasing dramatically. Therefore, maritime safety should be managed in a proper way to reduce and control ship-related risks.

Extensive oil pollution due to the collision between an oil tanker and a crane carrier some distance off Korea's Tae-An peninsula in December, 2007 is a typical example of the disastrous consequences of maritime accidents. The accident caused severe damage to the marine environment as well as to the health of human beings.

In Korea, the cargo volume of container ships in 2015 increased by 3.3 % compared to 2014 (from 24,798,000 TEU to 25,626,000 TEU). Also, the demand for smaller sized container ships (1,000 ~ 2,000 TEU) on routes between the Far East and South East Asia has increased due to the shallow water near ports and the high efficiency of the transportation. Considering the increase in the transport of a variety of cargoes using different sizes of container ships, it is likely that the frequency of ship accidents will continue to grow. Therefore, this paper carries out a risk analysis on maritime accidents, with a view to the safer operation of container ships. This method has been successfully employed in many industries as a useful tool to estimate the consequences and the frequencies of an accident, based on which the overall risk is presented to show the risk level.

In Korea, studies on risk analysis for container ship accidents have not been done explicitly, regardless of the increasing vessel traffic and complicated operations. In this research, we perform a

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risk analysis on container ship accidents based on accident data over the six year period from 2006 to 2011 and interpret the resulting risk in terms of fatality.

According to Portela (2005), human factors (trigger of human errors) are the main source of risk in maritime activities, and are the cause of 60-80 % of maritime accidents. Also, "in spite of the significant advances that have been achieved in recent years in marine related technology, the number of maritime accidents on a world-wide basis has not reduced dramatically" (Caridis, 1999).

Therefore, considering the importance of human factors as a main cause of marine accidents, the purpose of the study is twofold. (1) Unlike most of the other risk related studies, where fatalities are considered but not injuries, we convert injured people into fatality equivalents by assigning a proper weight between 0 and 1 (with a maximum weight of 1 for a fatality), depending on the severity of the wounds. This way, the risk to human lives of a ship accident can be more realistically presented. (2) Based upon the risk calculated in (1), we show the effect of human factors on risk mitigation, which will provide useful information on the selection of risk mitigation measures for the safer operation of container ships.

The remainder of the study is organized as follows. In Section 2, an extensive literature review is summarized. In Section 3, we perform a risk analysis through construction of an event tree diagram, which is commonly used to classify the cause of accident (initiating event) and further developments in order of occurrence after the first event. Also, the degree of the risk level is presented. In Section 4, some risk reduction measures are suggested, from which the overall risk levels are lowered. In the final Section, conclusions and future research directions will be discussed.

2. Literature review

Researches by risk analysis have been performed in various fields, such as chemical and nuclear plants, aircraft industry, land transportation (road and rail) and other dangerous places such as underground subway systems and long tunnels, for the calculation of possible harm to humans and damage to surrounding facilities and environments.

However, in the maritime industry, the formal method for risk analysis is carried out according to the "Guidelines for formal safety assessment (FSA) for use in IMO rule making process" (International Maritime Organization, 2002). The way that the IMO implements the principles of risk management and, in general, of a safety culture, is through a systematic process called the Formal Safety Assessment (FSA). FSA was introduced as a process to assess risks and to evaluate the costs and benefits of the IMO's options for reducing these risks and, thus, to support its decision-making process (Kontovas, 2005).

For the implementation of FSA, the risk level is quantified using the likelihood (frequency or probability) and consequence (fatality, monetary damages, or economic effects) when an accident occurs. Ronza et al. (2003) established an event tree diagram and estimated accident frequency based on port accidents data over the 20th century. Darbra and Casal (2004), using historical port accidents data over the period 1941-2002, showed that 56 % of all accidents happened during the operation of ships, while the accidents in ports were mainly due to physical impact such as collision.

Based on the general guideline for risk assessment in the maritime industry, the maritime safety authority of New Zealand provided guidance to port companies, regional councils and other related participants in 2004 for the purpose of improving the safety of ships and operations within port areas. Trbojevic and Carr (2000) illustrated the use of FSA in a step-by-step approach to analyze ship grounding accidents.

For risk analysis of port and ship accidents, Geijerstam and Svensson (2008) considered the case of ship collision with offshore installations and identified the major factors that contribute to collision. Kim and Kim (2008) proposed a methodology for ship accidents in domestic ports and presented the resulting risk with FN curves. Ronza et al. (2006) performed a risk analysis on hydrocarbon terminals located in ports. Rao and Raghavan(1996) described techniques to identify hazardous events and analyzed the effects of chemical releases through cause-consequence analysis. Trbojevic and Carr (2000) proposed an approach to identify hazards and carried out a risk assessment to establish hazard barriers. Yip (2008) investigated the port traffic risk in Hong Kong waters using the marine accidents data for 2001-2005 and showed that collisions are the most frequent accident when port traffic is heavy. Cho et al. (2013) performed a risk analysis on accidents involving Hazardous and Noxious Substances (HNS) during oil tanker transportation.

For human error related risk, Kim and Kwak (2011) classified various types of human factors which directly influence ship accidents. Portela (2005) developed a methodology to help identify the human factors present in maritime related accidents. He mentioned that approximately 80 % of maritime accidents are due to human error.

3. Risk analysis on container ship accidents

FSA, used by the IMO, is an integrated risk assessment method and also a procedure consisting of the following major steps: hazard identification, risk analysis, risk control options, cost/benefit assessment of risk control options, and decision making. Fig. 1 below shows a stepwise procedure for implementing FSA in the maritime field.

As the purpose of the study is to calculate the risk level of container ship accidents using probability and fatalities due to an accident, and to present the effects of mitigation measures on the changes in risk levels, the general procedure described above is more specifically modified as follows (see Fig. 2).

Based on the assessment flow in Fig. 2, each step of the procedure is performed.

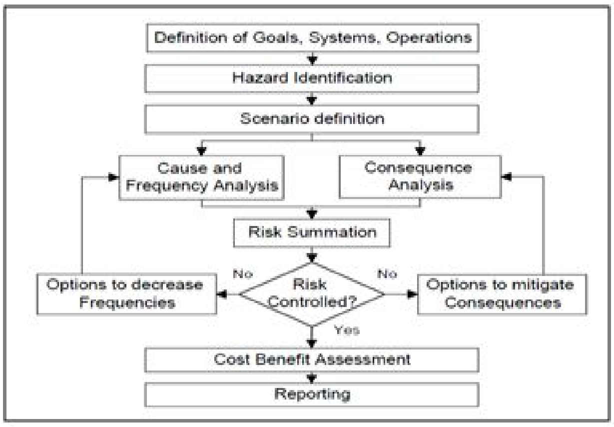

Fig. 1. Procedure for risk assessment (source: Risk assessment guideline, 2009).

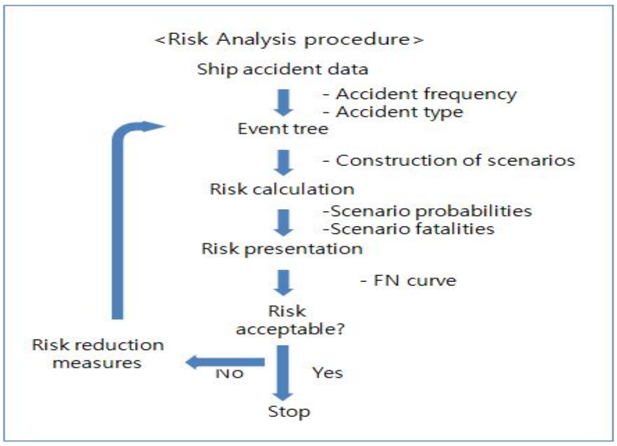

Fig. 2. Flow of Risk assessment for container ship accident (source: Revised from Kim and Kim, 2008).

3.1 Ship accident data

In order to analyze the accidents of the ships, we collected accident data from the Korea Maritime Safety Tribunal (KMST, hereinafter), went through all the accident details (accident types, regions of accidents, fatalities and injuries, human factors involved, etc.). Personal visits and calls were made to obtain more accurate estimates of accident types and the degree of injuries, if not clearly specified in the accident reports.

For container ships over the period 2006-2011, there were 50 accidents in total, among which collision was the dominating accident type, followed by stranding. As shown in Table 1 below, these two types accounted for 84 % of all accidents, whereas the occurrence of each of the other five types (malfunction, sinking, capsizal, explosion and fire) is in single digits, between 2 % and 6 %.

Table 1. Types of container ship accidents

Types of first accidents	Proportion	Rank
Collision	62 %	1
Stranding (Grounding)	22 %	2
Malfunction	6 %	3
Sinking	4 %	4
Capsizal	2 %	5
Explosion	2 %	5
Fire	2 %	5

For a more detailed description of the container ship accidents, the number of accidents, types, consequences, and regions per year are classified in the Appendix.

The South - East Sea including Pusan port is where accidents occur most frequently. One possible reason for this is the heavier vessel traffic and more cargo volume handling in the area. Pusan port is ranked as the 6th busiest container port in the world handling 75 % of the cargo volume across Korea on average (Ports and Airports Logistics statistics, Pusan Development Institute, 2014)

3.2 Assessment of container ship accidents

Generally, the term "risk" can be interpreted in a variety of ways, e.g., political, financial, economic, or other industrial. In performing a risk analysis, the frequency (probability) and consequence of an accident are the two main elements in the calculation of the risk, which are basically combined in the following way,

$$R = P \times C \quad (1)$$

where R = risk of an accident, P = the frequency (probability) of occurrence of an accident (e.g. ship collision), and C = the (expected) consequence of an accident (e.g. damage to the ship).

For the accident risk for a ship, usually one of following three consequences is of interest in risk calculation: the number of fatalities (people on board), environmental effects (contamination of sea environment) and economic or monetary losses (physical damage to ships, port facilities or cargoes). In the study, the number of lives lost (including injuries, as explained below) due to the accident is considered as a consequence of ship accidents for risk calculation.

1) Construction of event tree diagram for accident propagations

An event tree analysis is a useful method to evaluate the likelihood (probability) and severity (consequence) of accidents. Such a diagram makes the calculation simpler and gives a clear view of the whole structure of ship accidents in a more systematic way.

In general, for the event tree, each accident can be expressed as the combination of ensuing accident events in their order of occurrence after the first accident, and this combination of accidents is called the accident scenario. At the bifurcation of each event, there exist two branch probabilities. Each accident scenario has a corresponding scenario probability, which is calculated by multiplying all the branch probabilities on its path and the corresponding consequences.

Based on the accident data we constructed the corresponding event tree of container ship accidents (see Fig. 3) to express the propagations of chains of events (ship accidents) starting from a collision as an initiating event. The accident scenario Si in the tree diagram is a combination of ensuing events initiated by a collision.

For example, the accident scenario (S1) consists of collision - sinking - oil spill, with the corresponding branch probabilities of 0.62 (62.0 %), 0.258065 (25.8065 %) and 0.125 (12.5 %) respectively. Also, the scenario probability is 0.02 (2.0 %) and there is no fatality for consequence. From the event tree analysis, 13 accident scenarios were constructed, five of which (S2, S8, S9, S11 and S12) had casualties (fatalities, injuries or both), expressed by the numbers inside the boxes.

Usually, for risk calculation, most researches use only the number of fatalities as consequences without considering the wounded. However, these potential fatalities should be included in the risk analysis for a more accurate risk determination. To express the non-fatal injuries as death (fatality) equivalents, we employed

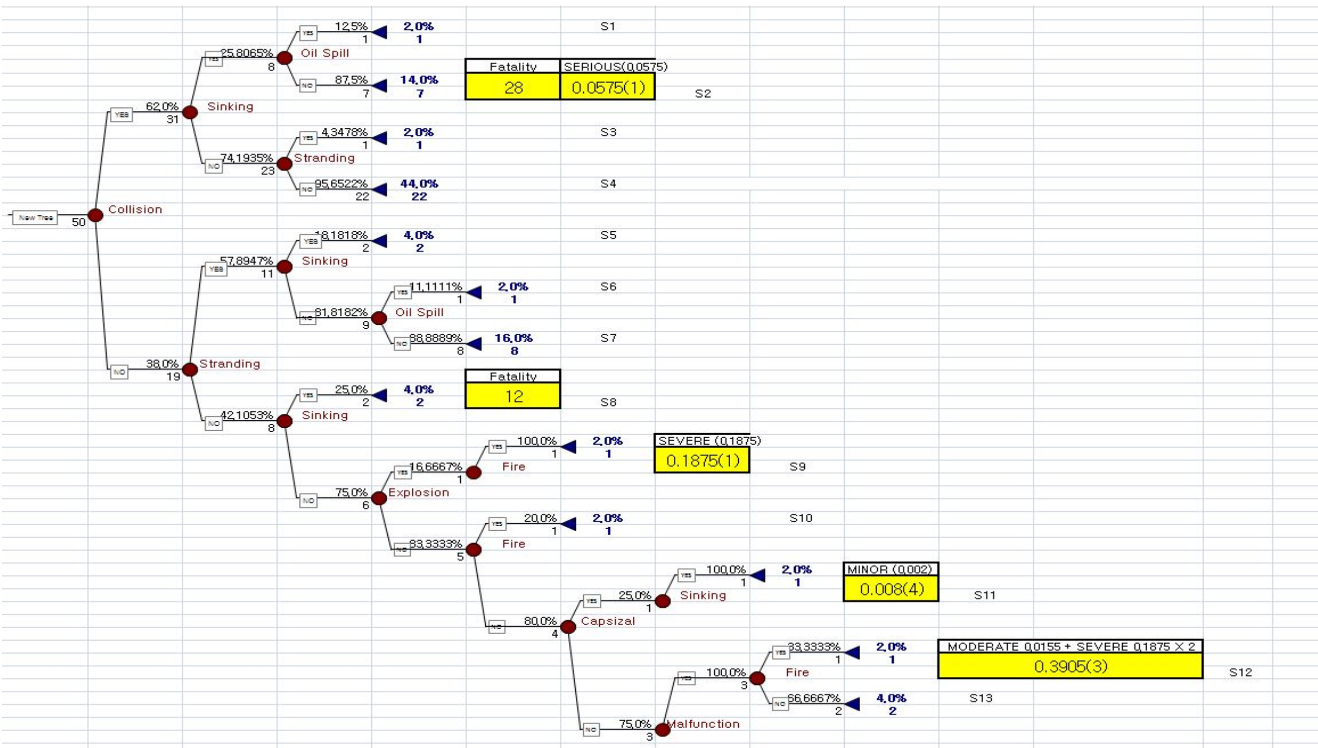

Fig. 3. Event tree diagram for containership accidents.

Table 2 below, where the severity of injuries are classified into six different levels, each of which has a corresponding weight.

From the event tree diagram, there are 28 fatalities and one seriously injured person for S2, which is translated into (28 + 0.0575) fatality equivalents. For the other cases (S8, S9, S11 and S12), the fatalities are recalculated in a similar way.

Table 2. Relative disutility factors by injury severity level (MAIS)

MAIS Level	Severity	Fraction of VSL
MAIS 1	Minor	0.0020
MAIS 2	Moderate	0.0155
MAIS 3	Serious	0.0575
MAIS 4	Severe	0.1875
MAIS 5	Critical	0.7625
MAIS 6	Fatal	1.0000

Source: Department guidance memorandum, U.S. Office of the Secretary of Transportation, 2008

2) Risk presentation

Once scenario probabilities and corresponding fatalities have been calculated the resulting risk can be evaluated by combining them in different ways. The simplified form of risk defined in equation (1) is expressed as the product of probability and consequence. However, presenting risk as a single probability of consequence is not common practice in risk analysis. Risk is normally considered as the probable frequency (probability) of consequences (e.g. the frequency of fatalities) either in a spatial context or as a frequency (probability) distribution of the level of consequence (U.S. Office of the Secretary of Transportation, 2008).

An FN curve is commonly employed worldwide to present the overall risk, showing the relationship of the number of fatalities (C = c) to the cumulative probability of c or more fatalities (P (C ≥ c)). More specifically, the X-axis represents the number of fatalities and the Y-axis is for the probability which is greater than or equal to the given number in the X-axis. Therefore, as the number of fatalities gets larger, the corresponding probability gets smaller. For more on the FN curve and its application, see Ball and Peter (2002). In the study, the FN graph curve is employed to present the risk level of container ship accidents.

Fig. 4 shows the resulting risk level. In the first graph in Fig. 4 injuries are not considered, and in the second graph injuries are included. By comparing the two graphs with the same straight line as a risk criterion, it is clear that the second one has a higher risk level than the first one, which is due to the consideration of injuries.

(a) Without MAIS

(b) With MAIS

Fig. 4. Risk level with FN curve.

4. Risk mitigation measures

When a risk is judged as being unacceptable, practical and executable risk mitigation options need to be implemented in an effort to lower the risk to an acceptable level. In this Section, some risk mitigation measures will be employed by lowering the probabilities of the occurrence of accidents, resulting from which the overall risk is shown to be much reduced. Several researches identify human error as the cause of 60 to 80 percent of maritime accidents, giving an idea of the importance to maritime safety of good living conditions on board (ship conditions and maintenance) and quality of crews (crew competence and qualification) (U.S. Department of Transportation, 1999). It is also commonly accepted that approximately 80 % of maritime accidents are due to human error (Portela, 2005).

In this regard, for illustrative demonstration, we take three cases in which the accidents were initiated by human factors and show the effects of reductions in human error on the resulting risk level.

Case 1: Decrease the number of collisions by 4
Case 2: Decrease the number of sinkings by 3
Case 3: Decrease the number of collisions and sinkings of the worst scenario (S2) by 4 and 3

For each case, based on the accident reports from KMST, we selected the human causes which directly led to the physical accidents. For Case 1, four of the collisions were due to navigation factors, the occurrence rate of which can be reduced by more detailed training programs for the crew members. Likewise, for Case 2, the number of sinkings can be reduced by three with thorough inspections of the ships before sailing or improved reaction ability of the crew before the sinking occurs.

Since the number of accidents are reduced for each case, all the branch probabilities and consequently each scenario probability in the event tree diagram are altered, which results in a different FN curve representing the new risk level. Table 3 summarizes the risk mitigation effects of each case.

Table 3. Risk mitigation measures

Case	Mitigation measure	From	To	Difference
Case 1	decreasing the number of collisions	31	27	4↓
Case 2	decreasing the number of sinkings	13	10	3↓
Case 3	decreasing the number of collisions and sinkings of the worst scenario	31 and 8	27 and 5	4 and 3 ↓

Based on Table 3, the overall risk levels are shown to be lowered in Figs. 5, 6 and 7, where the upper risk line (denoted "Normal") is the original risk level calculated from Section 3.

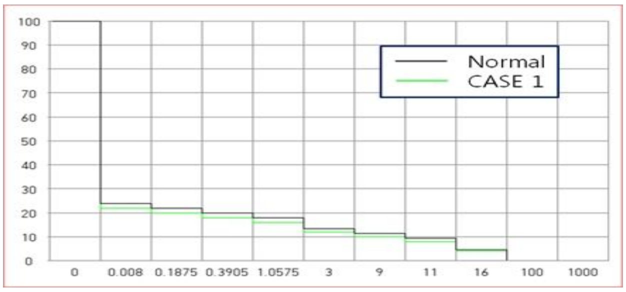

Fig. 5. Risk mitigation for Case 1.

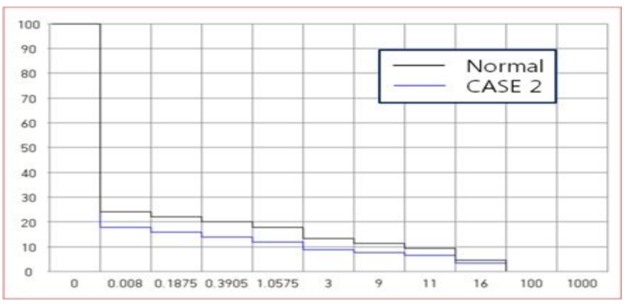

Fig. 6. Risk mitigation for Case 2.

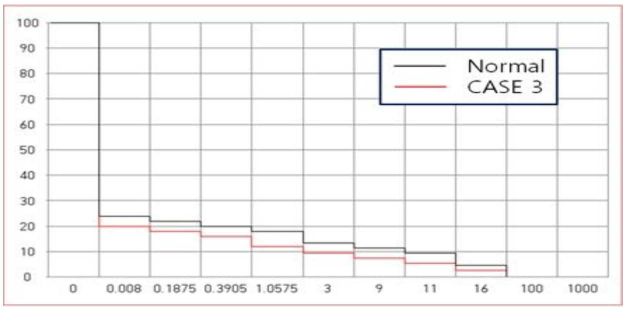

Fig. 7. Risk mitigation for Case 3.

From the following Fig. 8, the changes in risk levels of Case 2 and Case 3 show that for a small number of fatalities, Case 2 is more effective, whereas Case 3 is better mitigation measure for a large number of deaths.

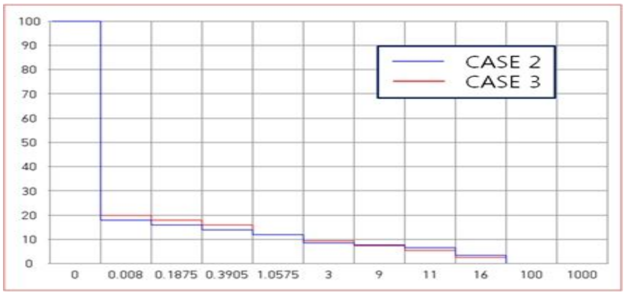

Fig. 8. Comparison of Cases 2 and 3.

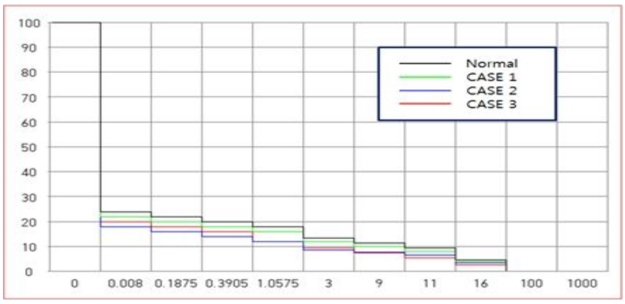

Fig. 9. Comparison of each mitigation measure.

As shown in Fig. 9, all three measures were proven to be effective compared with the original one. Of the three, Case 1 has the least effect on risk mitigation.

Alternatively, the effect of risk mitigation can be visualized with the method of average risk (E(R)) as follows.

$$E(R) = \sum R_i \times C_i \tag{2}$$

where R_i and C_i are the probability and consequence of scenario i, respectively.

Table 4 shows the degree of risk reduction for each mitigation measure, where Case 3 has the biggest improvement with 1.67 fewer fatalities compared to the original case.

Table 4. Comparison of E(R) with risk mitigation measures

Mitigation measure	E(R)	Mitigation (in number of fatality)	Rate
Normal	4.41977	0	0 %
Case 1	3.85862	0.56115 ↓	12.7 % ↓
Case 2	3.05747	1.3623 ↓	30.8 % ↓
Case 3	2.74413	1.67564 ↓	37.9 % ↓

As seen in Cases 1-3, the overall risk level could be lowered by putting more emphasis on the human factors, such as providing detailed and specific crew training programs, thorough inspections of ships as required in the regulations, and the direct corrective reaction capability of crew members in the event of accidents, to prevent or reduce accident risk.

The above mitigation measures suggest that through the investigation of ship-related accidents, the problems directly or indirectly related to human factors can be identified. Consequently, and depending on the maritime environment, more realistic accident prevention (reduction) measures can be chosen and implemented.

5. Conclusion

Various types of accidents that occur in the operation of container ships can result not only in monetary losses but in the loss of lives.

Since up to 80 % of maritime accidents are closely related to human factors, the decision maker must identify, evaluate and reduce the main existing risks (Portela, 2005).

In this paper, a risk analysis of container ship accidents was performed using accident data collected over the six years from 2006 to 2011. The risk level dropped significantly by employing some risk mitigation measures related to human factors (errors).

Unlike in other risk analysis studies, all the injured people were converted to fatalities by assigning a proper weight depending on the severity of their wounds, so that the effect of a ship accident on human lives can be fully explained and a more realistic risk evaluation can be realized.

For the research, since the probability of each accident depends entirely on the accident data available, there exists uncertainty in calculating probabilities for each event and scenario probabilities. Therefore, to get around the difficulty of estimating event probabilities, additional methods should be employed.

One way of overcoming this issue is to establish probability and consequence levels using a risk matrix in which each probability is classified as unlikely, seldom, occasional, and likely, and the severity of consequences is classified as negligible, marginal, critical, and catastrophic (Schleier and Peterson, 2010). Another way to handle uncertainty in risk analysis is to consider the concept of fuzzy numbers to represent the range of uncertainty of probability (Ferdous et al. 2009).

Future research should consider data up to recent years (one in 2012, three in 2013, one in 2014 and seven in 2015) with which more accurate analyses of ship accidents will be performed. Also, with most physical accidents due to human factors (errors), more precise classification and selection of these factors are needed for efficient and practical reduction of the risk level. Since each human factor has its own importance, through case studies on maritime risk analysis, the determination of more efficient mitigation measures for optimal solution to the risk mitigation problem is another issue to be considered in future research.

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Appendix

< Classification of container ship accidents >

Year	Number	Type(number)	Consequence			Sea Area (number)
			Death	Missing	Injury	
2006	3	Collision(2) Explosion (1)	0	0	1	South-East(3)
2007	7	Collision(2) Stranding(3) Sinking(1) Fire(1)	9	3	0	South-East(6) South-West(1)
2008	7	Collision(5) Malfunction(2)	0	0	3	South-East(5) South-West(2)
2009	7	Collision(5) Stranding(1) Sinking(1)	0	16	0	South-East(6) South-West(1)
2010	19	Collision(11) Stranding(6) Malfunction(1) Capsizal(1)	0	1	5	South-East(13) South-West(4) East(2)
2011	7	Collision(6) Stranding(1)	11	0	0	South-East(5) South-West(1) East(1)
Total	50		20	20	9	

< Accidents by sea region, year, and collision/non-collision >