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A Probabilistic Approach to Forecasting and Evaluating the Risk of Fishing Vessel Accidents in Korea

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Abstract : *Despite the accident rate for fishing vessels accounts for 70% of all maritime accidents, few studies on such accidents have been done and most of the them mainly focus on causes and mitigation policies to reduce that accident rate. Thus, this risk analysis on sea accidents is the first to be performed for the successful and efficient implementation of accident reducing measures. In risk analysis, risk is calculated based on the combination of frequency and the consequence of an accident, and is usually expressed as a single number. However, there exists uncertainty in the risk calculation process if one uses a limited number of data for analysis. Therefore, in the study we propose a probabilistic simulation method to forecast risk not as a single number, but in a range of possible risk values. For the capability of the proposed method, using the criteria with the ALARP region, we show the possible risk values spanning across the different risk regions, whereas the single risk value calculated from the existing method lies in one of the risk regions. Therefore, a decision maker could employ appropriate risk mitigation options to handle the risks lying in different regions. For this study, we used fishing vessel accident data from 1988 to 2016.*

Key Words : *Simulation, Probability distribution, Risk criteria, Uncertainty, Risk evaluation, Risk mitigation actions, IMO*

1. Introduction

In 2016, the total number of maritime accidents was 2,307, and the death toll including the missing was 118, where 71 % of the accidents and 87% of the deaths were from fishing vessel accidents. The accident number and death toll increased 9.8 % and 1.28 %, respectively, from 2015.

The Ministry of Oceans and Fisheries (2017) established a master plan focusing on three agendas, i. e., a decrease in major sea accidents by 30 %, a decrease in fatalities from accidents by 39 %, and the prevention of large scale accidents. Three of the five key tasks for them were related to fishing vessel accidents: preventing collisions with commercial ships, managing old and outdated vessels, and reducing the number of safety-related accidents. These precautionary measures will play an essential role in reducing the three major types (collisions, engine failures, and problems in safety operations) of fishing vessel accidents.

However, an accurate assessment of the sea accidents must occur first for the successful and efficient implementation of these accident reducing measures. The accidents among fishing vessels are ranked first in accident rates and fatalities and little study has been done on such accidents compared to other commercial ships. In this regard, we put our focus on calculating the risk of fishing vessel accidents of each type through risk analysis so that the results will help the decision-maker to better plan and implement necessary policies for the reduction of related accidents.

The term, "risk" is the combination of the frequency (or probability) and the severity of the consequence (International Maritime Organization [IMO], 2002). The consequences are unwanted events that can negatively affect interests such as people, property, environment etc. On the other hand, frequency is the number of occurrences of an undesirable event expressed as events per unit of time. Risk does not mean actual danger, but the possibility of danger (HSE, 2001).

In the context of risk, it has been defined and used in different ways by researchers to quantify the risk of an event. Further, a risk calculated based on the frequency (probability) of an accident and its resulting outcome (consequence) represents a level with which one could determine if it is low enough to be accepted. If not, proper actions (policies) need to be taken to reduce the risk until an allowable level is reached. Also, to employ appropriate risk mitigation measures one should consider not only the risk but the effects of frequency and consequence on the risk. However, in

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performing risk analysis, there exists some degree of uncertainty in frequency and consequence when data are insufficient or imprecise.

One fundamental problem needs to be addressed in one way or another for successful accomplishment of the risk analysis process which is the certainty of the derived risk value. Are the frequency and consequence of an accident adequately selected or calculated so that the resulting risk is reliable enough to represent the risk level of that accident?

The purpose of the study is twofold: (1) unlike most other studies calculating risk with a limited number of given data, we propose a method to forecast the risk of accidents using probability distributions for frequency and consequence. More specifically, using the fishing vessel accident data registered in the Korean Maritime Safety Tribunal (KMST) from 1988 to 2016, we create appropriate probability distributions of frequency and consequence for nine different types of accidents based on which the distributions of possible risk values are determined through the Monte Carlo simulation technique; (2) we present the risk obtained from the proposed method in the risk criteria with the ALARP region and, compared to the existing method, show the capability to deal with the uncertainty inherited in the risk calculation process.

The remainder of the paper is as follows. A literature review on risk analysis will follow in section 2. In section 3, a risk analysis using a simulation is performed to determine the risk values for each accident type, and risk is evaluated against risk criteria. In Section 4, the conclusions and limitations of this study are discussed along with the future research directions.

2. Literature review

In this section, a brief literature review on fishing vessel accidents and risk analysis methods is presented. For the studies focusing on fishing vessel accident types and causes, Kim et al. (2013) performed a risk analysis on fishing vessel accidents, where collision, sinking, and capsizing were found to be the three most risky accidents, and thus they presented the main control factors that can reduce these accidents. To find such factors, they consulted 165 official maritime accident reports (2009-2011). Jung et al. (2012) investigated the main causes of fishing vessel capsizing accidents using five years of data, and proposed some preventing actions for safe operation of the vessels. Lee and Chang (2005) used the fishing vessel accident data (1997-2001 years) to find that the main reason for injury-causing accidents was human error, and they suggested focusing on hazard awareness and the quality of the personnel, among others, to reduce such accidents. Cho et al. (2017) investigated the accident types for fishing vessels (1996- 2015) and found that engine failure and collision were the most frequent accident types, where poor maintenance of equipment and negligence by the lookouts for other vessels were the main causes of accidents, respectively.

For studies on risk analysis techniques, K¨ose et al. (1998) analyzed the fishing vessel accidents using a fault tree analysis, where loss of vessel is top event that branches out into events consisting of human error, equipment/steering/mechanical failure, weather condition, and other related factors. Through the fault tree diagram the events connected with and/or relations were weighted for the probability of the top event. Akyildiz (2015) described the procedure to apply the Formal Safety Assessment (FSA) proposed by IMO to a fishing vessel for risk calculation and introduced a risk matrix where each hazard was situated into a frequency and consequence category to evaluate the risk. Chlomoudis et al. (2016) conducted a risk analysis based on the FSA to calculate risk for human accidents in a container terminal at the port of Piraeus in Greece, and found that the best control policy was to reduce risk through cost/benefit analysis. Kim and Kwak (2016) calculated risk level on containership accidents with event tree analysis and compared the results against Frequency-Number (F-N : a plot of cumulative frequency versus consequences) curve criteria. They proposed some risk reduction policies to lower the overall risk and showed changes at the risk level.

In performing risk analysis with insufficient numbers of accidents, the Monte Carlo simulation is widely used to show all the possible outcomes (risk values), allowing for better decision-making under uncertainty. For the use of the simulation technique, determination of proper probability distributions of the accident data (frequency and consequence) is required to produce the resulting distribution of possible risk values. Probability distributions are a realistic way to consider the possible values of the variables of a quantitative analysis, so the simulation method is utilized in many disparate analytical fields such as engineering, management, transportation, chemical, energy, and environment.

Kim (2009) applied the Monte Carlo simulation technique in cost/benefit analysis by assuming a normal distribution for the cost and a triangle distribution for the benefit to find the best option for the construction of a traffic safety facility along the inland waterway in a Cambodian port.

3. Forecasting risk for fishing vessel accidents

For the risk analysis, two key factors (frequency and consequence) of an accident are required for the assessment of the risk, and the general formula is the product of the followings.

$$R = P \times C \tag{1}$$

where R = risk, P = frequency (probability), and C = consequence of an accident.

In this study, frequency is defined as the ratio of the number of accidents of each type to the total number of accidents of all types and consequences including fatalities, injuries, and missing persons from fishing vessel accidents. Usually, studies on risk analysis employ only the number of fatalities as a consequence without the wounded or missing, which needs to be considered as fatalities for a more accurate risk calculation. Therefore, we express the injuries or missing as death(fatality) equivalents by assigning corresponding weights from Kim et al. (2013) to these potential fatalities.

3.1 Risk of fishing vessel accidents with the traditional method

With the simple risk formula (1) and nine different types (collision, touching, sinking, capsizing, fire/explosion, death/injury, engine failure, stranding, etc.) of fishing vessel accident data for the 1988-2016 period from KMST, the risk of each accident type is calculated. Fig. 1 shows the risk of collision where the blue diamond shape is the risk for each year and the red line represents the average risk derived from the accident data. The risks of the other eight types of accidents are presented in Appendix 1.

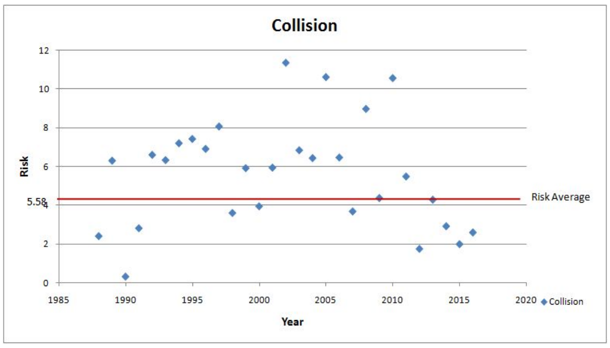
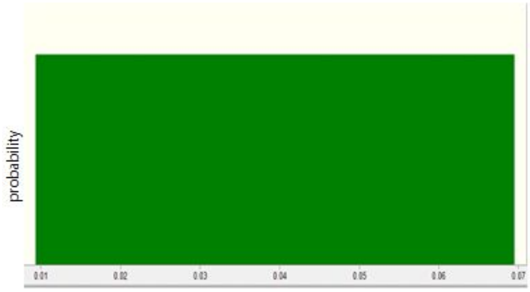


Fig. 1. Risk of collision.

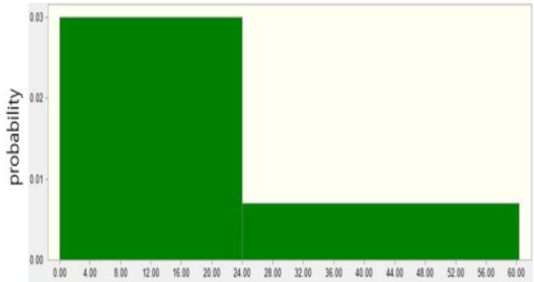
3.2 Forecasting risk of fishing vessel accidents using the simulation method

Given the accident data, one usually calculates the average risk level with averages of P and C as done in subsection 3.1, where the individual risks vary from year to year and consequently, the average risk denoted by a single value does not seem to properly reflect the overall risk level. This is mainly due to the uncertainty involved in forecasting P and C from a small data set of accidents. Therefore, in this subsection, we introduce a method to forecast the possible risk values using the probabilistic distributions of P and C for each type of accident.

For the determination of distributions for frequency and consequences we used the accident data to fit the known distribution functions. The number of accidents that occurred each year shows no specific patterns or relations in any way, and we assume the accident frequency to be uniformly distributed for the nine different accident types. However, considering that the consequence differs by the type of accident, we created the distributions of consequence of each type based on historical data. Fig. 2 shows distributions of frequency and consequence for capsizing accident type. For the upper graph, the X-axis represents frequency (ratio of capsizing accidents to total accidents per year) and the Y-axis is a probability distribution function for frequency. Frequency is uniformly distributed over the range of (0.01, 0.07) with a height of 16.67. For the lower graph, the X-axis is the consequence (number of fatalities) in the combination of two uniform distributions having ranges of (0, 24) and (24, 60.34) and the Y-axis represents the corresponding probability distribution functions for consequence.



Distribution for capsizing frequency (P)



Distribution for capsizing consequence (C)

Fig. 2. Distributions for capsizing frequency (P) and consequence (C).

The simulation calculates the risks from two distribution functions (frequency and consequence) in Fig. 2 and risk equation (1), each time using different random values. Fig. 3 produces the resulting distribution of capsizing risk, where the Y-axis is the probability distribution function for capsizing risk. For the study, the number of calculation runs was 10,000.

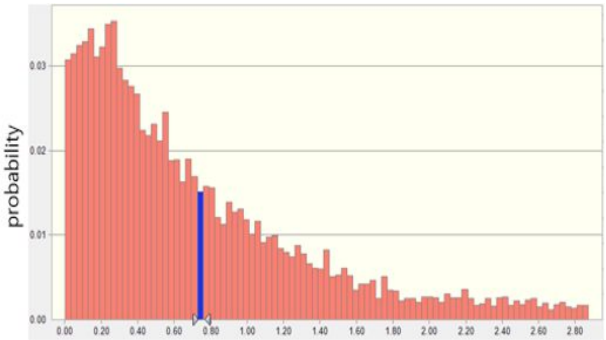


Fig. 3. Distribution for capsizing risk.

With other frequency and consequence distributions, the forecasted distributions of risk for each type of accident are similarly calculated and shown in Appendix 2, where the blue line represents the average risk from the traditional method in 3.1.

Table 1 shows the possible range of the risk values from simulation and the risk value from the traditional method for each accident type. For example, the risk values of a collision is (0.18, 16.66).

Table 1. Comparison of risk between the traditional vs. the simulation method

	Simulation			Traditional
	Max	Min	Average	Average
Collision	16.66	0.18	5.74	5.58
Touching	0.02	0	0.002	0.002
Stranding	2.37	0	0.28	0.25
Capsizing	4.12	0	0.78	0.75
Fire/ Explosion	3.19	0	0.64	0.60
Sinking	23.23	0	3.80	4.05
Engine Failure	13.8	0	0.77	0.45
Death / Injury	9.69	0	1.49	1.34
Etc.	3.98	0	0.17	0.07

The following Fig. 4 is a visual comparison of the two methods for each accident type based on Fig. 3 and Table 1.

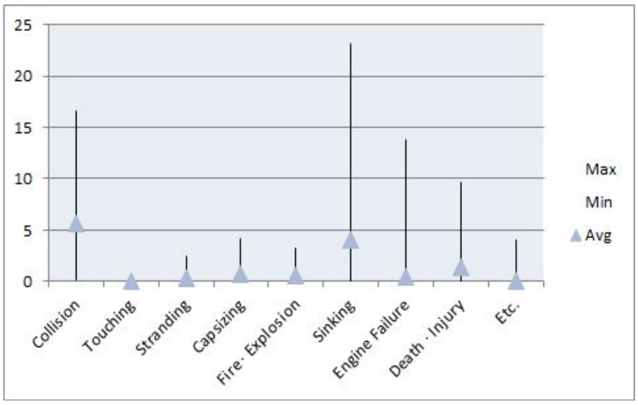


Fig. 4. Risk range for each accident type.

3.3. Evaluating and prioritizing risk against criteria

The purpose of a risk analysis of an event (accident in our case) is to evaluate whether the risk is acceptable by comparing it against the risk criteria provided. If the risk is low enough, no further control options or actions would be taken. If the risk is found to be unacceptable, one should employ appropriate risk mitigation measures to select the best or most cost effective option available to reduce the current risk to an acceptable level.

An F-N curve, one of the most widely used criteria for risk evaluation, presents the relationship of frequency and consequence as shown in Fig. 5. The interpretation of the criteria is as follows:

- If the risk is in an acceptable region, it is accepted with no further actions necessary and ensure that the risk remains in the region.
- If the risk is located in an unacceptable region, actions should be taken regardless of cost to reduce the risk to the As Low As Reasonably Practicable (ALARP) region.
- If the risk is located in an ALARP region, it is suggested that action be taken to reduce the risk.

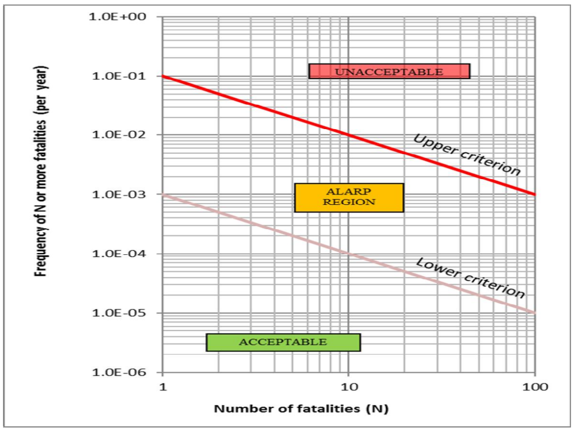


Fig. 5. F-N curve.

In general, when the risk is located in ALARP, it is recommended to take actions based on a cost/benefit analysis. When risk is close to the unacceptable region, action needs to be taken unless the cost incurred to reduce the risk is overly disproportionate to the benefits expected. On the other hand, when risk is close to the acceptable region, action may be taken if the benefit is expected to exceed the cost required to reduce the risk.

Regarding the capability of the proposed method in risk evaluation, we apply a simpler criteria with ALARP region as shown in Fig. 6, which is commonly used in determining the acceptability of the given risk level.

Currently, there is no criteria to apply in Korea, so we randomly assigned the criteria values to divide into three regions for illustration, and the criteria for unacceptability in Fig. 6 is ten. Taking the collision accident (see Fig. 4) for instance, Fig. 6 shows that the single risk value (triangle) from the traditional method is in ALARP, whereas the risk from the simulation method spans all the way up into an unacceptable region. Therefore, the decision-maker would be prepared to take proper options not only for ALARP, but for the unacceptable region.

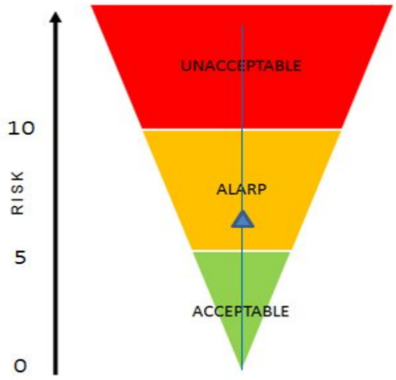


Fig. 6. Risk criteria for the evaluation of collision risk.

In the case of collision, using the risk distribution, the possibility of risk being in the unacceptable region, i.e., the probability that the risk is greater than or equal to ten, is 13.84 % (the blue-colored area) as shown in Fig. 7, where the Y-axis represents the probability distribution function for collision risk. Therefore, when a risk range extends to different regions, one could easily quantify the possibility of risk being in the specific region by calculating the probability with the corresponding risk distribution and prioritize the risk mitigation measures. A similar argument holds for other accident types, where risks in different risk regions will be treated not equally in employing appropriate risk control options. In the study, we used the Crystal Ball software program for the simulation and calculation of the probability.

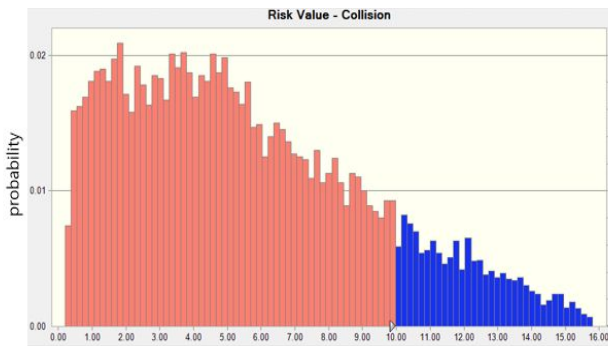


Fig. 7. Probability of collision risk being in the unacceptable region.

As illustrated in the simple risk evaluation process above, compared to the existing method, the proposed simulation technique is believed to be used as a tool in dealing with uncertainty stemming from frequency and consequence.

4. Conclusion

In this paper, we dealt with the uncertainty involved in risk analysis since the accident data for risk analysis are often not available or not enough to get credible results. Many previous studies focus mainly on the causes of the accidents and risk mitigation options based on the historical data for a certain period.

Therefore, we introduced a probabilistic simulation technique to forecast the risk of accidents and we calculated the range of possible risk values unlike other studies where risk was expressed in a single number. Regarding the capability of the proposed method, we employed the criteria with ALARP region, and we showed the uncertainty inherited in the risk calculation process. It is believed that the proposed approach will help a decision-maker employ appropriate risk mitigation measures.

The proposed risk forecasting simulation method assumes probability distributions to fit the actual data. However, the accuracy of the distribution functions needs to be enhanced as data accumulate over time. In the study, we paid attention only to methodology to forecast and evaluate the risk against a given criteria.

The difficulty one frequently encounters in applying a criteria with ALARP for the evaluation of the risk is how to adequately determine criteria levels, i. e., benchmarking values, that divide the whole criteria region into three subregions (unacceptable, ALARP, and acceptable).

For the future direction of research, however, it is required to establish more detailed risk criteria with proper benchmarking values and to perform cost/benefit analysis for better selection of risk reduction options for each type of accident. Also, the research should consider various consequences, i. e. sea environmental damage (oil slicks, contamination of the sea), economic damage (negative effects on international trade through marine transport), physical and monetary damage (ports, vessels), and other accident-related damages for more practical analysis of vessel accidents.

Acknowledgements

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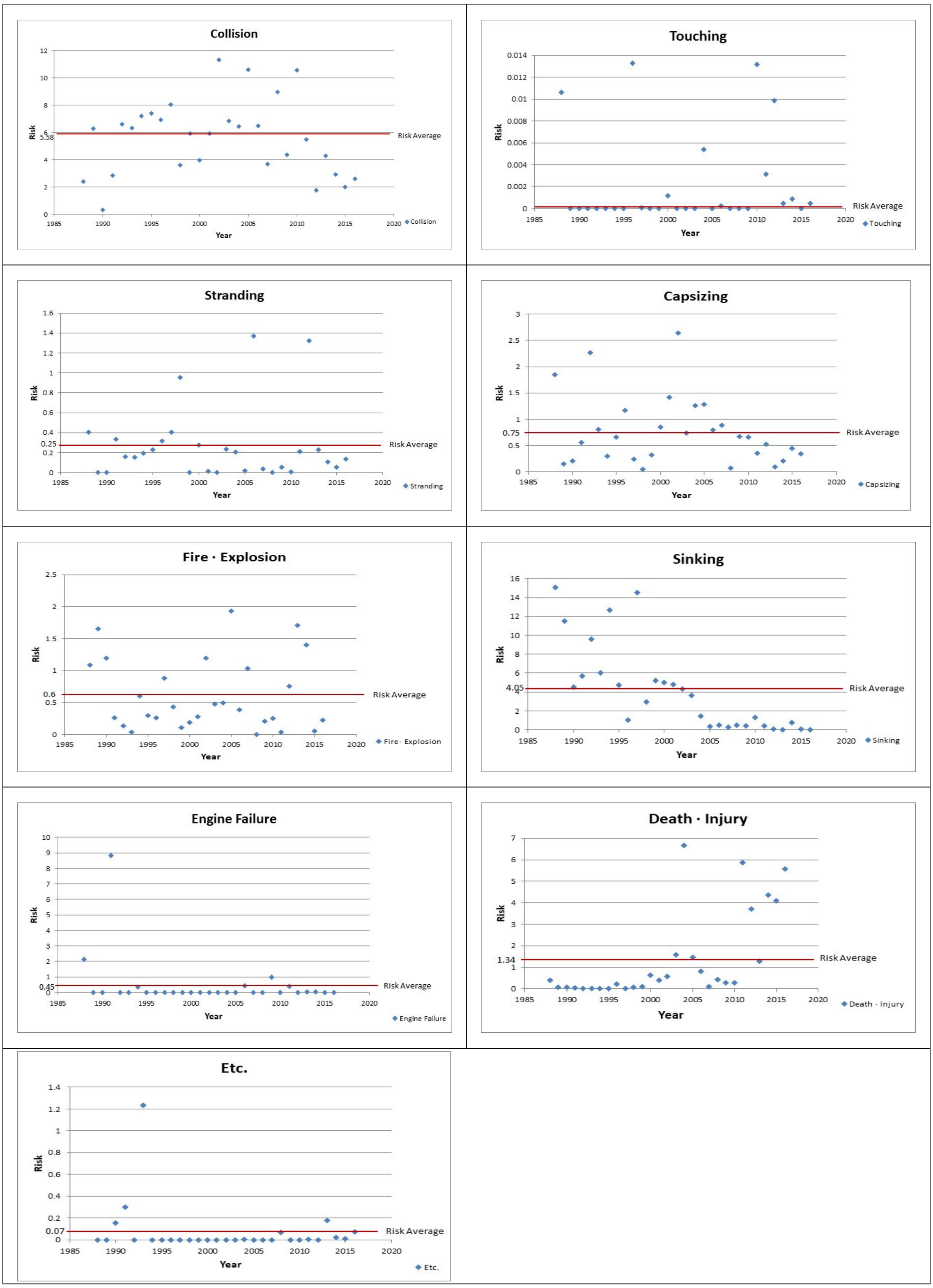
Appendix 1



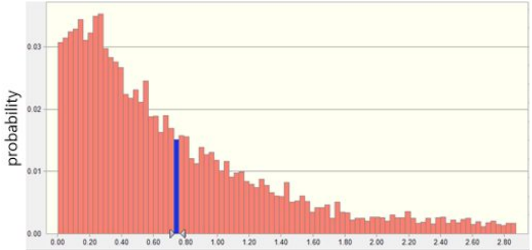
∗ Etc.: Equipment/Supporting device damages, Marine pollution, and so forth

Appendix 2

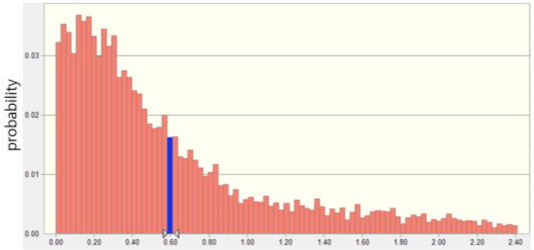
Distribution for collision risk

Distribution for touching risk

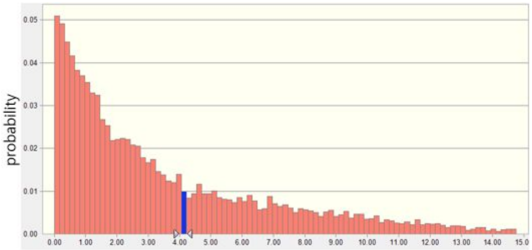
Distribution for stranding risk



Distribution for capsizing risk

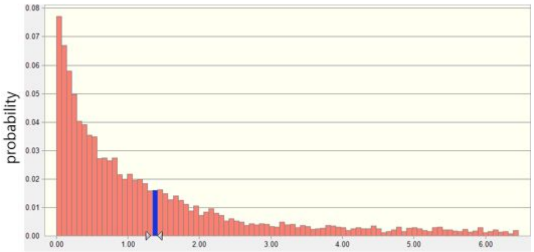


Distribution for fire/explosion risk

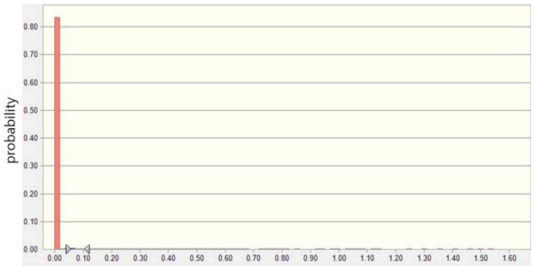


Distribution for sinking risk

Distribution for engine failure risk



Distribution for risk death/injury risk



Distribution for etc. risk