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Finding Hazard Factors by New Risks on Maritime Safety in Korea

Deuk-Jin Park* · Seong-Bug Park** · Hyeong-Sun Yang*** · Jeong-Bin Yim***†
*, ** Graduated School of Mokpo National Maritime University, Mokpo 58628, Korea
*** Division of Navigation Science, Mokpo National Maritime University, Mokpo 58628, Korea

Abstract: *The key features of maritime accidents are the change of their attributes by new risks from time to time. To prevent maritime accidents in Korea, the impacts by new risks on domestic safety environments should be identified or predicted. The purpose of this paper is to find the hazard factors by new risks on maritime safety in Korea. The meaning of new risks is the elements of accident hazard which is compiled from new or rare or unprecedented events in the worldwide maritime transportations. The problems of new risks are the lacks of optimum countermeasures to mitigate accident risks. Using the questionnaires with 152 event scenarios classified by 20 accident causes, the hazard identification and risk analysis of new risks was performed based on the Formal Safety Assessment (FSA) by IMO. A total of 22 Influence Diagrams, which is to depict the transit flows between accident causes to consequences, is used in the construction of 152 event scenarios. A total of 20 accidents causes is the same contents as the causation factors represented in Statistical Year Book for Maritime Accidents of Korean Maritime Safety Tribunals. After defining the evaluation equations to the response results of questionnaires by 46 experts, the work for risk analysis is carried out. As results from the analysis of 152 scenarios, it is known that the root cause to affect on maritime safety in Korea is the pressure of business competition and it led to the lacks of well experienced crews, the overload of vessel operations and crew's fatigue. In addition, as results from the analysis of 20 accident causes, the three accident causes are to be candidate as main issues in Korea such as the inadequate preparedness of departure, the neglecting of watch keeping in bridge and the inadequate management of ship operations. All of the results are thought to be as basic hazard factors to safety impediments. It is thus found that the optimum Risk Control Options to remove the hazard factors and to mitigate consequences required are the following two factors: business competition and crewing problems.*

Key Words: *Maritime accident, Safety, Risk, Hazard, Risk assessment, FSA, Risk control options*

1. Introduction

The key features of maritime accidents are the change of their attributes by new risks from time to time. It is due to the change of maritime transportation environments such as the types of cargo, the size of ship, the types of fuels, the nationality of seafarers, and so on (Park et al., 2015a). The meaning of new risks is the elements of accident hazard which is compiled from a new/rare or an unprecedented event in the world marine industry. The differences between near-miss and new risks are the presence or absence of accidents. In case of near-miss, the accident has not occurred, and it is classified into an incident. On the other hand, new risks are the combination of concepts of accident causations and consequences regardless of the presence or absence of accidents (Park et al., 2015b; Yim et al., 2015a; Yim et al., 2015b). The problems of new risks are the lacks of optimum countermeasures to mitigate accident risks (Park et al., 2015b; Yim et al., 2015a; Yim et al., 2015b).

In 2013, a 19,000 TEU (Twenty-foot Equivalent Unit) container vessel 'M/V MOL Comport' that was wrecked in the Indian ocean (Allianz, 2015). As a result of the change of energy consumption type from fossils to natural/clean energy, the transportation volume of LNG/LPG (Liquefied Natural Gas/Liquefied Petroleum Gas) has increased dramatically (Hightower et al., 2004; Hightower, 2013; Luketa and Hightower, 2006; Luketa et al., 2008). Human error by OOW (Officer Of the Watch) is still remaining as key causation factor of accidents (Allianz, 2013; Allianz, 2014). The estimated costs by a total loss of 19,000 TEU container has reached up to 1 billion USD (US Dollar) (Allianz, 2015). It was not a precedented loss in the world maritime transportations.

And the other new risks, such as natural catastrophes with emerging virus, cyber attack against electronic navigation system, unmanned ship operating, ice shipping, and so on, have appeared as technology advanced. To prevent maritime accidents in Korea, the impacts by new risks on domestic environments should be identified or predicted (Yim et al., 2014). In addition, if it is possible that finding the key causation factors by new risks

* First Author : pdj@mmu.ac.kr, 061-240-7156
† Corresponding Author : jbyim@mmu.ac.kr, 061-240-7170

contributing to accidents with a prior time then, any measures, so called Risk Control Options (RCOs), can be prepared to prevent accidents by modern technology or rules (Yim et al., 2014). The creation works to optimum RCOs can be done with Formal Safety Assessment (FSA) proposed by IMO (International Maritime Organization, 2001). FSA is one of the well-known approaching procedures or tools for the maritime accident evaluation in the world.

The purpose of this paper is to find the hazard factors of new risks affecting on the maritime safety in Korea based on the FSA. Also, the last goal of this work is to propose adequate RCOs for new risks. As preparatory works to implement the last goal, the hazard factors of new risks were identified with questionnaires on Influence Diagrams (IDs), the risk analysis of the response to questionnaires. As a result of the risk analysis, the hazard factors of maritime safety in Korea can be derived.

2. Approaching Procedures

2.1 Study Approaching Procedures

As the basic working procedures, FSA was introduced. FSA have five successive working steps with the preparatory step as shown below (IMO, 2001).

- Preparatory step is to define goals, systems and operations to predict the risks which are the key causation factors influencing maritime accidents.
- Step 1 is Hazard Identification, so called HAZIP, which is to find the possible risk factors by expert brainstorming or scenarios.
- Step 2 is Risk Analysis which is to calculate quantitative amount of risks by the cause and frequency analysis and the consequence analysis. In this step, Quantitative Risk Analysis (QRA), Probabilistic Risk analysis (PRA) and Human Resource Assessment (HRA) are used.
- Step 3 is Risk Control Options (RCOs) which is to give optimum accident measures to decrease the frequency or to mitigate consequences. RCOs may be defined as an optimum rule, adequate navigation systems and high-tech tools, so on.
- Step 4 is Cost Benefit Analysis (CBA) which is to evaluate RCOs by comparing costs versus benefits.
- Step 5 is reporting of suggestions for decision-making.

Because the three steps from Preparatory step to Step 2 are enough to identify and analyze the new risks, the three steps are introduced in this study. The second half of steps from Step 3 to Step 5 are reserved for future studies.

Fig. 1 represents the study approaching procedures with FSA applied to the first half three steps mentioned above.

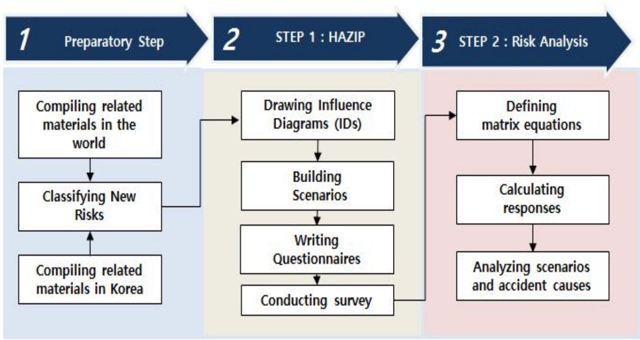

Fig. 1. Study approaching procedures to find the hazard factors of new risks affecting on the maritime safety in Korea.

In Preparatory Step, the reference materials related to the maritime transportation accidents around the world and in Korea are compiled and classified new risks after reviewing the compiled materials.

In HAZIP Step, Influence Diagrams (IDs) are implemented to express how to transit the new risks from causes to consequences. Then, after the scenarios are built with IDs, a survey for the scenarios was conducted.

In Risk Analysis Step, the response results for the questionnaires are analyzed using mathematical matrix equations to find high scored scenarios. As a result from this step, we can find how new risks can be transit into the risky environments.

The detailed results of each step are shown hereunder.

2.2 Preparatory Step

In this preparatory step, we have collected related materials on the analysis reports of maritime accidents and on the trend overview reports of maritime industries.

The main reference materials used in this study are the safety and shipping reviews from 2012 to 2015 published by Allianz (Allianz, 2012; Allianz, 2013; Allianz, 2014; Allianz, 2015). Allianz reports contained the expert analysis results on maritime accidents around the world and predicted high risks which may have large impacts on maritime accidents in the future. In addition, survey results on the seafarer’s conscious results published by Korea Marine Officers' Associations (KMOA, 2010a; KMOA, 2010b; KMOA, 2012a; KMOA, 2012b) were also used. After summarizing all of the materials, new risks were classified into five classes as shown in Table 1.

Table 1. Classified new risks extracted from various reference materials (Class is arbitrary given by authors)

Class	New risks
Crew	Human error, Crew fatigue, Reduced crewing numbers, Crewing level, Over-dependence on technology, Poor communications, Bureaucracy onboard, None-standardized training, Lacks of skilled workforce, Overconfidence of electronic equipments, Safe minimum crewing levels
Company	Increasing competition, Absence of self safety culture of company, Management worse, Economic deteriorations, Tonnage, Poor monitoring and enforcement of regulation
Vessel	Noxious emission control, Ship building quality, Increasing ship size, Passenger vessel evacuation and rescue, Use of none-OEM parts, Cat fines, Construction standards, Vessel quality, Salvaging of large vessel, Large vessel fire-fighting, LNG as a fuel, Slow steaming, Unmanned ships
Cargo	Increasing fire risks due to the inadequate cargo loadings, Cargo liquefaction, Misappropriation of cargoes
Safety	Piracy, Concentrating accident position, Inadequate risk management, Commerciality of Class and Flag, None-sector specific safety management system, Ice shipping, ECDIS implementation, Insufficient ECDIS training, Passenger ship safety, Places of refuge, Cyber attacks, Virus infection, Human trafficking, Natural catastrophes

2.3 HAZIP

Hazard Identification (HAZIP) is to create scenarios using the group of new risks and to find possible hazard factors by expert brainstorming.

To present the cause-to-effect relationships in the group of new risks shown in Table 1, the concept of accident chain (van Drop et a1., 2001) is used to identify accident transition mechanism having five transition steps; hazard, peril, risk, consequences and impact. Based on this accident chain, the accident scenario for the group of new risks was created to search for the effect of new risks on maritime safety by expert brainstorming.

Also, to identify the relationship between the causes and consequences in the group of new risks, Influence Diagram (ID) is introduced. ID uses flow diagrams to find the transition trends of accidents between causes and consequences. A total of 22 IDs was constructed from new risks in Table 1. In example, Fig. 2 and Fig. 3 only show two kinds of IDs for the class of crew and vessel in Table 1, respectively.

In the two figures, the various Hazards are collected from the group of new risks as root causes. The summarized results of Hazard factors are propagated into one of the Perils and the Perils can be concluded as one of the Risk as accidents. Lastly, the Risk was propagated into consequences (denoted as letter 'C') and impacts (denoted as letter 'I').

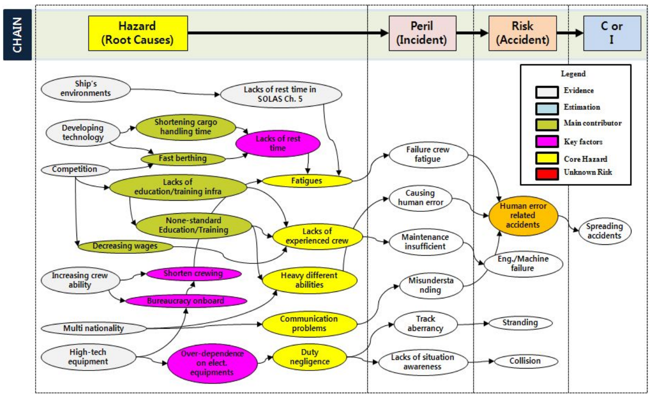

Fig. 2. Influence Diagram to identify the relationships of new risks for crew class as shown in Table 1 (Yim et al., 2015a).

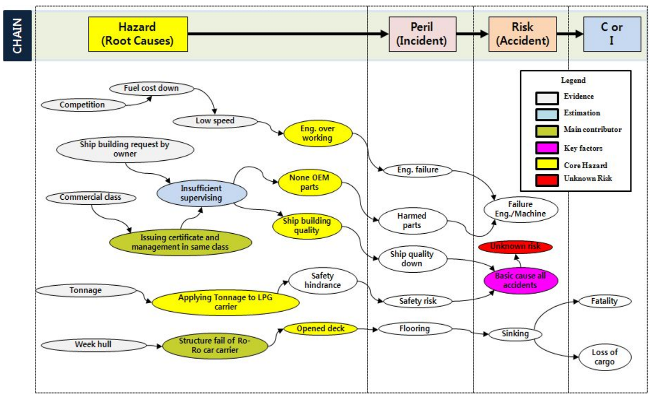

Fig. 3. Influence Diagram to identify the relationships of new risks for vessel class as shown in Table 1 (Yim et al., 2015a).

Fig. 4 shows the summarized relationships of new risks in Table 1. The basic hazard factor is the change of maritime transportation environments in the world. The three independent new risks are identified as the problems for insufficient dangerous cargo separation, the spread of virus (SARS, MAERS and Ebola) infections, and issuing and managing certificates in same class.

The most important hazard factor is the increasing competition of companies in the view point of economics. In case of the vessel factor, a total of seven new risks appeared: the increasing ship size, the lack of large berth for big-sized ships, the virus infections of navigational equipment, the lack of refuge places for large-sized ships, the low speed problem to prevent CO2 emission, and the use of LNG as fuel and increasing LNG transportations.

In case of crew factor, the lack of minimum safety crewing, crew fatigue, early changing occupation of junior officers, overconfidence of electronic equipment, and emerging abnormal officers who have mental disorders are identified as new risks.

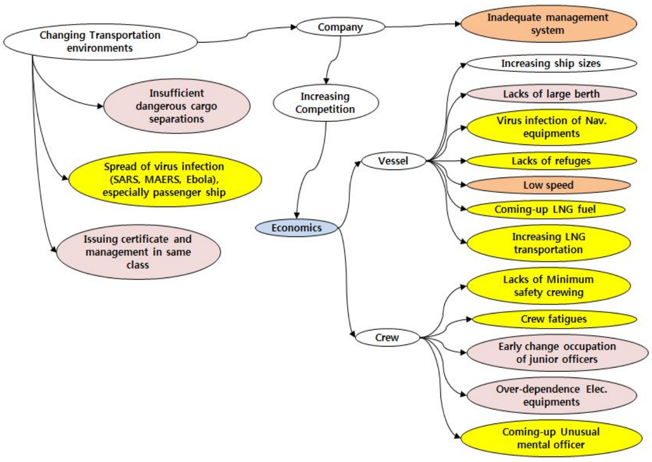

Fig. 4. Influence Diagram for summarized relationships of new risks as shown in Table 1.

From the a total of 22 IDs, a total of 152 scenarios can be created. To survey the impacts of new risks on the safety of maritime transportations in Korea, we have prepared the questionnaires using 152 scenarios and 20 questions to each scenario. A total of 20 questions is the causation type of maritime accidents representing the statistical year book for maritime accidents published by Korean Maritime Safety Tribunals (KMST, 2014). The reason why we use the causation type as questions is to find the impact of new risks on the maritime accidents in Korea. This concept is about that if Korean experts give high points to 20 questions in 152 scenarios, then we can realize the impact of new risks on the safety of maritime accidents in Korea.

Table 2 shows the form of questionnaire with 152 scenarios in the rows and 20 questions in the columns. In Table 3, a total of 152 scenarios is developed into four steps with one root cause and three transition effects. The root cause is new risks itself and the transition events from the first to the third are predicted based on the referenced materials. The contents of 20 accident causes from Q1 to Q20 are as follows;

Q1: Inadequate preparation of departures
Q2: Insufficient check for traffic routes
Q3: Inadequate keeping course
Q4: Neglection of position checking
Q5: Bad ship maneuvering
Q6: Neglecting of watch keeping
Q7: Inadequate preparation/response for bad weather
Q8: Inadequate anchoring/berthing
Q9: Violation of navigation rules
Q10: Neglecting of service supervision
Q11: Neglecting of duty
Q12: None-compliance of safety regulations
Q13: Bad handling of equipment/facilities
Q14: Bad handling of fire-fighting facilities
Q15: Fault of hull/engine equipments
Q16: Inadequate passenger/cargo loadings
Q17: Inadequate vessel operating managements
Q18: Inadequate crewing placements
Q19: Inadequate supporting facilities of route/harbor/traffics
Q20: Seaworthiness to abnormal weather/sea states

Table 2. The form of questionnaire with 152 scenarios by 20 questions

Scenarios \ Accident causes					Q1	Q2	Q3	…	Q18	Q19	Q20
No. \ Con-tents	Root causes	Transit effects									
		1st	2nd	3rd							
1											
2											
3											
…											
…											
150											
151											
152											

Using the questionnaires in Table 2, the survey was conducted with a total of 46 experts working for the Ministry of Oceans and Fisheries, Korea Coast Guard, Maritime Universities and ship operations as deck officers. A relative percentile (%) scale from 0 to 100 is used to answer the questions in each scenario. The scale on 0 means that the question has no relationship with the scenario and the scale on 100 means most significant relationship with the scenario. Because the questionnaires are composed with 152 scenarios by 20 accident causes, the matrix equation with n-by-m dimension is required to evaluate the response results.

2.4 Risk Analysis

Risk Analysis is to calculate the quantitative amount of risks through two ways: the cause and frequency analysis and the consequence analysis. In this step, Quantitative Risk Analysis (QRA) method is applied to calculate the risk ranking for the 152 scenarios and 20 questions as a type of matrix.

QRA is to deal the risks with Risk Index (RI) based on a logarithmic scale and as a form of RI = Frequency Index (FI) + Severity Index (SI). The risk level of FI and SI can be found in the Risk Acceptance Criteria (RAC), which is the group of threshold values calculated by accident history. However, the new risks are not found or rare in accident history and led to the absence of RAC for new risks. This is the reason why we use the questionnaires without the use of RAC.

The calculation process of RI to survey the questionnaires with 46 experts is as follows:

Let $\boldsymbol{Q} \in \{q_{i,j}\}$ in Eq.(1) as the matrix of questionnaires with 152 scenarios by 20 accident causes (herein after use the type of 152-by-20).

$$\boldsymbol{Q} = \begin{pmatrix} q_{1,1} & q_{1,2} & q_{1,3} & \cdots & q_{1,j-1} & q_{1,j} \\ q_{2,1} & q_{2,2} & q_{2,3} & \cdots & q_{2,j-1} & q_{2,j} \\ q_{3,1} & q_{3,2} & q_{3,3} & \cdots & q_{3,j-1} & q_{3,j} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ q_{i-1,1} & q_{i-1,2} & q_{i-1,3} & \cdots & q_{i-1,j-1} & q_{i-1,j} \\ q_{i,1} & q_{i,2} & q_{i,3} & \cdots & q_{i,j-1} & q_{i,j} \end{pmatrix} \quad (1)$$

Where

i : Indices of scenarios ($i = 1,2,3,\cdots,I$, I= 152)

j : Indices of accident causes ($j = 1,2,3,\cdots,J$, J = 20)

$q_{i,j}$: Question elements with the dimension of i-by-j

Let $\boldsymbol{R} \in \{r_{i,j,k}\}$ in Eq.(2) as response results for the questions $\boldsymbol{Q}$.

$$\boldsymbol{R} = \begin{pmatrix} r_{1,1,k} & r_{1,2,k} & r_{1,3,k} & \cdots & r_{1,j-1,k} & r_{1,j,k} \\ r_{2,1,k} & r_{2,2,k} & r_{2,3,k} & \cdots & r_{2,j-1,k} & r_{2,j,k} \\ r_{3,1,k} & r_{3,2,k} & r_{3,3,k} & \cdots & r_{3,j-1,k} & r_{3,j,k} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ r_{i-1,1,k} & r_{i-1,2,k} & r_{i-1,3,k} & \cdots & r_{i-1,j-1,k} & r_{i-1,j,k} \\ r_{i,1,k} & r_{i,2,k} & r_{i,3,k} & \cdots & r_{i,j-1,k} & r_{i,j,k} \end{pmatrix} \quad (2)$$

Where

k : Indices to the number of respondents ($k = 1,2,3,\cdots,K$, K= 46)

Let $\boldsymbol{M} \in \{m_{i,j}\}$ in Eq.(3) as the mean values to the response results $\boldsymbol{R}$.

$$\boldsymbol{M} = \begin{pmatrix} m_{1,1} & m_{1,2} & m_{1,3} & \cdots & m_{1,j-1} & m_{1,j} \\ m_{2,1} & m_{2,2} & m_{2,3} & \cdots & m_{2,j-1} & m_{2,j} \\ m_{3,1} & m_{3,2} & m_{3,3} & \cdots & m_{3,j-1} & m_{3,j} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ m_{i-1,1} & m_{i-1,2} & m_{i-1,3} & \cdots & m_{i-1,j-1} & m_{i-1,j} \\ m_{i,1} & m_{i,2} & m_{i,3} & \cdots & m_{i,j-1} & m_{i,j} \end{pmatrix} \quad (3)$$

The elements $m_{i,j}$ of $\boldsymbol{M}$ (152-by-20) in Eq.(3) are the mean values to the total number of respondents N_r (N_r = 46) as in Eq.(4).

$$m_{i,j} = \frac{\sum_{k=1}^{K} r_{i,j,k}}{N_r} \quad (4)$$

Using Eq.(5) and Eq.(6), the averaged scores SC_j to each accident causes in $\boldsymbol{M}$ and the averaged scores SS_i of each scenario in $\boldsymbol{M}$ are obtained, respectively.

$$SC_j = \frac{\sum_{i=1}^{I} m_{i,j}}{N_s} \quad (5)$$

$$SS_i = \frac{\sum_{j=1}^{J} m_{i,j}}{N_a} \quad (6)$$

Where

N_s : Total number of scenario (N_s = 152)

N_a : Total number of types of accident causes (N_a = 20)

3. Experimental Results and Discussions

3.1 Experimental Respondent analysis

Table 3 shows the demographics of respondents of this experiment. The survey is conducted only on experienced deck officers. The age group of 35 to 45 has the most common respondents. The largest group of boarding career is 3 to 10 years.

The largest group of experienced career on safety is 10 to 25 years, but 3 to 10 years also took a big portion.

Table 3. Respondent demographics

Variable	Classification	Response	Ratio (%)
Age	20 ~ 35	11	24
	35 ~ 45	29	63
	45 ~ 60	6	13
	Total	46	100
Boarded career (year)	≦ 3	15	33
	3 ~ 10	26	56
	10 ~ 15	5	11
	Total	46	100
Job experienced career on safety (year)	≦ 3	5	11
	3 ~ 10	20	43
	10 ~ 25	21	46
	Total	46	100

3.2 Experimental Results

Fig. 5 is the color map representing the results of survey using M in Eq.(3) for the entire questionnaires. The reason why the color map is used is because the survey results have large data of 3,080 (152-by-20) and we wish to know the comprehensive trends of survey results between the scenarios and the accident causes. It means higher scores closer to red and lower scores closer to blue.

Based on the results from Fig. 5, it is known that the area between the index number of scenarios 1 to 25 and the index number of accident causes 1 to 19 has higher scores than others. The contents of scenarios to this area are related to the crew's fatigue and lack of well-experienced crews. From these results, it can be assumed that the common issue of new risks is the management of crews onboard a ship.

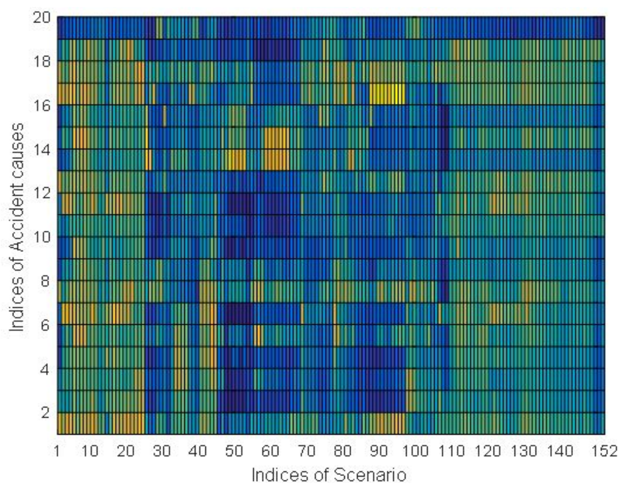

Fig. 5. Color map to present survey results for the questionnaires. The x-axis is the index of scenario number and y-axis is the index of accident causes.

Fig. 6 shows the mean values with 95 % confidence levels to the response scores of accident causes calculated from SC_j in Eq.(5). The high scored values are the index of 1 (inadequate preparedness for departure), 7 (the neglecting of watch keeping in bridge) and 16 (the inadequate managements of ship operations). From these results we found that the accident causes of new risks is mainly due to human errors and inadequate managements of ship operations.

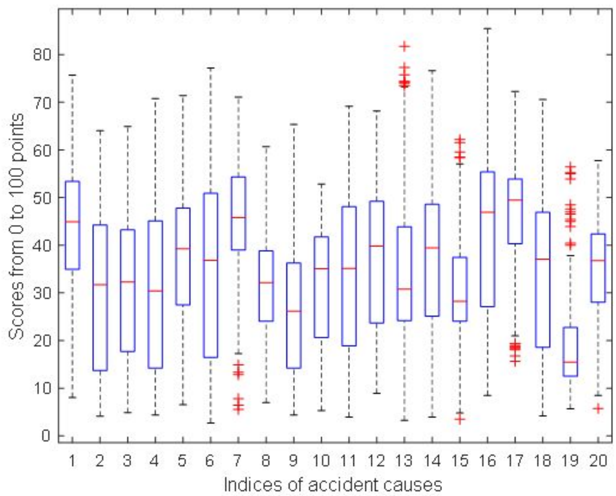

Fig. 6. Scores to accident causes with 95 % confidence levels.

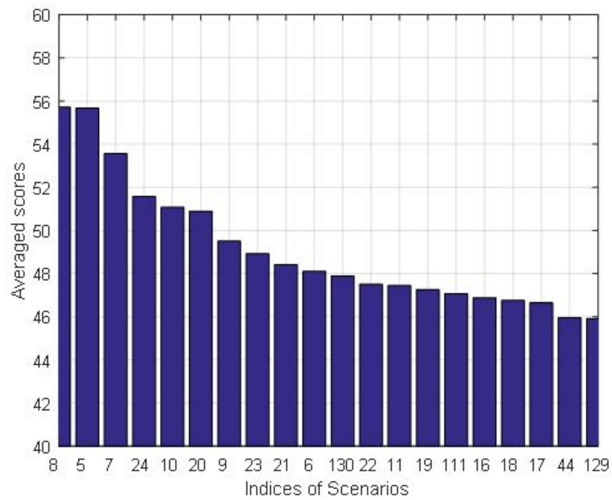

Fig. 7. The higher ranked scenarios and scores. The x-axis is the indices of scenarios in descending ranking order from left to right and, the y-axis is averaged values to 20 accident causes by 46 experts.

The x-axis is the indices of accident causes and the y-axis is averaged values to 152 scenarios responded by 46 experts. In the figure, the tree lines of the bar (center lines, lower lines and upper lines) are shown in the mean values with 25th and 75th percentile of the sample, respectively. The extended dotted line from the bar is the rest of samples.

Fig. 7 shows the response scores to 152 scenarios calculated from SS_i in Eq.(6). The x-axis represents the index of higher scored scenarios in descending order from left to right. The high scored scenarios are the index number of 8, 5, 7, 24 and 10 and, the contents of five high scored scenarios are represented in Table 4.

Table 4. The higher ranked five scenarios and contents

Ran-king	Index of scenario	Root causes	First transit effects	Second transit effects	Third transit effects
1	8	Competition pressure	Reduced wages	none	Lacks of well experienced crew
2	5	Competition pressure	Lack of education/training infrastructure in a company	none	Lacks of well experienced crews
3	7	Competition pressure	Lack of education/training infrastructure in a company	None-standard education /training	Lacks of well experienced crew
4	24	Competition pressure	Busy operation schedule	High speeding vessel operation	Vessel operation overload
5	10	Increasing officer's duty ability	Increasing Paper working onboard	Reduced crewing	Crew's fatigue

The meaning of five high ranked scenarios are as follows:

- The 1st ranked scenario (index number of 8) is the lack of well-experienced crews with the low wage due to the increasing competition in the industry.
- The 2nd ranked scenario (index number of 5) is the lack of well-experienced crews with the lack of infrastructure for the education and training of crews in a company due to increasing the increasing competition in the industry.
- The 3rd ranked scenario (index number of 7) is the lack of well-experienced crews with unstandardized education and training of crews due to the lack of infrastructure in a company and the increasing the increasing competition in the industry.
- The 4th ranked scenario (index number of 24) is the overloading of high-speed vessel operation due to busy schedule with the increasing competition in the industry.
- The 5th ranked scenario (index number of 10) is the increasing fatigue crews due to reduced crew members and increasing paperwork onboard with the increasing working capabilities of officers.

As a result of the analysis of higher ranked scenarios, it is known that the keen competition of businesses in vessel operation has the most impact on the maritime safety in Korea. It also appeared in the root causes as the competition in the industry.

4. Conclusions

To find the hazard factors by new risks on maritime safety in Korea, this paper discusses the identification of new risks and the analysis of their effects. Using the questionnaires composed of 152 scenarios by 20 accident causes, risk estimation is carried out based on the Formal Safety Assessment (FSA). Summarized results are as follows:

1. As a result of the analysis of 152 scenarios, it is known that the pressure of competition in ship operation is a root cause that affects the maritime safety. This root cause is to be propagated into the lack of well-experienced crews, the overloading of vessel operation, and the crews' fatigue. All of those are thought to be as basic hazard factors as safety impediments.
2. As a result of the analysis of 20 accident causes, three accident causes are nominated for the main issues of accidents in Korea: inadequate preparedness for departure, neglecting of watch keeping in bridge, and inadequate managements of ship operations. All of those are thought to be as operating hazard factors of maritime accidents.
3. The method of analysis of new risks with no accident history data is proposed as a substitution technique for Quantitative Risk Analysis (QRA). In addition, the application method of domestic accident data is also discussed to evaluate the impact of new risks on maritime safety.
4. It is known that the optimum Risk Control Options to remove the hazard factors and to mitigate the consequences are the following two factors: business competition and crewing problems.
5. It is an important issue that the new risks should be identified at least every year due to the fast-paced maritime industry of the world.

According to the FSA, the amount of risk should be calculated with RI (Risk Index) = FI (Frequency Index) + SI (Severity Index). We thought that the combination of FI and SI can give accurate estimation of hazard factors by new risks. We also used the survey results of experts due to the absence of historical data of new risks. The combination of FI and SI will be discussed in a future study.

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