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An Analysis on the Relative Importance of the Risk Factors for the Marine Traffic Environment using Analytic Hierarchy Process

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Abstract : *The classification of risk factors and the identification of risk acceptance criteria are core works to assess risk levels with high enough confidential level in the field of marine traffic environment. In the previous study work, the twenty kinds of risk factors and its assessment criteria for the domestic marine traffic environment were proposed. In this paper, with these previous studying results, the relative importance of the risk factors were analyzed by questionnaire survey of marine traffic experts using the analytic hierarchy process. The analysis results showed that the relative importance of the visibility restriction is the highest among the twenty kinds of risk factors, and the relative importance of the traffic condition is the highest among the five kinds of risk categories. As results from analysis, it is expected that the approaching method on the relative importance is to be one of basic techniques for the development of risk assessment models in the domestic marine traffic environment.*

Key Words : *Marine Traffic Environment, Risk, Risk Factor, Relative Importance, Analytic Hierarchy Process*

1. Introduction

The representative risk evaluation techniques of the marine traffic environment are the FSA, PAWSA, and IWRAP. For the development of these techniques, the risk factors suitable to the marine traffic environment should be selected and the assessment criteria of these risk factors should be provided. The risk factors were selected as the factors that relate both to the frequency of casualty and to the consequence of casualty because the risk was defined as the frequency of casualty times the consequence of that casualty on the existing techniques. But, the risk factors related to the consequence of casualty are excluded because the risk was defined as the sum of the risk factors including the frequency and the consequence by factors on the previous paper related to this study. The twenty kinds of risk factors to compose the risk are selected and classified into five categories according to similar nature through the analysis of the representative risk evaluation techniques on the same paper. Also, the practical assessment criteria of these risk factors are suggested including the counting-method of the frequency.

In this study, based on the previous paper, the consequence of risk factors were calculated through the questionnaire survey of the marine traffic experts, and the relative importance of risk factors were analyzed through the questionnaire by the marine traffic experts using analytic hierarchy process (AHP). These results of analysis will be used as the foundation of the risk assessment model's development for the domestic marine traffic environment on future studies.

2. Review of Previous Paper

The risk was expressed as the risk matrix (Table 1) that is the sum of the frequency index and the consequence index (Table 2) by equation (1) and (2) on the previous paper(IMO, 2002). Also, on the same previous paper, the twenty kinds of risk factors(Table 3) to compose the risk and its assessment criteria (Table 4) for the domestic marine traffic environment were suggested by the analysis of the waterway risk model on the PAWSA(IALA, 2009), the classification of risk factors on the Japanese navigational safety assessment guide(Kim, 2011), the classification of risk factors on

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the Korean maritime safety audit(Jeong et al., 2012), and etc(Kim and Lee, 2012).

$$R = C_f \times C_c \tag{1}$$

where R denotes risk, C_f is frequency of casualty, and C_c is consequence of casualty.

$$Log(R) = Log(C_f) + Log(C_c) \ \ or$$
$$RI = FI + CI \tag{2}$$

where R denotes risk, C_f is frequency of casualty, C_c is consequence of casualty, RI is risk index, FI is frequency index, and CI is consequence index.

Table 1. Risk Matrix

FI \ CI	1	2	3	4	5
1	2	3	4	5	6
2	3	4	5	6	7
3	4	5	6	7	8
4	5	6	7	8	9
5	6	7	8	9	10

Table 2. Frequency and Consequence Index

Index \ Parameter		Frequency	Consequence
FI or CI	1	Extremely Remote	Extremely Minor
	2	Remote	Minor
	3	Normal	Normal
	4	Frequent	Major
	5	Extremely Frequent	Extremely Major

Table 3. Classification of Risk Factors on Previous Paper

Risk Categories	Sub-Categories	Risk Factors
Natural Conditions	Weather Conditions	Winds
		Visibility Restrictions
	Sea Conditions	Water Movements
		Waves
Fairway Conditions	Dimension Conditions	Widths
		Depths
	Interference Conditions	Complexities
		Obstructions
Traffic Conditions	Fairway-use Traffic Conditions	Traffic Flows
		Volume of Traffics
	Open-use Traffic Conditions	Traffic Flows
		Volume of Traffics
Vessel Conditions	Fairway-use Vessel Conditions	Vessel Qualities
		Crew Qualities
	Open-use Vessel Conditions	Vessel Qualities
		Crew Qualities
Assistance Conditions	Material Resource Conditions	Tug Boats
		AtoN
	Human Resource Conditions	Pilotage
		VTS

Table 4. Assessment Criteria of Risk Factors

Risk Factors	Assessment Criteria
Winds	Wind Speed 13.9m/s or more
Visibility Restrictions	Visibility Range 1km or less
Waves	Wave Height 3m or more
Water Movements	Current Speed 3knots or more
Widths	Width of Fairway under 2.0L
Depths	Depth of Fairway under 1.15D
Complexities	Fairway Bend 30° or more
Obstructions	Existence of Obstructions
Fairway-use Traffic Flows	Sailing with Opposite Direction in Fairway
Fairway-use Traffic Volumes	50Fairway-use Vessel Transits or more per Day
Open-use Traffic Flows	Impediment by Open-use Vessel in Fairway
Open-use Traffic Volumes	50 Open-use Vessel Transits or more per Day
Fairway-use Vessel Qualities	PSC Detention Ratio of Fairway-use Vessel
Fairway-use Crew Qualities	Low Class Cert. of Fairway-use Vessel's Crew
Open-use Vessel Qualities	Marine Accidents of Open-use Vessel
Open-use Crew Qualities	Low Class Cert. of Open-use Vessel's Crew
Tug Boats	Tug Boat Available in Emergency
AtoN	Suitable AtoN Available in Fairway
Pilotage	Pilot Available in Fairway
VTS	VTS Available in Fairway

It is necessary to calculate the frequency index and the consequence index on the twenty kinds of risk factors for the domestic marine traffic environment based on the assessment criteria of each risk factor in Table 4. But the counting-method of the frequency index was suggested as the days per year or the ratio (or number) per sea area of the assessment criteria in Table 4 on the previous paper.

3. Consequence Index of Risk Factors

The risk level of each risk factor in Table 3 is expressed as the sum of the frequency index and the consequence index for each risk factor by equation (2). The size of the consequence index for each risk factor is different from each stakeholder on the analyzing marine traffic environment. The questionnaire by the marine traffic experts was conducted to grasp these differences of opinions between stakeholders, and to calculate the average value of various consequence index between stakeholders.

The target of the questionnaire are marine traffic experts who have onboard career, whose present occupations are professors, researchers, PSC officers, VTS officers, pilots, captains, deck officers, and etc. that are connected to Mokpo national maritime university, Korea national maritime university, regional maritime affairs & port office, regional VTS office, Korea maritime pilot's association, Korea shipping association, Korea ship safety technology authority, Korea institute of ocean science & technology, shipping companies, and etc.

Total of one hundred copies of questionnaire were analyzed except the unfaithful answer sheets of twenty copies. The three figures from Fig. 1 to Fig. 3 show the distribution of respondent's occupation, deck officer's certificate of respondent, and respondent's onboard career, respectively.

The assessment criteria of each risk factor in Table 4 were suggested to the respondents, and then the respondents answered the size of consequence for each risk factor using the consequence index of 1 to 5 scale in Table 2. The average value of answer is showed in Table 5. The level of risk of each risk factor is expressed as the risk index of 1 to 10 scale in Table 1 that is the sum of the frequency index for each risk factor and the average value of the consequence index for each risk factor in Table 5.

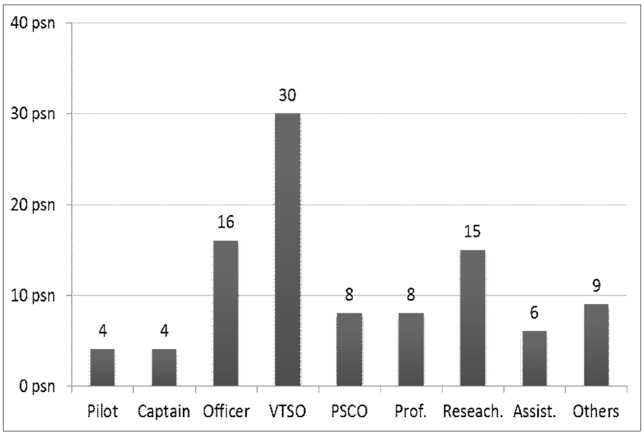

Fig. 1. Respondent's Occupation.

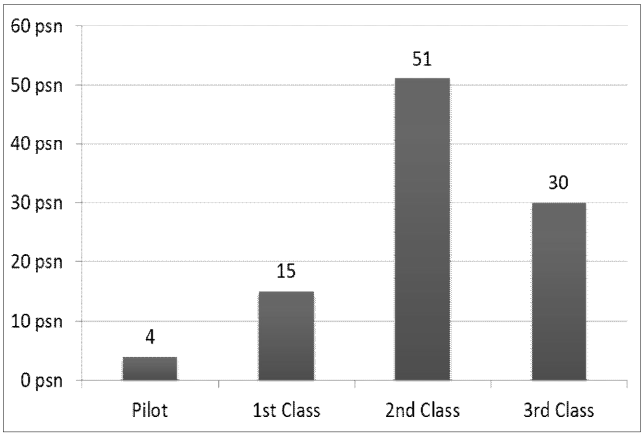

Fig. 2. Deck Officer's Certificate of Respondent.

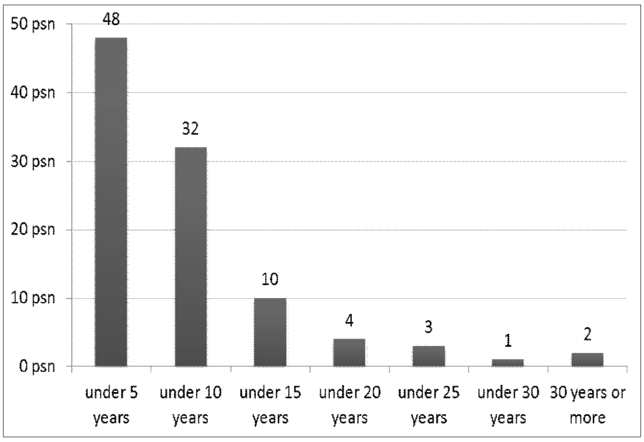

Fig. 3. Respondent's Onboard Career.

Table 5. Consequence Index of Risk Factors

Risk Factors	Average Value of CI
Winds	4.18
Visibility Restrictions	4.29
Waves	3.95
Water Movements	3.89
Widths	3.95
Depths	4.04
Complexities	3.66
Obstructions	3.96
Fairway-use Traffic Flows	4.13
Fairway-use Traffic Volumes	3.64
Open-use Traffic Flows	3.98
Open-use Traffic Volumes	3.88
Fairway-use Vessel Qualities	3.54
Fairway-use Crew Qualities	3.31
Open-use Vessel Qualities	3.77
Open-use Crew Qualities	3.46
Tug Boats	3.71
AtoN	4.02
Pilotage	3.75
VTS	3.98

4. Relative Importance of Risk Factors

The equation (3) shows that the risk is expressed as the sum of the whole risk factors to compose the risk, each risk factor has different size of weight. The 'ω_i' means the relative importance of each risk factor in equation (3), and is used as the weight of each risk factor on the total risk.

$$R = R_{f1} \cdot \omega_1 + R_{f2} \cdot \omega_2 + \ldots + R_{fn} \cdot \omega_n \qquad (3)$$

where R denotes risk, R_{fi} is risk factor, and ω_i is weight.

The pairwise comparison between the five risk categories and between the four risk factors in each risk category was conducted using AHP method to analyze the relative importance for the five kinds of risk categories and the twenty kinds of risk factors in Table 3.

The AHP method has recognized as the major method of decision making in the field of management engineering after the 1980's since professor Saaty of University of Pittsburgh developed the AHP method in the 1960's.

The basic AHP model form the goal at the top, the criteria at the middle, and the alternatives at the bottom. But, the criteria is divided into the sub-criteria or the sub-sub-criteria if necessary. Therefore, the classification of the risk categories and the risk factors in Fig. 4 on this study correspond to these basic AHP structure, that is, the risk of marine traffic environment denotes the goal, the risk categories are the criteria, and the risk factors are the sub-criteria (the alternatives are not necessary on this study).

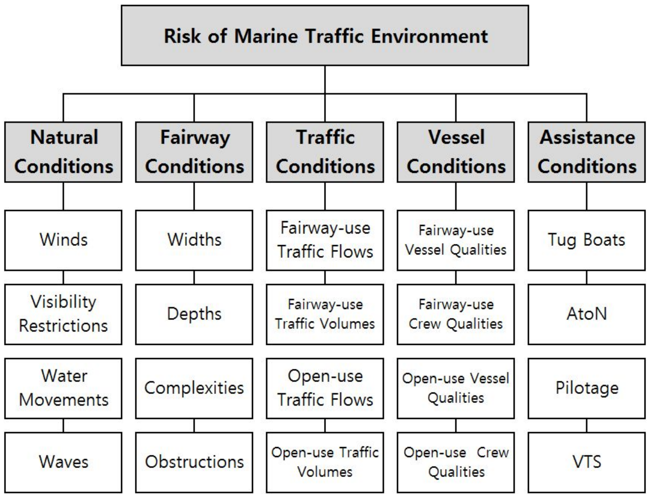

Fig. 4. Hierarchy on Risk of Marine Traffic Environment.

The pairwise comparison is conducted between factors of each hierarchy for the decision making using the structured AHP model, and then the weight of each factor is calculated by these comparisons. The scale of assessment for the pairwise comparison between factors of each hierarchy is used 1 to 9 scale in Table 6 generally(Saaty, 1994). When A is absolute important(9) than B between A & B comparison, value of B is a reciprocal of A(1/9).

Table 6. Pairwise Comparison Scale

Scale	Definitions
1	Equal Importance
2	↓
3	Moderate Importance
4	↓
5	Strong Importance
6	↓
7	Very Strong Importance
8	↓
9	Absolute Importance

The two figures of Appendix 1 and Appendix 2 at the end of this paper are the design of questionnaire for pairwise comparison between five risk categories (the criteria), and between four risk factors (the sub-criteria) in natural conditions risk category as an example, respectively.

The respondents have to be careful not to get logical contradiction on these questionnaires for pairwise comparison. As an example, if the respondent answer that A is more important than B between A & B comparison and B is more important than C between B & C comparison, the respondent must answer that A is more important than C between A & C comparison (because the relationships of A > B > C made in previous two comparison). But some respondents may answer that C is more important than A. This logical contradiction of respondent is measured as inconsistency ratio in AHP method. In case that inconsistency ratio of pairwise comparison is zero, it means that respondent keep consistency perfectly. If inconsistency ratio is more than 0.1, it means lack of consistency, the pairwise comparison of this case must be reviewed.

In this paper, the relative importance and inconsistency ratio by pairwise comparison were analyzed using AHP software 'MakeIt'. The targets of questionnaire for pairwise comparison are the same with the marine traffic experts of chapter 3 on this paper. Total of one hundred copies of questionnaire were analyzed except the unfaithful answer (inconsistency ratio more than 0.1) sheets of twenty copies.

Table 7 is the pairwise comparison matrix that is the analysis result of the relative impotance between five risk categories in Fig. 4. Each values of matrix in Table 7 is geometric mean of one hundred respondent's answers.

Table 7. Pairwise Comparison Matrix between Risk Categories

Categories	A	B	C	D	E	Priority
A	1	0.678	0.567	1.223	1.640	0.180
B	1.475	1	0.861	1.630	2.265	0.259
C	1.764	1.162	1	1.555	2.195	0.280
D	0.818	0.614	0.643	1	1.688	0.168
E	0.610	0.441	0.456	0.592	1	0.113
Inconsistency Ratio = 0.004						

where A denotes natural conditions, B is fairway conditions, C is traffic conditions, D is Vessel conditions, and E is Assistance conditions.

The five tables from Table 8 to Table 12 are the pairwise comparison matrices that are the analysis results of the relative importance between four risk factors by each risk categories in Fig. 4. The total priorities in these tables are calculated using the priority of each risk categories in Table 7.

Table 8. Pairwise Comparison Matrix in Natural Conditions

Factors	A	B	C	D	Priority in Category	Total Priority
A	1	0.339	0.563	0.818	0.137	0.025
B	2.952	1	2.850	3.137	0.494	0.089
C	1.777	0.351	1	1.316	0.208	0.037
D	1.223	0.319	0.760	1	0.161	0.029
Inconsistency Ratio = 0.010						

where A denotes winds, B is visibility restrictions, C is waves, and D is water movements.

Table 9. Pairwise Comparison Matrix in Fairway Conditions

Factors	A	B	C	D	Priority in Category	Total Priority
A	1	1.180	0.662	0.645	0.208	0.054
B	0.848	1	0.852	0.784	0.214	0.056
C	1.510	1.173	1	1.021	0.287	0.074
D	1.550	1.275	0.980	1	0.291	0.075
Inconsistency Ratio = 0.008						

where A denotes widths, B is depths, C is complexities, and D is obstructions.

Table 10. Pairwise Comparison Matrix in Traffic Conditions

Factors	A	B	C	D	Priority in Category	Total Priority
A	1	0.768	0.650	0.647	0.185	0.052
B	1.301	1	0.730	0.704	0.221	0.062
C	1.539	1.370	1	0.840	0.283	0.079
D	1.546	1.420	1.190	1	0.311	0.087
Inconsistency Ratio = 0.002						

where A denotes fairway-use traffic flows, B is fairway-use traffic volumes, C is open-use traffic flows, and D is open-use traffic volumes.

Table 11. Pairwise Comparison Matrix in Vessel Conditions

Factors	A	B	C	D	Priority in Category	Total Priority
A	1	0.966	0.861	0.805	0.223	0.037
B	1.035	1	0.766	0.692	0.213	0.036
C	1.162	1.306	1	0.692	0.250	0.042
D	1.242	1.444	1.446	1	0.314	0.053
Inconsistency Ratio = 0.005						

where A denotes fairway-use vessel qualities,
B is fairway-use crew qualities, C is open-use vessel qualities, and D is open-use crew qualities.

Table 12. Pairwise Comparison Matrix in Assistance Conditions

Factors	A	B	C	D	Priority in Category	Total Priority
A	1	1.520	0.750	0.900	0.246	0.028
B	0.658	1	0.599	0.739	0.179	0.020
C	1.333	1.670	1	1.509	0.331	0.037
D	1.111	1.354	0.663	1	0.244	0.028
Inconsistency Ratio = 0.004						

where A denotes tug boats, B is AtoN, C is pilotage, and D is VTS.

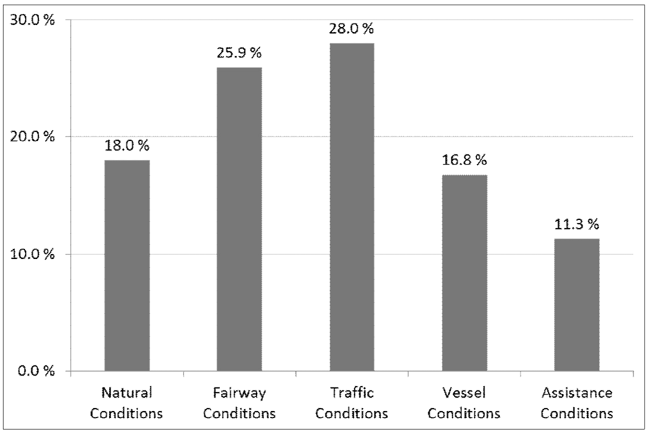

Fig. 5. Relative Importance between Risk Categories.

Fig. 5 is a bar graph that express the priority of each risk categories in Table 7 as the percentage. Fig. 5 shows that the relative importance of traffic condition is 28.0%, fairway condition is 25.9%, natural condition is 18.0%, vessel condition is 16.8%, and assistance condition is 11.3% in five risk categories to compose the risk of the domestic marine traffic environment. In other words, it is analyzed that the relative importance of fairway condition and traffic condition are higher than the average value 20.0%, and the relative importance of natural condition, vessel condition, and assistance condition are lower than the average value 20.0%.

Fig. 6 is a bar graph that express the total priority of each risk factors from Table 8 to Table 12 as the percentage. Fig. 6 shows that the relative importance of visibility restriction is the highest (8.9%) among 20 risk factors to compose the risk of the domestic marine traffic environment. Furthermore, all risk factors in fairway condition and traffic condition are higher than the average value 5.0%.

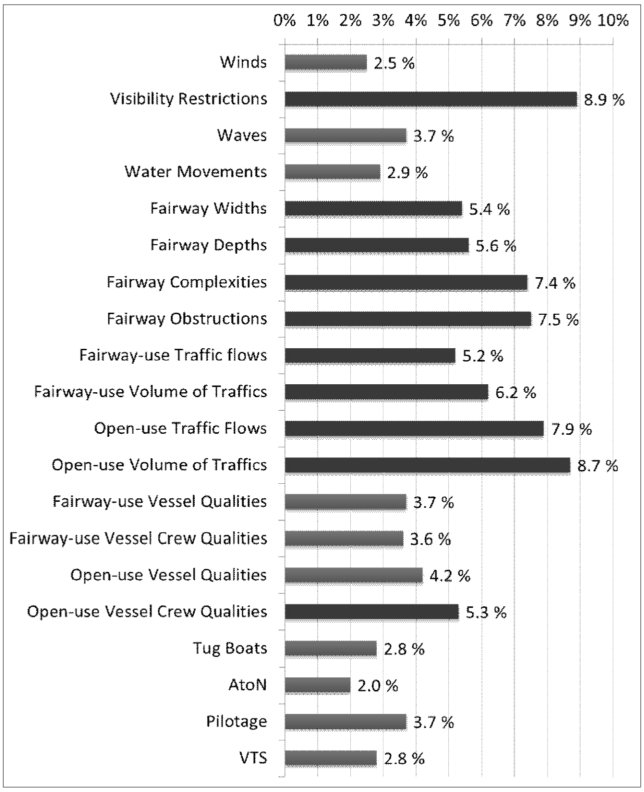

Fig. 6. Relative Importance between Risk Factors.

These analysis results of the relative importance for each risk factor are used as the weight of each risk factor, and are multiplied by the risk index of each risk factor shown in equation (3). Therefore, the total risk of the analyzing marine traffic environment is able to express as the sum of the risk index of each risk factor applying the weight on this study.

5. Conclusion

The risk was defined as the risk index that is the sum of the frequency index and the consequence index, and the five kinds of risk categories and the twenty kinds of risk factors were classified for the domestic marine traffic environment on the previous study.

The average value of the consequence index for each risk factor was calculated through the questionnaire by the marine traffic experts on this study. Also, the weight of each risk factor was analyzed through the questionnaire by the marine traffic experts using AHP method. The analysis result of the weight was that the traffic condition is the highest among the five risk categories, the visibility restriction is the highest among the twenty risk factors.

Therefore, the whole process to calculate total risk was provided for the analyzing marine traffic environment on this study.

The previous study is the basic step, and this study is the middle step for the development of risk assessment model using the qualitative evaluation by stakehoders and the quantitative data for domestic marine traffic environment.

The user-familiarized risk assessment model for the marine traffic environment using EXCEL software will be developed on the following-future study as the final output of these study process. Then, the comparative study of the risk for the marine traffic environment will be carried out on all domestic ports and waterways using this model. Also, the reliability improvement of the developing risk assessment model will be going on at the same following-future study.

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Appendices

Risk Cate-gories	Absolute Importance >		Very Strong Importance >		Strong Importance >		Moderate Importance >		Equal Importance >		Moderate Importance <		Strong Importance <		Very Strong Importance <		Absolute Importance <	Risk Cate-gories
	⑨	⑧	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	⑧	⑨	
Natural Cond.																		Fairway Cond.
Natural Cond.																		Traffic Cond.
Natural Cond.																		Vessel Cond.
Natural Cond.																		Assist. Cond.
Fairway Cond.																		Traffic Cond.
Fairway Cond.																		Vessel Cond.
Fairway Cond.																		Assist. Cond.
Traffic Cond.																		Vessel Cond.
Traffic Cond.																		Assist. Cond.
Vessel Cond.																		Assist. Cond.

Appendix 1. Pairwise Comparison between Risk Categories.

Risk Factors	Absolute Importance >		Very Strong Importance >		Strong Importance >		Moderate Importance >		Equal Importance >		Moderate Importance <		Strong Importance <		Very Strong Importance <		Absolute Importance <	Risk Factors
	⑨	⑧	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	⑧	⑨	
Winds																		Fogs
Winds																		Currents
Winds																		Waves
Fogs																		Currents
Fogs																		Waves
Currents																		Waves

Appendix 2. Pairwise Comparison between Risk Factors.

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