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Investigation of Hazard Sources of A Research Vessel Based On Fahp

Assoc. Prof. Dr. Murat Ozkok
Karadeniz Technical University, Sürmene Faculty of Marine Sciences, Camburnu Campus, 61530, Camburnu/Trabzon, Turkey

Assist. Prof. Dr. Ismail Altin
Karadeniz Technical University, Sürmene Faculty of Marine Sciences, Camburnu Campus, 61530, Camburnu/Trabzon, Turkey

Corresponding Author: *Associate Prof. Dr. Murat Ozkok*

Abstract: In recent years, the scientific researches on ocean environment have remarkably increased and the utilization of research vessels by scientists has been accordingly scaled up. Thus, the number of navigation performed by research vessels has ascended significantly and at this point, safety concept came into question. The fact that the scientists and vessel crew safely go ashore is much more important than everything. In this study, a research vessel was considered and the hazard sources were attempted to determine by utilizing Fuzzy Analytic Hierarchy Process (FAHP). The research vessel has been divided into five parts such as engine room, rudder room, bridge, accommodation, and deck. Hazard sources and their weights were determined for each section. The purpose of this study is that the scientists and crew working at research vessels notice the hazard sources and make provision against these hazards in order to prevent possible accident in research vessel.

Keywords: Research vessel, engine room, hazard sources, risk zones, FAHP.

1. Introduction

Research vessels are the types of vessels used for scientific activities. Since the number of scientific research activities has significantly increased on ocean environment in recent years, the new building research vessels are equipped with state of the art technological devices. Before going ashore, the data achieved from ocean environment are able to be evaluated and interpreted in dry and wet laboratories being available in research vessel. In this way, the quality of the scientific researches carried out on ocean environment has scaled up and accordingly the demand to the research vessels for scientific works has increased as well. The enhancement of the research vessel utilization has brought the measures to be taken to ensure safe navigation to the agenda. In literature, the works containing the evaluation of the hazard sources of a research vessel haven't been encountered. The studies performed are mostly related to the risk analysis of ship collisions and ocean environment. Hetherington, et al. [1] evaluated the human factors such as fatigue, stress, health on maritime safety. Storheim and Amdahl [2] investigated the offshore structures subjected to ship collisions. Zhang et al [3] presented a new efficient method for screening traffic data for the near ship collisions. Balmat, et al. [4] determined a fuzzy risk factor for ships consisting of static and dynamic risk factors by using ship characteristics such as age, gross tonnage, flag etc and meteorological cases as sea situation, wind speed and so on. Lois, et al. [5] proposed a formal safety assessment methodology for cruise ships by using cruise ship accidents statistics and an analysis of cruise ship characteristics. Celik, et al. [6] presented the model combining the effects of organizational faults and ship technical system breakdowns by using a fuzzy extended fault tree analysis and tested the model on a case study containing machinery breakdown and the fire on a containership. Soares and Teixeira [7] investigated the ship accident statistics and presented the causes of the accidents by ship types. Hu, et al. [8] discussed quantitative risk assessment and generic model in formal safety assessment by adding the criteria such as frequency and severity. Carrillo and Ritter [9] examined the vessel whale collisions in Canary Islands and mentioned that human safety and whales were influenced unfavorably by these strikes. Pietrzykowski and Uriasz [10] analyzed and showed how to determine the ship domain and also investigated its importance in order to prevent the collisions. Ulusçu, et al. [11] examined the safety risk and modeled the traffic situation of Istanbul Strait by using simulation and presented some proposals in order to reduce the traffic. Jin,

et al. [12] built up a probability model by utilizing the data of 13 years in order to investigate fishing vessel accidents and found that accident occurrence probability was influenced by weather conditions, vessel characteristics, locations, and time of year. Lincoln, et al. [13] described an engineering design solution for deck winch leading to injuries of Alaska commercial fishermen in order to mitigate the accidents based on deck winches.

In this study, a research vessel was taken into account and the hazard sources causing accidents were determined. Therefore, the danger levels on the research vessel zones were indicated and it was aimed to attract the attention of vessel crew in order to reduce the accidents.

2. Methodology

In this work, the research vessel was divided into five zones such as engine room (ER), rudder room (RR), bridge (B), accommodation (A) and deck (D) as can be seen from Figure 1. Engine room (ER) contains main and auxiliary engines. Main engine moves the research vessel and auxiliary engines as generator, pumps support the vessel operations. Rudder room (RR) is a section where the rudder machine is located, which ensures the vessel maneuver. Bridge (B) includes the necessary devices as navtex, sonar, rudder, compass needed for navigation. Accommodation (A) section contains crew rooms, wet and dry laboratories where the scientists study. And finally, deck (D) is a part opened to the air where the windlass, crane, chains etc are located on.

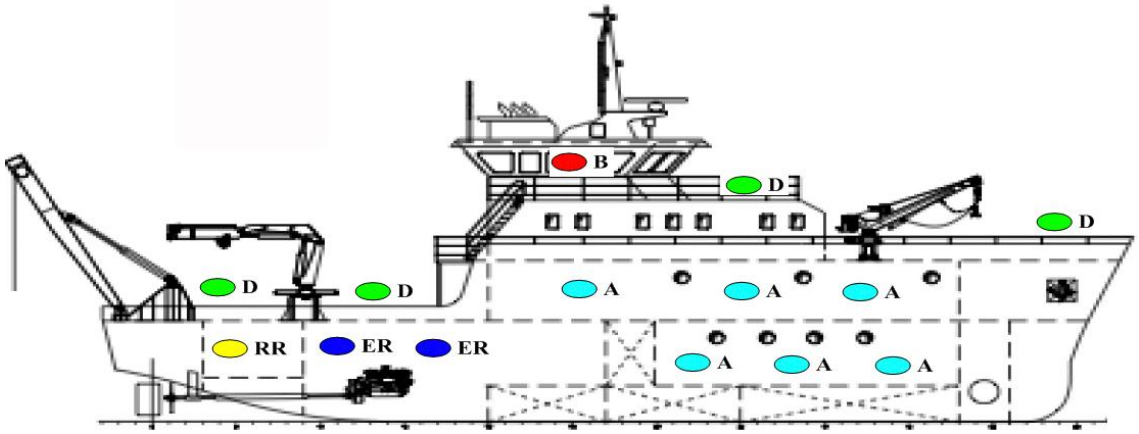

Fig. 1 Research vessel zones

In this study, Buckley's Fuzzy AHP (Buckley, [14] was utilized in order to find the risk weights of the hazard sources for research vessel. At the initial stage of the study, hazard sources in a research vessel were determined. Then, a pair wise matrix was prepared by using these hazard sources so that the experts can rate the hazards. Here, some scales were used for evaluation. The scales used by Erensal et al [15] were shown in Table 1:

Table 1 Linguistic expressions and fuzzy numbers

Linguistic expressions	Fuzzy Numbers
Row is demonstrated important	(7,9,11)
Row is very strong important	(5,7,9)
Row is strong important	(3,5,7)
Row is moderate important	(1,3,5)
Row and column are equal important	(1,1,1)
Column is moderate important	(0.200,0.333,1.000)
Column is strong important	(0.143,0.200,0.333)
Column is very strong important	(0.111,0.143,0.200)
Column is demonstrated important	(0.091,0.111,0.143)

The experts rate the hazard sources by making use of these linguistic expressions. After the completion of the evaluation job, fuzzy values of the linguistic terms were placed for each of these evaluation matrices shown in Equation 1. Then, these matrices were combined and only one matrix was obtained. At the next stage, geometric mean of the fuzzy numbers was calculated by using Equation 2 and the weights values of the fuzzy numbers were determined by utilizing Equation 3:

$$A=\begin{bmatrix} a_{11}a_{12}a_{13}a_{14}\dots a_{1n} \\ a_{21}a_{22}a_{23}a_{24}\dots a_{2n} \\ \vdots \quad \vdots \quad \vdots\vdots\vdots \quad \vdots \\ a_{n1}a_{n2}a_{n3}a_{n4}\dots a_{nn} \end{bmatrix} \tag{1}$$

$$\tilde{z}_i=\left[\prod_{j=1}^{n}\tilde{a}_{ij}\right]^{1/n} \quad i,\ j=1,2,\dots\dots,n \tag{2}$$

$$\tilde{w}_i=\tilde{z}_i\otimes(\tilde{z}_1+\tilde{z}_2+\dots+\tilde{z}_n)^{-1} \tag{3}$$

In Equation 2, means the fuzzy value of the hazard source *i* and represents the geometric mean of the hazard source *i*. Besides, shows the fuzzy weight vector.

After the calculation of geometric mean and fuzzy weight vector, defuzzification of the fuzzy numbers is performed. Here, the Best Non-Fuzzy Performance (BPN) value by Cheng et al[16] is used for defuzzification operation. Equation 4 shows defuzzification of the fuzzy weights:

$$BPN_j=\frac{[(u_i-l_i)+(m_i-l_i)]}{3}+l_i \tag{4}$$

Here, l_i is the lower boundary, m_i is the mean value and u_i is the upper boundary of the fuzzy numbers. In this way, crisp values of the hazard sources were calculated. Then, the normalization operation was performed as demonstrated in Equation 5.

$$(BPN_N)_i^c=\frac{BPN_i^c}{\sum_{i=1}^{n}BPN_i^c} \tag{5}$$

In Equation 5, $(BPN_N)_i^c$ is normalized weight of i^{th} main criterion, *n* is number of main criteria; for sub criteria the Eq 5 is used:

$$(BPN_N)_i^{sc}=\frac{BPN_i^{sc}}{\sum_{i=1}^{n}BPN_i^{sc}} \tag{6}$$

where $(BPN_N)_i^{sc}$ is normalized weight of i^{th} sub criterion, *n* is number of sub criteria.

In order to evaluate sub criteria among themselves, relative crisp weights are calculated by using Eq. 7.

$$(BPN_R)_i^{sc}=(BPN_N)^c\times(BPN_N)_i^{sc} \tag{7}$$

where $(BPN_R)_i^{sc}$ is relative crisp weight of i^{th} sub criterion, $(w_N)^c$ is normalized crisp weight of main criterion which includes that sub criterion, $(BPN_N)_i^{sc}$ is normalized crisp weight of i^{th} sub criterion.

3. Case Study

In this section of the study, hazard sources will be determined and the risk level of them will be presented. After hazard sources are found, they are converted to pair wise matrices in order for experts to evaluate them. The evaluation matrices are gathered from the experts and the linguistic terms are diverted to

fuzzy numbers. Then, one matrix is achieved by combining each of pair wise evaluation matrices. After that, geometric means of each row are taken and the results are multiplied by the inverse of the total value of the columns and fuzzy weights are calculated. Crisp values are determined by making defuzzification operation and in this way, the percentage values of the hazard sources have been found.

3.1 Hazard sources

Here, hazard sources which may cause serious accidents in research vessel were presented. Total number of 51 hazard sources was found. Table 2-6 show the sub hazard sources of the main hazards. Accordingly, engine room has 14 hazard sources leading to accidents as seen in Table 2. In the same way, the other sub hazard sources were presented in the tables from 2 to 6.

Table 2 Hazard sources based on engine room of research vessel

Hazard source	**Hazard no**
The risk of slipping descending stairs	ER1
Overtaken the clothes of staff working around the moving parts of the machine	ER2
Exposure to toxic fumes while cleaning the ballast and double bottom tanks	ER3
Hearing loss due to load noises	ER4
Not fixed of the sheets on the ground and harm to staff moving on	ER5
Risk of electric shock in the engine room	ER6
Pressing back of flue gas into engine room and consequently affected staff	ER7
Burning as a result of contact with hot part of the machine by staff	ER8
Fire in the engine room while cutting with oxygen	ER9
Falling and injury of staff walking or working	ER10
Striking the head of the working staff	ER11
Risk of explosion caused by the compressor keeping constantly to fill itself as a result of deterioration of compressor switch	ER12
Not operating of carbon dioxide tubes during the fire	ER13
Involuntary touching of the working staff to control arms and negative effects to ship propulsion	ER14

Table 3 Hazard sources based on accommodation of research vessel

Hazard source	**Hazard no**
Electric shock in accommodation	A1
Injuries due to slipping in the bathroom	A2
Forgetting the door open in rough seas and staff injuries due to being struck by the opened door	A3
Fire in the kitchen	A4
Burning of the staff as a result of contact with hot equipment in the kitchen in rough seas	A5
Falling of the staff walking down the aisle in rough seas	A6
Falling of the chemicals to the floor in the laboratory and spreading around the staff affected by the emissions	A7
Falling of the staff as a result of inadequate lighting	A8

Table 4 Hazard sources based on deck of research vessel

Hazard source	**Hazard no**
Falling overboard	D1
Injury of the staff as a result of rupture of the rope during anchorage	D2
Falling of the parts on the staff when crane is moving the part	D3
The sea and rainwater cause slip on the floor and the staff falls	D4
Hydraulic oil spills and the staff falls due to the slippery floor	D5
Breakage of the steel rope of windlass during troll towing and injury of the staff	D6
The impact of the moving parts of the crane to the staff during the crane maneuver	D7
Dropping of the staff from reagent deck	D8

Falling due to catching worker's foot on anchor chain	D9
Rope breaking during the lowering of the life boat	D10
Electric shock while the staff is working on windlass	D11
Falling due to catching worker's foot on windlass chain	D12
Being affected from emissions during the control of flue gas in reagent deck	D13
Falling while coming down the stairs from the deck	D14

Table 5 Hazard sources based on rudder room of research vessel

Hazard source	**Hazard no**
Bursting of the hydraulic circuit in rudder room and the vessel control is being influenced unfavorably	RR1
Falling of the staff while passing between stiffeners	RR2
Falling of the staff coming down the stairs to rudder room	RR3
Hitting the head of the staff to rudder room ceiling	RR4
Collision risk of the vessel due to the broken down of rudder machine	RR5
Electric shock in rudder room	RR6
Squeezing the hand while closing the hatch	RR7
Falling the hatch on staff head	RR8

Table 6 Hazard sources based on bridge of research vessel

Hazard source	**Hazard no**
Electric shock in bridge	B1
Staff affected by radiation emitted from the devices	B2
Falling of the staff in rough seas	B3
Collision risk due to the inexperienced ship captain	B4
Collision risk due to heart attack of ship captain	B5
Falling while coming down stairs from bridge	B6
Collision risk due to the broken down of the devices	B7

3.2 Creating of evaluation tables

In this section, firstly, evaluation tables were created. Afterwards, these evaluation tables were sent to 5 experts. The verbal statements of the experts were converted to fuzzy numbers which are given in Table 1. Table 7 and 8 show the Expert 1 evaluation on main hazard sources and hazard sources based on bridge, respectively. Expert 1 evaluated Engine Room as "demonstrated important" in comparison with Accommodation, as can be seen from Table 7. However, for bridge, B1 (Electric shock in bridge) hazard source was rated as "moderate important" compared with B3 (Falling of the staff in rough seas) as shown in Table 8.

Table 7 Main hazard sources' evaluation by Expert 1

	ER			A			D			RR			B		
ER	1	1	1	7	9	11	3	5	7	3	5	7	5	7	9
A	0.091	0.111	0.143	1	1	1	0.143	0.200	0.333	0.143	0.200	0.333	0.200	0.333	1
D	0.143	0.200	0.333	3	5	7	1	1	1	0.2	0.333	1	3	5	7
RR	0.143	0.200	0.333	3	5	7	1	3	5	1	1	1	3	5	7
B	0.111	0.143	0.200	1	3	5	0.143	0.200	0.333	0.143	0.200	0.333	1	1	1

Table 8 Hazard sources' evaluation of bridge by Expert 1

	B1	B2	B3	B4	B5	B6	B7
B 1	1,1,1	7,9,1 1	1,3,5	3,5,7	7,9,11	3,5,7	3,5,7
B	0.091,	1,1,1	0.111,0.143,0.	0.143,0.200,0.	0.200,0.33	0.111,0.143,0.	0.143,0.200,0.

2	0.111,0.143		200	333	3,1	200	333
B 3	0.200,0.333,1	5,7,9	1,1,1	3,5,7	7,9,11	1,3,5	0.143,0.200,0.333
B 4	0.143,0.200,0.333	3,5,7	0.143,0.200,0.333	1,1,1	3,5,7	0.200,0.333,1	1,1,1
B 5	0.091,0.111,0.143	1,3,5	0.091,0.111,0.143	0.143,0.200,0.333	1,1,1	0.111,0.143,0.200	0.143,0.200,0.333
B 6	0.143,0.200,0.333	5,7,9	0.200,0.333,1	1,3,5	5,7,9	1,1,1	1,3,5
B 7	0.143,0.200,0.333	3,5,7	3,5,7	1,1,1	3,5,7	0.200,0.333,1	1,1,1

3.3 Creating of combined tables and determination of crisp values

After being converted all assessments done by 5 experts for main and sub source of hazard to fuzzy numbers, the joined tables were created by combining the whole assessments. These combined tables were presented in Appendix Table1, Table 2, Table 3, Table 4, Table 5 and Table 6. Here, the weights of hazard sources, in other words crisp values, were determined. Table 9, 10, 11, 12, 13 and 14 demonstrate the hazard weights (crisp values) for main, engine room, accommodation, deck, rudder room, and bridge hazard sources, respectively.

Table 9 Crisp values for main hazard sources

Main hazard source	Geometric mean ($\tilde{z}_i$)	Fuzzy weight ($\tilde{w}_i$)	Defuzzification value (BPN_j)	Crisp value $(BPN_N)_i^{sc}$
ER	(2.245,3.324,4.515)	(0.220,0.457,0.927)	0.535	0.449
A	(0.280,0.366,0.528)	(0.027,0.050,0.108)	0.062	0.052
D	(1.356,2.184,3.056)	(0.133,0.300,0.628)	0.354	0.297
RR	(0.718,1.045,1.576)	(0.070,0.144,0.324)	0.179	0.150
B	(0.269,0.360,0.529)	(0.026,0.049,0.109)	0.062	0.052

Table 10 Crisp values for engine room

Hazard source	Geometric mean ($\tilde{z}_i$)	Fuzzy weight ($\tilde{w}_i$)	Defuzzification value (BPN_j)	Crisp value $(BPN_N)_i^{sc}$
ER1	(0.643,0.973,1.586)	(0.030,0.066,0.159)	0.085	0.070
ER2	(0.880,1.406,2.086)	(0.040,0.095,0.209)	0.115	0.094
ER3	(0.714,1.077,1.601)	(0.033,0.072,0.161)	0.089	0.073
ER4	(0.732,1.161,1.738)	(0.034,0.078,0.174)	0.095	0.078
ER5	(0.441,0.619,0.947)	(0.020,0.042,0.095)	0.052	0.043
ER6	(1.049,1.612,2.276)	(0.048,0.109,0.228)	0.128	0.106
ER7	(0.367,0.520,0.756)	(0.017,0.035,0.076)	0.043	0.035
ER8	(1.143,1.704,2.321)	(0.052,0.115,0.233)	0.133	0.110
ER9	(1.003,1.465,2.044)	(0.046,0.099,0.205)	0.117	0.096
ER10	(0.674,0.976,1.430)	(0.031,0.066,0.143)	0.080	0.066
ER11	(0.573,0.828,1.266)	(0.026,0.056,0.127)	0.070	0.057
ER12	(0.593,0.821,1.232)	(0.027,0.055,0.124)	0.069	0.057
ER13	(0.692,1.036,1.605)	(0.032,0.070,0.161)	0.087	0.072
ER14	(0.464,0.657,0.930)	(0.021,0.044,0.093)	0.053	0.044

Table 11 Crisp values for accommodation

Hazard source	Geometric mean ($\tilde{z}_i$)	Fuzzy weight ($\tilde{w}_i$)	Defuzzification value (BPN_j)	Crisp value $(BPN_N)_i^{sc}$
A1	(1.016,1.637,2.455)	(0.076,0.186,0.438)	0.233	0.183
A2	(0.749,1.095,1.685)	(0.056,0.124,0.300)	0.160	0.126
A3	(0.482, 0.767,1.284)	(0.036,0.087,0.229)	0.117	0.092
A4	(0.999,1.662,2.512)	(0.074,0.189,0.448)	0.237	0.187
A5	(0.884,1.472,2.193)	(0.066,0.167,0.391)	0.208	0.164
A6	(0.743,1.070,1.569)	(0.055,0.122,0.280)	0.152	0.120
A7	(0.293,0.397,0.643)	(0.022,0.045,0.115)	0.060	0.048
A8	(0.445,0.699,1.086)	(0.033,0.079,0.194)	0.102	0.080

Table 12 Crisp values for deck

Hazard source	Geometric mean ($\tilde{z}_i$)	Fuzzy weight ($\tilde{w}_i$)	Defuzzification value (BPN_j)	Crisp value $(BPN_N)_i^{sc}$
D1	(1.243,1.884,2.645)	(0.056,0.123,0.256)	0.145	0.120
D2	(0.959,1.508,2.333)	(0.043,0.099,0.226)	0.123	0.101
D3	(1.063,1.605,2.345)	(0.048,0.105,0.227)	0.127	0.105
D4	(0.716,0.981,1.344)	(0.032,0.064,0.130)	0.075	0.063
D5	(0.575,0.804,1.123)	(0.026,0.053,0.109)	0.062	0.052
D6	(0.641,0.958,1.441)	(0.029,0.063,0.140)	0.077	0.064
D7	(0.551,0.806,1.251)	(0.025,0.053,0.121)	0.066	0.055
D8	(0.819,1.161,1.694)	(0.037,0.076,0.164)	0.092	0.076
D9	(0.811,1.206,1.783)	(0.036,0.079,0.173)	0.096	0.079
D10	(0.487,0.718,1.053)	(0.022,0.047,0.102)	0.057	0.047
D11	(0.864,1.297,1.826)	(0.039,0.085,0.177)	0.100	0.083
D12	(0.886,1.261,1.860)	(0.040,0.083,0.180)	0.101	0.083
D13	(0.200,0.274,0.425)	(0.009,0.018,0.041)	0.023	0.019
D14	(0.515,0.798,1.185)	(0.023,0.052,0.115)	0.063	0.052

Table 13 Crisp values for rudder room

Hazard source	Geometric mean ($\tilde{z}_i$)	Fuzzy weight ($\tilde{w}_i$)	Defuzzification value (BPN_j)	Crisp value $(BPN_N)_i^{sc}$
R1	(1.210,1.842,2.686)	(0.098,0.211,0.442)	0.250	0.213
R2	(0.911,1.336,1.752)	(0.074,0.153,0.288)	0.172	0.146
R3	(0.544,0.716,1.024)	(0.044,0.082,0.168)	0.098	0.084
R4	(0.616,0.816,1.135)	(0.050,0.094,0.187)	0.110	0.094
R5	(1.064,1.552,2.282)	(0.086,0.178,0.375)	0.213	0.181
R6	(0.856,1.256,1.865)	(0.069,0.144,0.307)	0.173	0.147
R7	(0.446,0.567,0.745)	(0.036,0.065,0.123)	0.075	0.063
R8	(0.433,0.628,0.885)	(0.035,0.072,0.145)	0.084	0.072

Table 14 Crisp values for bridge

Hazard source	Geometric mean ($\tilde{z}_i$)	Fuzzy weight ($\tilde{w}_i$)	Defuzzification value (BPN_j)	Crisp value $(BPN_N)_i^{sc}$
B1	(0.654,0.923,1.358)	(0.060,0.114,0.228)	0.134	0.119
B2	(0.266,0.366,0.545)	(0.024,0.045,0.092)	0.054	0.048
B3	(0.700,0.990,1.388)	(0.064,0.123,0.233)	0.140	0.124

B4	(1.968,2.548,3.249)	(0.181,0.315,0.546)	0.347	0.309
B5	(1.100,1.441,1.840)	(0.101,0.178,0.309)	0.196	0.174
B6	(0.577,0.838,1.153)	(0.053,0.104,0.194)	0.117	0.104
B7	(0.685,0.971,1.353)	(0.063,0.120,0.227)	0.137	0.122

After the combined tables were created, the crisp values of sub hazard sources were identified by utilizing the method expounded in Section 3. The crisp values calculated were represented in Table 15.

Table 15 Crisp values of main and sub hazard sources

Hazard No.	ER			A			B			D			RR		
	C	RC	P	C	RC	P	C	RC	P	C	RC	P	C	RC	P
1	0.070	0.031	3.130	0.183	0.010	0.956	0.119	0.006	0.616	0.120	0.036	3.566	0.213	0.032	3.204
2	0.094	0.042	4.239	0.126	0.007	0.657	0.048	0.002	0.247	0.101	0.030	3.013	0.146	0.022	2.198
3	0.073	0.033	3.273	0.092	0.005	0.481	0.124	0.006	0.643	0.105	0.031	3.113	0.084	0.013	1.257
4	0.078	0.035	3.524	0.187	0.010	0.972	0.309	0.016	1.594	0.063	0.019	1.856	0.094	0.014	1.408
5	0.043	0.019	1.931	0.164	0.009	0.853	0.174	0.009	0.900	0.052	0.015	1.534	0.181	0.027	2.728
6	0.106	0.047	4.740	0.120	0.006	0.624	0.104	0.005	0.536	0.064	0.019	1.893	0.147	0.022	2.219
7	0.035	0.016	1.571	0.048	0.002	0.248	0.122	0.006	0.628	0.055	0.016	1.627	0.063	0.010	0.955
8	0.110	0.049	4.925	0.080	0.004	0.419	N/A	N/A	N/A	0.076	0.023	2.268	0.072	0.011	1.078
9	0.096	0.043	4.306	N/A	N/A	N/A	N/A	N/A	N/A	0.079	0.024	2.360	N/A	N/A	N/A
10	0.066	0.030	2.956	N/A	N/A	N/A	N/A	N/A	N/A	0.047	0.014	1.400	N/A	N/A	N/A
11	0.057	0.026	2.574	N/A	N/A	N/A	N/A	N/A	N/A	0.083	0.025	2.463	N/A	N/A	N/A
12	0.057	0.025	2.536	N/A	N/A	N/A	N/A	N/A	N/A	0.083	0.025	2.479	N/A	N/A	N/A
13	0.072	0.032	3.232	N/A	N/A	N/A	N/A	N/A	N/A	0.019	0.006	0.557	N/A	N/A	N/A
14	0.044	0.020	1.955	N/A	N/A	N/A	N/A	N/A	N/A	0.052	0.016	1.558	N/A	N/A	N/A

C: Crisp, RC: Relative Crisp, P: Percent (%), N/A: Not Available

4. Results and Discussions

At this stage, the results achieved from the study will be judged. Figure 2 shows the weight of the main source of danger. Accordingly, the largest part of the risk of accidents in research vessel is the engine room with 44.89%. However, the deck is the second most hazardous part of the research vessel and it has a weight of 29.69%. Other high-risk regions on research vessel are rudder room, accommodation and bridge, respectively. As can be understood from Figure 2, the bridge is the least risky region of research ship.

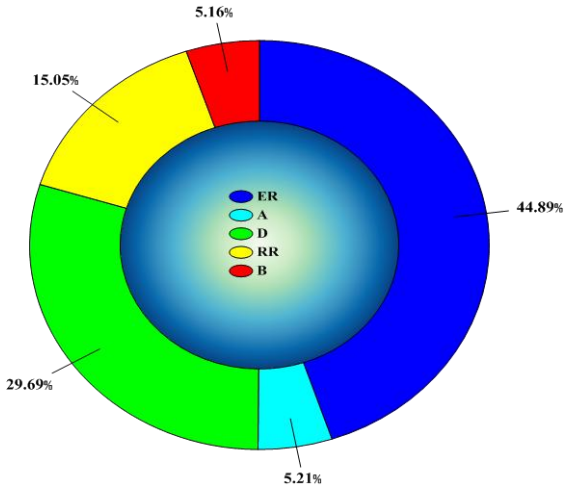

Fig. 2 Weights of main hazard sources

Figure 3 presents the hazard situation in the engine room of the research vessel. It can be concluded from Figure 3 that the most hazardous accident source is ER8 (burning as a result of contact with hot part of the machine by staff) with the weight of %10.97. The second most risky accident source is ER6 (Risk of electric shock in the engine room) with the weight of %10.56. ER2 (Overtaken the clothes of staff working around the moving parts of the machine) is the third most hazardous accident source.

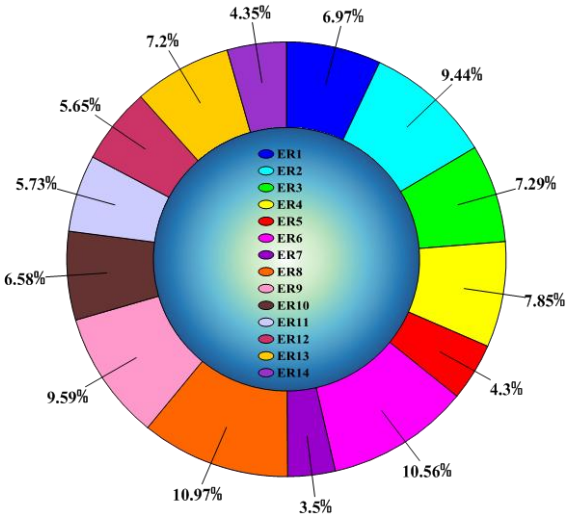

Fig. 3 Weights of engine room hazard sources

Figure 4 shows the weight of hazards in accommodation zone of the research vessel. While A4 (Fire in the kitchen) is the most dangerous accident source, A1 (Electric shock in accommodation) is the second most risky accident source.

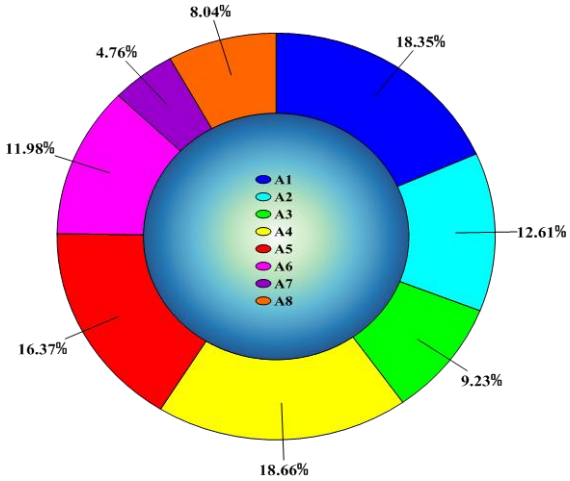

Fig. 4 Weights of accommodation hazard sources

Possible sources of danger in the deck zone of the research ship were depicted in Figure 5. The most hazardous accident source is D1 (Falling overboard) with the weight of 12.01%. Furthermore, the second and third most risky hazard sources are D3 (Falling of the parts on the staff when crane is moving the part) with the weight of 10.49% and D2 (Injury of the staff as a result of rupture of the rope during anchorage) with the weight of 10.15%.

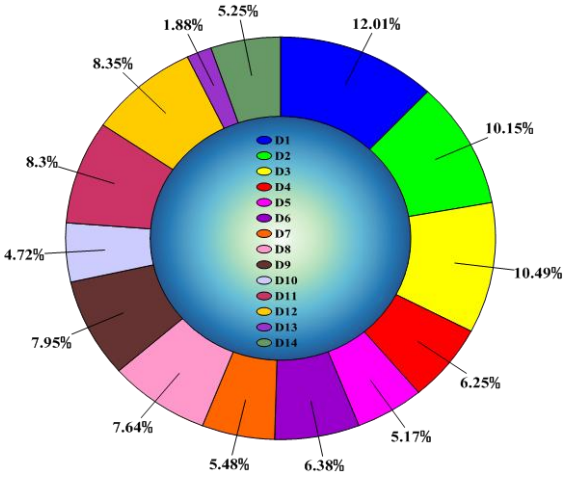

Fig. 5 Weights of deck hazard sources

Figure 6 and 7 depict the weights of the rudder room and bridge of the research vessel, respectively. As can be seen from Figure 6, the most risky hazard sources of rudder room are RR1(Bursting of the hydraulic circuit in rudder room and the vessel control is being influenced unfavorably) and RR5 (Collision risk of the vessel due to the broken down of rudder machine) Furthermore, B4(Collision risk due to the unexperienced ship captain) and B5 (Collision risk due to heart attack of ship captain) are the most hazardous accident sources for bridge region of the research vessel.

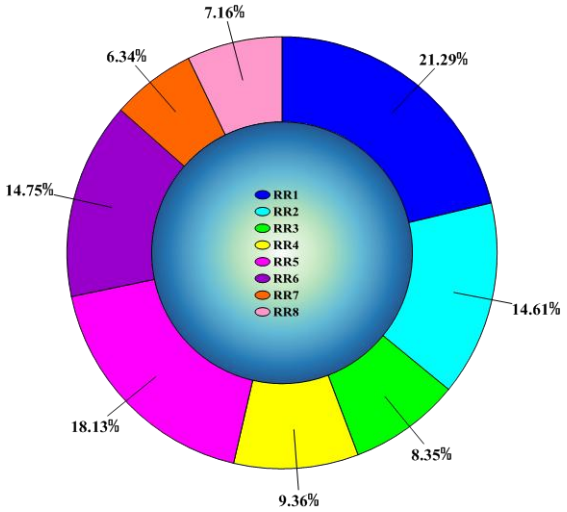

Fig. 6 Weights of rudder room hazard sources

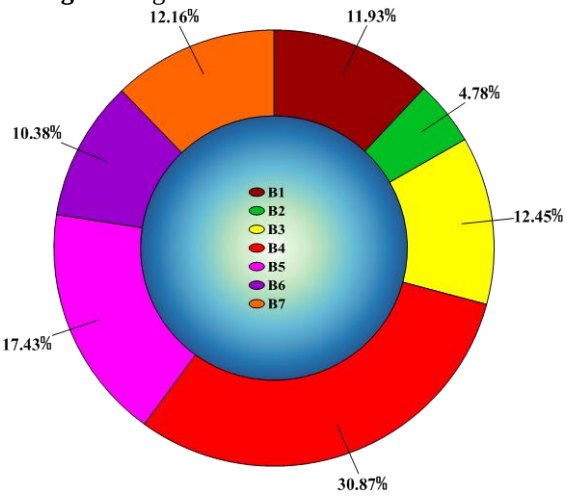

Fig. 7 Weights of bridge hazard sources

Considering all of the sub hazards that can cause accidents and evaluating among themselves, the results in Table 15 are emerging. Accordingly, when sub hazard sources are considered, the most risky hazard sources are ER8 (Burning as a result of contact with hot part of the machine by staff), ER6 (Risk of electric shock in the engine room), ER9 (Fire in the engine room while cutting with oxygen) and ER2 (Overtaken the clothes of staff working around the moving parts of the machine), respectively. Moreover, the most significant hazards based on deck are D1 (Falling overboard) and D3 (Falling of the parts on the staff when crane is moving the part). Besides, the most hazardous accident sources for rudder room are RR1 (Bursting of the hydraulic circuit in rudder room and the vessel control is being influenced unfavorably)and RR5(Collision risk of the vessel due to the broken down of rudder machine). And finally, while B4 (Collision risk due to the inexperienced ship captain) has the highest hazard weight for bridge, A4 (Fire in the kitchen) is the most dangerous one for accommodation.

5. Conclusions

In this study, it is aimed to identify the source of danger that can cause an accident on a research vessel and determine the most hazardous ones with calculation of weights of these hazard sources. Accordingly, when examining the results obtained from the study, the occurrence possibility of the accidents caused by engine room is more. So, it is concluded that engine room in a research vessel is more hazardous zone in terms of causing accidents. Furthermore, after the engine room, the most hazardous zones in terms of causing accidents are deck and rudder room, respectively. In the study, the hazard sources and their weights of these zones were given

comprehensively. It is crucial that the crew take the hazard sources presented in this study into account and they must review preventions in order to mitigate the accidents in research vessel.

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Appendix

App. Table 1. Combined evaluation table for main hazard sources

	ER			A			D			RR			B		
ER	1.000	1.000	1.000	5.524	7.610	9.654	1.016	1.692	3.214	2.290	4.584	6.697	4.435	6.871	9.026
A	0.104	0.131	0.181	1.000	1.000	1.000	0.124	0.166	0.254	0.206	0.272	0.437	0.654	1.107	2.036
D	0.311	0.591	0.984	3.936	6.015	8.057	1.000	1.000	1.000	1.070	2.408	4.243	3.500	5.809	7.921
RR	0.149	0.218	0.437	2.290	3.680	4.854	0.236	0.415	0.935	1.000	1.000	1.000	2.371	3.743	4.904
B	0.111	0.145	0.226	0.491	0.903	1.528	0.126	0.172	0.286	0.204	0.267	0.422	1.000	1.000	1.000

App. Table 2. Combined evaluation table for engine room

	ER1			ER2			ER3			ER4			ER5			ER6			ER7		
ER1	1.000	1.000	1.000	0.655	1.000	1.913	0.333	0.499	1.000	0.394	0.544	0.858	1.246	1.719	2.036	0.459	0.775	1.379	0.491	0.858	1.718
ER2	0.523	1.000	1.528	1.000	1.000	1.000	0.525	1.245	2.627	0.525	0.802	1.380	0.762	1.379	2.412	0.844	1.184	1.838	3.500	4.663	5.741
ER3	1.000	2.002	3.005	0.381	0.802	1.904	1.000	1.000	1.000	0.844	1.401	2.119	0.889	1.552	2.141	0.245	0.350	0.725	1.838	2.141	2.384
ER4	1.165	1.838	2.536	0.725	1.245	1.904	0.472	0.713	1.185	1.000	1.000	1.000	0.678	1.069	1.718	0.415	0.725	1.312	0.678	1.265	1.981
ER5	0.491	0.582	0.803	0.415	0.725	1.312	0.467	0.644	1.125	0.582	0.935	1.476	1.000	1.000	1.000	0.253	0.339	0.491	1.070	1.838	3.459
ER6	0.725	1.290	2.178	0.544	0.844	1.184	1.380	2.853	4.076	0.762	1.379	2.412	2.036	2.955	3.957	1.000	1.000	1.000	3.500	4.663	5.741
ER7	0.582	1.165	2.036	0.174	0.214	0.286	0.420	0.467	0.544	0.505	0.790	1.476	0.289	0.544	0.935	0.174	0.214	0.286	1.000	1.000	1.000
ER8	1.000	2.408	3.624	1.476	1.933	2.229	1.000	1.745	2.468	1.246	1.634	2.290	2.667	3.876	4.988	0.619	0.951	1.451	2.178	2.852	4.050
ER9	0.582	1.165	2.036	0.381	0.644	1.380	1.838	2.141	2.384	0.572	0.903	1.312	1.766	2.626	3.519	1.246	1.634	2.290	2.290	2.954	3.518
ER10	0.725	1.245	1.904	1.000	1.184	1.552	0.491	0.858	1.718	0.525	0.950	2.141	0.903	1.718	2.809	0.354	0.467	0.644	1.227	1.660	2.263
ER11	0.771	0.889	1.000	0.449	0.582	0.879	0.289	0.394	0.637	0.420	0.689	1.165	1.000	2.290	4.076	0.449	0.724	1.212	1.000	1.576	2.319
ER12	0.449	0.724	1.212	0.301	0.459	0.725	0.844	1.125	1.536	0.854	1.069	1.364	0.951	1.246	1.817	0.301	0.459	0.725	0.775	1.245	2.229
ER13	0.405	0.713	1.380	0.321	0.517	1.184	0.725	1.245	1.904	0.394	0.544	0.858	1.475	2.002	2.550	0.619	0.904	1.632	1.332	2.141	3.289

ER14	0.210	0.281	0.491	0.196	0.316	0.544	0.388	0.525	0.763	0.210	0.350	0.678	1.064	1.312	1.552	0.253	0.339	0.491	1.000	1.745	2.468

App. Table 2. Combined evaluation table for engine room (continue)

	ER8			ER9			ER10			ER11			ER12			ER13			ER14		
ER1	0.276	0.415	1.000	0.491	0.858	1.718	0.525	0.802	1.380	1.000	1.125	1.296	0.825	1.379	2.229	0.725	1.401	2.468	2.036	3.554	4.772
ER2	0.449	0.517	0.678	0.725	1.552	2.627	0.644	0.844	1.000	1.138	1.718	2.229	1.380	2.177	3.323	0.844	1.933	3.111	1.838	3.159	5.104
ER3	0.405	0.573	1.000	0.420	0.467	0.544	0.582	1.165	2.036	1.571	2.536	3.459	0.651	0.889	1.185	0.525	0.802	1.380	1.310	1.904	2.580
ER4	0.437	0.612	0.803	0.762	1.107	1.748	0.467	1.052	1.904	0.858	1.451	2.384	0.733	0.935	1.171	1.165	1.838	2.536	1.476	2.852	4.772
ER5	0.201	0.258	0.375	0.284	0.381	0.566	0.356	0.582	1.107	0.245	0.436	1.000	0.550	0.803	1.052	0.392	0.499	0.677	0.644	0.762	0.940
ER6	0.689	1.052	1.615	0.437	0.612	0.803	1.552	2.141	2.824	0.825	1.379	2.229	1.380	2.177	3.323	0.613	1.106	1.615	2.036	2.955	3.957
ER7	0.247	0.350	0.459	0.284	0.338	0.437	0.442	0.603	0.815	0.431	0.634	1.000	0.449	0.802	1.290	0.304	0.467	0.750	0.405	0.573	1.000
ER8	1.000	1.000	1.000	0.619	0.903	1.212	1.246	1.719	2.036	1.246	2.141	2.809	0.799	1.017	1.310	1.332	2.667	4.538	0.966	1.379	2.384
ER9	0.825	1.107	1.616	1.000	1.000	1.000	0.858	1.451	2.384	1.138	1.718	2.229	0.844	1.552	2.255	0.844	1.246	1.634	1.552	2.141	2.824
ER10	0.491	0.582	0.803	0.420	0.689	1.165	1.000	1.000	1.000	0.459	0.654	0.889	0.799	1.267	1.807	0.579	0.858	1.165	1.246	1.552	1.913
ER11	0.356	0.467	0.803	0.449	0.582	0.879	1.125	1.528	2.178	1.000	1.000	1.000	0.825	1.379	2.229	0.325	0.467	0.879	0.449	0.724	1.212
ER12	0.763	0.984	1.252	0.444	0.644	1.184	0.553	0.789	1.252	0.449	0.724	1.212	1.000	1.000	1.000	0.525	0.724	1.296	0.689	0.844	1.171
ER13	0.220	0.375	0.750	0.612	0.803	1.184	0.858	1.165	1.728	1.138	2.141	3.076	0.771	1.379	1.904	1.000	1.000	1.000	1.246	1.634	2.290
ER14	0.420	0.725	1.035	0.354	0.467	0.644	0.523	0.644	0.803	0.825	1.379	2.229	0.854	1.184	1.451	0.437	0.612	0.803	1.000	1.000	1.000

App. Table 3. Combined evaluation table for accommodation

	A1			A2			A3			A4			A5			A6			A7			A8		
A1	1.000	1.000	1.000	1.418	2.371	3.290	1.165	2.290	3.499	0.344	0.572	1.476	0.467	0.844	1.380	0.951	1.310	1.615	2.627	4.988	7.114	1.719	3.004	4.904
A2	0.304	0.422	0.705	1.000	1.000	1.000	0.654	1.053	2.290	0.935	1.499	2.228	0.381	0.644	1.380	0.725	0.951	1.552	1.246	2.667	3.876	1.552	1.904	2.178
A3	0.286	0.437	0.858	0.437	0.950	1.528	1.000	1.000	1.000	0.311	0.474	0.713	0.356	0.467	0.803	0.356	0.582	1.107	0.903	1.634	3.160	0.654	1.379	2.809
A4	0.678	1.745	2.908	0.449	0.667	1.070	1.401	2.108	3.214	1.000	1.000	1.000	1.000	2.002	3.005	0.803	1.380	2.290	2.853	5.078	7.164	1.016	1.692	3.214
A5	0.725	1.184	2.141	0.725	1.552	2.627	1.246	2.141	2.809	0.333	0.499	1.000	1.000	1.000	1.000	0.725	1.245	1.904	1.719	3.160	4.360	1.380	2.853	4.076
A6	0.619	0.763	1.052	0.644	1.052	1.380	0.903	1.718	2.809	0.437	0.725	1.245	0.525	0.802	1.380	1.000	1.000	1.000	1.904	2.178	2.408	0.591	0.984	2.178
A7	0.140	0.201	0.381	0.258	0.375	0.803	0.316	0.612	1.107	0.140	0.197	0.350	0.229	0.316	0.582	0.415	0.459	0.525	1.000	1.000	1.000	0.356	0.467	0.803
A8	0.204	0.333	0.582	0.459	0.525	0.644	0.356	0.724	1.528	0.311	0.591	0.984	0.245	0.350	0.725	0.459	1.016	1.692	1.316	2.141	2.809	1.000	1.000	1.000

App. Table 4. Combined evaluation table for deck

	D1			D2			D3			D4			D5			D6			D7		
D1	1.000	1.000	1.000	1.719	3.160	4.360	0.898	1.312	1.838	2.142	3.160	4.382	1.934	2.954	4.167	0.775	1.551	3.075	1.246	2.408	3.642
D2	0.229	0.316	0.582	1.000	1.000	1.000	0.523	1.000	1.528	1.634	2.668	3.700	1.380	2.068	2.776	1.070	1.933	3.075	1.125	1.718	2.824
D3	0.544	0.762	1.113	0.655	1.000	1.913	1.000	1.000	1.000	1.418	1.903	2.384	1.246	1.933	2.640	1.476	2.290	3.459	1.070	1.933	3.075
D4	0.228	0.316	0.467	0.270	0.375	0.612	0.420	0.525	0.705	1.000	1.000	1.000	1.380	1.476	1.552	0.977	1.245	1.769	1.380	2.177	3.323
D5	0.240	0.338	0.517	0.360	0.484	0.725	0.379	0.517	0.803	0.644	0.678	0.725	1.000	1.000	1.000	0.379	0.517	0.803	0.544	0.844	1.184
D6	0.325	0.644	1.290	0.325	0.517	0.935	0.289	0.437	0.678	0.566	0.802	1.024	1.246	1.933	2.640	1.000	1.000	1.000	0.678	1.016	1.436
D7	0.275	0.415	0.803	0.354	0.582	0.889	0.325	0.517	0.935	0.301	0.459	0.725	0.844	1.184	1.838	0.696	0.984	1.476	1.000	1.000	1.000
D8	0.420	0.582	0.750	0.251	0.369	0.678	0.354	0.467	0.644	0.644	0.762	0.940	0.689	0.844	1.171	0.229	0.316	0.582	1.184	2.252	3.289
D	0.	1.	1.	0.	0.	1.	0.	0.	1.	0.	1.	1.	1.	1.	2.	0.	1.	2.	0.	1.	1.

9	803	310	913	394	678	184	525	802	380	689	052	615	069	607	550	903	379	036	725	125	789
D10	0.191	0.241	0.338	0.337	0.544	0.803	0.206	0.338	0.602	0.771	1.053	1.552	0.559	0.889	1.380	0.619	1.552	2.456	0.544	0.803	1.332
D11	0.803	1.052	1.387	0.572	1.125	1.810	0.405	0.573	1.000	1.418	1.903	2.384	1.634	2.142	2.681	1.552	2.371	3.005	1.125	1.718	2.824
D12	0.644	0.903	1.458	0.430	0.700	1.107	0.525	1.000	1.904	0.662	0.950	1.699	0.914	1.184	1.699	1.246	1.634	2.290	1.246	1.552	1.913
D13	0.235	0.333	0.544	0.179	0.281	0.459	0.337	0.437	0.582	0.210	0.281	0.491	0.186	0.238	0.356	0.133	0.184	0.316	0.167	0.254	0.369
D14	0.257	0.351	0.552	0.383	0.612	0.984	0.341	0.517	0.713	0.437	0.762	1.107	0.356	0.724	1.528	0.579	0.858	1.165	0.523	1.000	1.528

App. Table 4. Combined evaluation table for deck (continue)

	D8			D9			D10			D11			D12			D13			D14		
D1	1.332	1.718	2.384	0.523	0.763	1.246	2.954	4.146	5.245	0.721	0.951	1.246	0.686	1.108	1.552	1.839	3.000	4.264	1.810	2.854	3.890
D2	1.476	2.709	3.987	0.844	1.475	2.536	1.246	1.838	2.969	0.552	0.889	1.748	0.903	1.429	2.330	2.178	3.553	5.587	1.017	1.632	2.609
D3	1.552	2.141	2.824	0.725	1.245	1.904	1.660	2.954	4.854	1.000	1.745	2.468	0.525	1.000	1.904	1.719	2.290	2.969	1.403	1.933	2.935
D4	1.064	1.312	1.552	0.619	0.951	1.451	0.644	0.950	1.296	0.420	0.525	0.705	0.589	1.052	1.511	2.036	3.554	4.772	0.903	1.312	2.290
D5	0.854	1.184	1.451	0.392	0.622	0.935	0.725	1.125	1.789	0.373	0.467	0.612	0.589	0.844	1.095	2.809	4.210	5.367	0.654	1.379	2.809
D6	1.719	3.160	4.360	0.491	0.725	1.107	0.407	0.644	1.615	0.333	0.422	0.644	0.437	0.612	0.803	3.160	5.431	7.533	0.858	1.165	1.728
D7	0.304	0.444	0.844	0.559	0.889	1.380	0.750	1.246	1.838	0.354	0.582	0.889	0.523	0.644	0.803	2.713	3.935	5.976	0.655	1.000	1.913
D8	1.000	1.000	1.000	0.491	0.858	1.718	3.743	4.904	5.976	1.332	2.141	3.289	1.000	1.838	2.954	4.146	5.245	6.284	1.332	2.035	3.700
D9	0.582	1.165	2.036	1.000	1.000	1.000	1.165	1.660	2.383	0.634	0.966	1.379	0.644	0.844	1.000	2.537	3.743	5.741	0.951	1.246	1.817
D10	0.167	0.204	0.267	0.420	0.602	0.859	1.000	1.000	1.000	0.236	0.333	0.678	0.354	0.467	0.644	3.380	5.711	7.841	1.107	1.719	2.290
D11	0.304	0.467	0.750	0.725	1.035	1.579	1.476	3.000	4.243	1.000	1.000	1.000	0.375	0.509	0.775	2.290	4.584	6.697	0.619	1.000	1.290
D12	0.338	0.544	1.000	1.000	1.184	1.552	1.552	2.141	2.824	1.290	1.966	2.667	1.000	1.000	1.000	2.178	3.553	5.587	0.914	1.475	2.344

D13	0.159	0.191	0.241	0.174	0.267	0.394	0.128	0.175	0.296	0.149	0.218	0.437	0.179	0.281	0.459	1.000	1.000	1.000	0.136	0.194	0.369
D14	0.270	0.491	0.750	0.550	0.803	1.052	0.437	0.582	0.903	0.775	1.000	1.615	0.427	0.677	1.095	2.713	5.156	7.331	1.000	1.000	1.000

App. Table 5. Combined evaluation table for rudder room

	RR1			RR2			RR3			RR4			RR5			RR6			RR7			RR8		
RR1	1.000	1.000	1.000	1.246	1.838	2.969	2.037	3.209	4.484	1.956	2.809	3.700	0.304	0.467	0.750	0.903	1.718	2.809	2.290	3.499	5.460	1.476	2.852	4.772
RR2	0.337	0.544	0.803	1.000	1.000	1.000	1.246	2.141	2.809	0.844	1.246	1.634	0.379	0.644	1.108	0.854	1.475	2.002	2.141	2.809	3.380	1.933	2.627	3.214
RR3	0.223	0.312	0.491	0.356	0.467	0.803	1.000	1.000	1.000	0.491	0.725	1.107	0.420	0.525	0.705	0.420	0.553	0.844	1.125	1.528	2.178	1.000	1.475	2.141
RR4	0.270	0.356	0.511	0.612	0.803	1.184	0.903	1.379	2.036	1.000	1.000	1.000	0.289	0.394	0.637	0.420	0.654	0.973	1.476	1.933	2.229	0.775	1.000	1.615
RR5	1.332	2.141	3.289	0.903	1.552	2.640	1.418	1.903	2.384	1.571	2.536	3.459	1.000	1.000	1.000	0.525	0.763	1.552	1.165	1.660	2.383	1.000	1.660	2.776
RR6	0.356	0.582	1.107	0.499	0.677	1.171	1.184	1.808	2.384	1.028	1.528	2.384	0.644	1.310	1.904	1.000	1.000	1.000	1.719	2.290	2.969	1.203	1.903	3.518
RR7	0.183	0.286	0.437	0.296	0.356	0.467	0.459	0.654	0.889	0.449	0.517	0.678	0.420	0.602	0.859	0.337	0.437	0.582	1.000	1.000	1.000	1.000	1.184	1.552
RR8	0.210	0.350	0.678	0.311	0.381	0.517	0.467	0.678	1.000	0.619	1.000	1.290	0.360	0.602	1.000	0.284	0.525	0.831	0.644	0.844	1.000	1.000	1.000	1.000

App. Table 6. Combined evaluation table for bridge

	B1			B2			B3			B4			B5			B6			B7		
B1	1.000	1.000	1.000	1.070	1.745	2.890	0.644	1.183	1.789	0.320	0.408	0.525	0.459	0.591	0.835	1.069	1.607	2.550	0.474	0.713	1.476
B2	0.346	0.573	0.935	1.000	1.000	1.000	0.350	0.459	0.622	0.124	0.166	0.254	0.126	0.172	0.286	0.254	0.369	0.622	0.196	0.316	0.544
B3	0.559	0.845	1.552	1.607	2.178	2.852	1.000	1.000	1.000	0.354	0.582	0.889	0.579	0.775	1.094	0.725	1.245	1.904	0.619	0.903	1.212
B4	1.904	2.450	3.122	3.936	6.015	8.057	1.125	1.718	2.824	1.000	1.000	1.000	1.719	2.036	2.290	3.005	4.209	6.284	2.627	3.214	3.737
B5	1.197	1.692	2.178	3.500	5.809	7.921	0.914	1.290	1.728	0.437	0.491	0.582	1.000	1.000	1.000	1.247	1.632	2.127	0.935	1.267	1.933
B6	0.392	0.622	0.935	1.607	2.713	3.935	0.525	0.802	1.380	0.159	0.238	0.333	0.470	0.613	0.802	1.000	1.000	1.000	0.854	1.475	2.002
B7	0.678	1.401	2.108	1.838	3.159	5.104	0.825	1.107	1.616	0.267	0.311	0.381	0.517	0.790	1.070	0.499	0.677	1.171	1.000	1.000	1.000