Quantifying the Severity of Marine Collision Accidents Caused by Human Factors

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Abstract

The severity of an accident is evaluated based on the degree of damage, the loss of human life, environmental impact, etc. Since 80% or more of marine accidents are caused by human factors, it is necessary to quantify the severity of an accident considering human factors, and it is important that the result of the quantification is made use of in accident investigation and accident prevention measures.

In this study, authors examined the severity of ship collisions with numerical value using CREAM (Cognitive Reliability and Error Analysis Method) which is a human reliability analysis method.

The main conclusions obtained by this study are as follows:

1) CPCs (Common Performance Conditions) in CREAM were modified especially for the marine field.
2) Applied modified CPSs to marine collision accident analysis.
3) In consideration of the frequency of occurrence and the importance of CPCs, authors quantified the severity of marine collision accident.
4) Comparing accidents designated as "serious" by the accident investigation standard and those designated as "serious" by means of numerical values derived from the importance of human factors, the effectiveness of quantifying the marine accident severity with numerical value was confirmed.

Keywords **:** *marine casualty, human reliability analysis, CREAM, CPCs, marine collision accident*

1. INTRODUCTION

Generally, the severity of an accident is evaluated based on the degree of damage, the loss of human life, the environmental impact, etc. Accident investigation is carried out and measures against accidents are planned depending on the accident severity.

Japan Transport Safety Board which take charge of marine accident investigation defines serious marine accidents as follows (accident investigation standard), and, as for serious accidents, the accident investigation are more detailed than non-serious accidents.

1) Cases where a passenger died or went missing, or two or more passengers were severely injured.
2) Cases where five or more persons died or went missing.
3) Cases involving a vessel engaged in international voyages where the vessel was a total loss, or a person on the vessel died or went missing.
4) Cases of spills of oil or other substances where the environment was severely damaged.
5) Cases where unprecedented damage occurred following a marine accident or incident.
6) Cases which made a significant social impact.
7) Cases where identification of the causes is expected to be significantly difficult.
8) Cases where essential lessons for the mitigation of damage are expected to be learned.

However, because 80% or more of marine accidents are caused by human factors, it is important to quantify the severity of marine collision accidents in consideration of human factors as well as the degree of accidents' seriousness, and it is effective to use the result for accident investigation and accident prevention measures.

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Therefore we examined the method to evaluate the severity of ship collisions using numerical value based on human factors using CREAM (Cognitive Reliability Error Analysis Method) [1] which is a human reliability analysis method.

2. CPCs AND HUMAN FACTORS

2.1 Overview of CREAM

In first-generation Human Reliability Analysis (HRA), human errors are regarded as processing error of information. However, in second-generation HRA, human errors are considered as the final results and it is considered that there are many background factors. Methods such as CREAM and ATHEANA [1] are examples of second generation human reliability analysis. CREAM in particular has been utilized for analyzing some marine accidents. Additionally, CREAM is characterized by the method wherein laypersons can analyze background factors. There are two techniques associated with CREAM: one involves analysis by screening and the other involves detailed analysis. Analysis by screening is used in this study. CREAM defined working conditions as Common Performance Conditions (CPCs) which are possible factors in human errors. The concept of CPCs is introduced to qualitatively analyze human behavioral environments. Nine categories of CPCs are defined.

1) Adequacy of organization
2) Working conditions
3) Adequacy of man-machine interface and operational support
4) Availability of procedures / plans
5) Number of simultaneous goals
6) Available time
7) Time of day (circadian rhythm)
8) Adequacy of training and experience
9) Crew collaboration quality

In addition, dependencies are defined between each of the CPCs. Since CREAM is utilized for general working tasks in nuclear plants, it cannot apply directly to marine accidents. For the purpose of this study, the CPCs are adapted for marine accidents to utilize CREAM, and items for assessing CPCs are extracted.

2.2 Discussion of adaptation of the CPCs to marine accidents

By assessing the cognitive processes of navigators, or the processes that influence their actions within CPCs, it is possible to improve qualitative assessment. Moreover, with the assessment items clearly expressed by the navigators, it is possible for laypersons to assess the influence of CPCs on navigators. By introducing CPCs into the analysis of marine accidents, even laypersons can identify the relevant factors in marine accidents in an automated process; thus, the analysis of marine accidents is made homogeneous. This will result in efficient, effective, and reasonable preventions of marine accidents. To adapt CPCs to marine accidents, collision accidents—which are the most frequently occurring marine accidents—are discussed in this study as objects of analysis with CPCs. Then new CPCs adapted for marine accidents are proposed.

2.3 Modified CPCs for analyses of collision accidents

New CPCs and its items modified for collision accidents [2] [3] are shown as below,

1) Adequacy of safety management
・Contents of educational training
・Systems of educational training
・Management of navigational watch
・Outside support and communication
2) Navigation conditions
・Traffic density
・Weather conditions
・Visibility
・Area in which the vessel is navigating
・Ship maneuvering characteristics
・Watch condition on the bridge
3) Adequacy of human-machine interface
・Installed navigational equipment
・Accessibility of navigational aids
4) Adequacy of navigation manuals
・Chain of command
・Criteria for avoiding-action
・Navigational conditions
・Standards, procedures, and guidance
・Unification of terminology
・Readability of manual
5) Number of simultaneous goals
・Traffic density
・Weather conditions
・Visibility
・Area in which the vessel is navigating
・Additional workload
6) Available time
・Traffic density
・Weather conditions
・Visibility
・Area in which the vessel is navigating
・Additional workload
7) Time of day
・Day or night
8) Resources of navigators
・Systems of educational training
・Knowledge of and confidence in the professional watch

・Experience of the navigator of the watch

9) Communication and information-sharing

・Communication and information sharing with the bridge team

・Communication and information sharing with other ships

・External assistant communication and information sharing

3. APPLICATION OF CPCs TO MARINE COLLISION ACCIDENTS

Human factor analyses were performed on twenty five cases of actual marine accidents (52 vessels) using CPCs with information of records of marine accident inquiry [(4)] and marine accident and incident reports [(5)]. Table 1 is an example of the CPC evaluation matrix which evaluates the degree that each CPC element influences marine collision accidents, and is divided into five categories. The number in the matrix shows the details of applicable CPC element. For example, the detail number 3.1 of "Adequacy of safety management" refers to "Labor management" and its evaluation is "very bad".

The quantification of the severity of marine collision accident in consideration of human factors is enabled when the coefficient is given in the degree of evaluation shown in table 1. In this study, the score of coefficient "Standard" is 0 points, "Good" is 1 point and "Bad" is -1 points. "Very good" is 3 points, and "Very bad" is -3 point because "Very good" and "Very bad" have big impacts to give accident outbreak. In the example, the detail number 3.1 of "Adequacy of safety management" is evaluated as "very bad", so the total sore of evaluation is "-3".

4. EVALUATION OF THE SEVERTIY OF MARINE COLLISION ACCIDENTS WITH NUMERICAL VALUE

The quantification of the severity of collision accidents considering human factors using the CPCs' matrix which is shown in table 1 is possible, but to evaluate the severity of collision accidents with numerical value realistically, it is necessary to consider the frequency of occurrence of nine categories of CPCs, and which CPCs the navigator thinks to be of more importance. For that purpose, in consideration of frequency of occurrence and importance of CPCs, the authors quantified the severity of a marine collision accident.

Table 1 A example of the CPCs evaluation matrix

CPC's	Very Good (3 point)	Good (1point)	Standard (0 point)	Bad (-1point)	Very Bad (-3point)	Total Number of occurrence	Total Score
Adequacy of safety management	-	-	-	-	3.1	1	-3
Navigation conditions	-	-	-	4.4	-	1	-1
Adequacy of human-machine interface	-	-	-	-	-	-	-
Adequacy of navigation manuals	-	-	-	-	-	-	-
Number of simultaneous goals	-	-	-	-	-	-	-
Available time	-	-	-	-	-	-	-
Time of day	-	-	-	-	-	-	-
Resources of navigators	-	-	-	-	3.4 3.6	2	-6
Communication and information-sharing	-	-	-	2.1 2.2	-	2	-2
Total Score				**-3**	**-9**	**6**	**-12**

4.1 The frequency of occurrence of CPCs in accidents

Twenty five marine collision accidents (52 vessels) shown in section 3 were analyzed using CPCs, and the total number of occurrence of each CPCs was found. And the frequency of occurrence of "Communication and the information-sharing" that was much of the number of occurrence was considered to be 10.00. The coefficient of each CPC was calculated depending on the frequency of occurrence on the basis of this coefficient. The relation of the total number of occurrence of each CPCs and the frequency of occurrence is shown Table 2.

4.2 The subjective importance of CPCs in accidents

A questionnaire about the correlation of each CPC was carried out in which twenty-eight participants evaluate the subjective importance of each CPC on marine collision accidents[(6)].

The questionnaire for officers on Watches (OOWs), including those on training ships, was administered in cooperation with the National Institute for Sea Training, Japan. A pairwise comparison questionnaire was created to clarify the priority of CPCs that were adapted to marine collision accidents. There were 36 combinations. The participants compared and answered those which are more important for prevention of collision accident. Twenty-eight copies were distributed; all copies were collected. The time period for tallying the results of the questionnaires was July 2013 through September 2013. Table 3 shows the profile of the participants. Figure 1 shows the dependencies between CPCs and table 4 shows the results of the pairwise comparison matrix for criteria and weights.

The highest ranking of the CPCs was "Resource of the officer", so it was judged that OOWs think this CPC to be the most important factor in avoiding collision accidents. To assume the weight a positive number, "-1.47" that was a value

Table 2 The relation of the total number of occurrence of each CPCs and the coefficient of the importance

CPC's	Total Number of occurrence	Frequency of occurrence
Adequacy of safety management	15	1.70
Navigation conditions	28	3.18
Adequacy of human-machine interface	8	0.91
Adequacy of navigation manuals	0	0.00
Number of simultaneous goals	31	3.52
Available time	37	4.20
Time of day	33	3.75
Resources of navigators	85	9.66
Communication and information-sharing	88	10.00
Grand Total	325	

Table 3 Characteristics of survey participants

	No (%) of respondents
Ranks	
Captain	2 (7)
Instructor	3 (11)
Chief Officer	7 (25)
1st Officer	4 (14)
2nd Officer	3 (11)
B2nd Officer	1 (3)
3rd Officer	3 (11)
B3rd Officer	2 (7)
C3rd Officer	3 (11)
Age	
60-	0 (0)
50-59	2 (7)
40-49	9 (32)
30-39	8 (29)
20-29	9 (32)
-19	0 (0)

of "Time of day" was take from the average and the coefficient of the importance of "Resource of the officer" was considered to be 10.00. The coefficient of each CPC was calculated depending on the subjective importance of CPCs on the basis of this coefficient.

4.3 Evaluation of the severity of accident with numerical value using CPCs

Table 5 shows the evaluation coefficient to quantify the severity of marine collision accidents considering the frequency of occurrence and the importance of CPCs. The evaluation coefficient was calculated adding up the frequency of occurrence and the subjective importance of CPCs.

Figure 2 shows the comparison of the evaluation coefficient which evaluates the severity of marine collision accidents in

Table 4 Pairwise comparison matrix for criteria and weights

	Adequacy of safety management	Navigation conditions	Adequacy of Human Machine Interface	Adequacy of navigation manuals	Number of simultaneous goals	Available time	Time of day	Resource of the officer	Communication and Information sharing
Adequacy of safety management	0.00	0.57	0.46	0.37	0.79	1.07	-0.37	1.07	0.79
Navigation conditions	-0.57	0.00	-0.37	-0.57	-0.09	0.18	-0.57	1.24	0.37
Adequacy of Human Machine Interface	-0.46	0.37	0.00	-0.09	0.67	0.57	-0.92	1.07	0.37
Adequacy of navigation manuals	-0.37	0.57	0.09	0.00	0.67	0.79	-0.46	0.92	0.79
Number of simultaneous goals	-0.79	0.09	-0.67	-0.67	0.00	-0.09	-0.92	0.67	0.00
Available time	-1.07	-0.18	-0.57	-0.79	0.09	0.00	-1.80	0.67	0.09
Time of day	0.37	0.57	0.92	0.46	0.92	1.80	0.00	1.24	1.07
Resource of the officer	-1.07	-1.24	-1.07	-0.92	-0.67	-0.67	-1.24	0.00	-0.57
Communication and Information sharing	-0.79	-0.37	-0.37	-0.79	0.00	-0.09	-1.07	0.57	0.00
Total Weight	-4.75	0.37	-1.57	-3.00	2.39	3.55	-7.35	7.45	2.91
Average	-0.95	0.07	-0.31	-0.60	0.48	0.71	-1.47	1.49	0.58
Positive number(+1.47)	0.52	1.54	1.16	0.87	1.95	2.18	0.00	2.96	2.05
Subjective importance	1.76	5.21	3.91	2.94	6.58	7.37	0.00	10.00	6.93

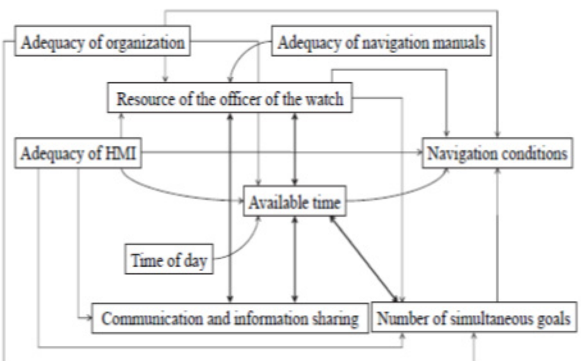

Figure 1 ependencies between CPCs

Table 5 Evaluation coefficient

CPC's	Frequency of occurrence	Subjective importance	Evaluation coefficient
Adequacy of safety management	1.70	1.76	3.46
Navigation conditions	3.18	5.21	8.39
Adequacy of human-machine interface	0.91	3.91	4.82
Adequacy of navigation manuals	0.00	2.94	2.94
Number of simultaneous goals	3.52	6.58	10.10
Available time	4.20	7.37	11.57
Time of day	3.75	0.00	3.75
Resources of navigators	9.66	10.00	19.66
Communication and information-sharing	10.00	6.93	16.93

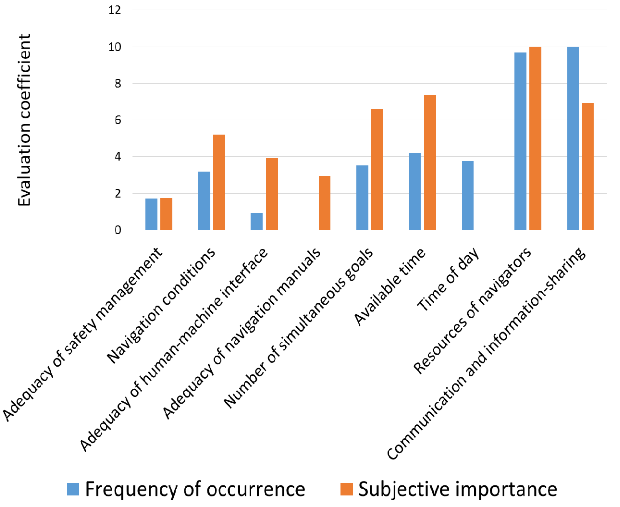

Figure 2 Comparison of the evaluation

Table 6 Sample evaluation value

CPC's	Score	Evaluation coefficient	Evaluation Value
Adequacy of safety management	-3	3.46	-10.38
Navigation conditions	-1	8.39	-8.39
Adequacy of human-machine interface	-	4.82	0.00
Adequacy of navigation manuals	-	2.94	0.00
Number of simultaneous goals	-	10.10	0.00
Available time	-	11.57	0.00
Time of day	-	3.75	0.00
Resources of navigators	-6	19.66	-117.96
Communication and information-sharing	-2	16.93	-33.86
Total	**-12**		**-170.59**

consideration of frequency of occurrence and subjective importance of CPCs.

Both evaluation coefficients of frequency of occurrence and subjective importance of "Resource of the officer" are high. On the other hand, although the evaluation coefficient of frequency of occurrence of "Communication and the information-sharing" is 10.0, the evaluation coefficient of subjective importance is 6.93. Therefore there is a gap of evaluation coefficients between the frequency of occurrence and the subjective importance of CPCs. From this result, the effectiveness of using two evaluation coefficients was confirmed.

Table 6 shows the sample evaluation values which were quantified using the evaluation coefficient shown in Table 1.

4.4 Verification of the evaluation value in consideration of the importance of the accident

Using twenty five cases (52 vessels) of actual marine accidents shown in section 3, evaluation values and orders of accidents using only CPCs and evaluation values and orders using the frequency of occurrence and the subjective importance of CPCs were calculated. Table 7 shows the calculated evaluation values, orders, and the designation of the accident (serious or non-serious) in the accident investigation report.

Table 7 Evaluation values and order

Vessel Number	Only CPC		Frequency and importance of CPCs		Serious or Non-serious
	Evaluation Value	Order	Evaluation Value	Order	
37	2	1	83.37	1	Non-Serious
40	−1	2	3.08	2	Non-Serious
33	−1	2	−6.48	3	Non-Serious
19	−2	4	−12.14	4	Non-Serious
39	−2	4	−15.32	5	Serious
15	−2	4	−25.32	6	Serious
13	−5	13	−26.9	7	Serious
46	−4	10	−34.36	8	Non-Serious
4	−3	7	−36.05	9	Serious
45	−3	7	−40.34	10	Non-Serious
18	−5	13	−48.58	11	Non-Serious
20	−3	7	−53.52	12	Non-Serious
52	−4	10	−57.27	13	
30	−5	13	−62.09	14	Non-Serious
6	−5	13	−64.74	15	Serious
22	−4	10	−65.09	16	Non-Serious
10	−7	24	−67.24	17	Serious
8	−5	13	−71.12	18	Serious
5	−7	24	−71.68	19	Serious
14	−6	21	−72.32	20	Serious
35	−5	13	−75.19	21	Non-Serious
42	−5	13	−78.84	22	Non-Serious
23	−5	13	−82.02	23	Non-Serious
3	−6	21	−85.47	24	Serious
24	−6	21	−86.88	25	Non-Serious
38	−7	24	−87.33	26	Serious
50	−7	24	−89.79	27	Non-Serious
12	−9	29	−96.13	28	Serious
1	−9	29	−106.8	29	Non-Serious
44	−9	29	−115.42	30	Non-Serious
51	−7	24	−116.25	31	
2	−11	33	−127.02	32	Non-Serious
25	−10	32	−154.6	33	Non-Serious
43	−13	39	−163.36	34	Non-Serious
7	−12	36	−166.72	35	Serious
21	−12	36	−170.59	36	Non-Serious
9	−15	42	−179.64	37	Serious
41	−11	33	−179.87	38	Non-Serious
28	−11	33	−180.07	39	Non-Serious
11	−12	36	−185.88	40	Serious
34	−13	39	−202.08	41	Non-Serious
17	−15	42	−220.42	42	Serious
29	−14	41	−222.42	43	Non-Serious
16	−17	44	−232.27	44	Serious
27	−17	44	−263.93	45	Non-Serious
36	−18	48	−267.45	46	Non-Serious
32	−17	44	−270.28	47	Non-Serious
26	−17	44	−277.11	48	Non-Serious
47	−22	50	−306.97	49	Non-Serious
48	−21	49	−319.97	50	Non-Serious
49	−27	51	−324.63	51	Non-Serious
31	−31	52	−440.19	52	Non-Serious

Based on the result of analyzing collision accidents of fifty two vessels, the order with the evaluation value of each accident was calculated. Compared with the order which was calculated by using only CPCs shown in table 1 and the frequency of occurrence and the subjective importance of CPCs, there was replacement of the order of the tenth place at the maximum. Furthermore, only one serious accident was included within the last ten places with the evaluation value using the frequency of occurrence and the subjective importance of CPCs, and only four serious accidents were included within the last twenty places. So, it was revealed that there is a clear difference between an accident designated as “serious” on the basis of the accident investigation standard, and that determined in consideration of human factors.

5. CONCLUSION

In this study, we examined a method which uses numerical values based on human factors to quantify the severity of ship collisions. In order to do this, CPCs in CREAM were modified especially for the marine field, and applied to analyze ship collisions. Consequently, the evaluation values using the frequency of occurrence and the subjective importance of CPCs were calculated and the severity of ship collisions in consideration of human factors using the evaluation values was quantified.

The main conclusions obtained by this study are as follows:

1) Human reliability analysis method, CREAM was introduced in the analysis of marine accidents.
2) To introduce CREAM, CPCs in CREAM were modified to specialize the marine field.
3) Calculated the evaluation value using the frequency of occurrence and the subjective importance of CPCs in order to quantify the severity of ship collision in consideration of human factors.
4) It was revealed that there is a clear difference between an accident designated as “serious” on the basis of the accident investigation standard, and that determined in consideration of human factors.
5) The evaluation of the severity of ship collisions by means of numerical values based on human factors was achieved.

It is important to evaluate accidents, based on damage, loss of human life, and environmental impact. From the viewpoint of accident prevention, it is effective to take measures in human factors which are the main cause of ship collisions.

This research suggests that the analytical method in consideration of human factors has to be established.

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