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A Study on the Analysis and Identification of Seafarers' Skill-Rule-Knowledge Inherent in Maritime Accidents

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Abstract : *The purpose of this study is to classify the deficient abilities of seafarers into SRK (Skill, Rule, and Knowledge) and analyze and identify the SRK by the type of accident and ship. Experimental data used the SRK cumulative frequency for 1,606 marine accident records and two-way ANOVA and t-test were used for the analysis tools. The results of two-way ANOVA showed that it is possible to identify the deficient abilities by using the cumulative frequency of SRK in both accident and ship types. As a result of the t-test, the adoption of the null hypothesis (H=0) that the mean of two pairs is equal and the rejection of the null hypothesis (H=1) were 29.2 % and 70.8 %, respectively. For the ship type, H=0 is 33.3 % and H=1 is 66.7 %. Through this study, it was found that about 70 % of the deficient abilities of seafarers inherent in maritime accidents can be identified using the proposed method.*

Key Words : *Maritime accident, Seafarer, Skill-rule-knowledge, Frequency of accidents, Two-way ANOVA, t-Test*

1. Introduction

The seafarer must have sufficient ability for smooth vessel operation. On the other hand, the lack of seafarer's ability when a marine accident occurs can be a major cause of marine accidents (Park et al., 2017). The purpose of this study is to classify the SRK (Skill, Rule and Knowledge) lacking abilities of seafarers in case of marine accidents caused by seafarers and to analyze and to identify SRK for the types of accident and ship.

The human error of a seafarer is known to be a major cause of marine accidents. And the human errors are reported to be determined by seafarer's competences, situational awareness, and behavior and so on (Chauvin et al., 2008). To prevent marine accidents, it is necessary to identify, analyze and predict the causes of human error by seafarer. However, the exact cause of human error by seafarer has not yet been confirmed, but the research is proceeding (Allianz, 2012; Allianz, 2014; Allianz, 2015).

Previously, human error was mainly classified as SLMV (Slip, Lapses, Mistakes, Violation), but there was a limitation in measuring and analyzing human error for the behavior of seafarer in actual ship (Yim et al., 2014). Endsley proposed the situation awareness frames (Endsley, 1995), which is a conceptual representation of the process of thinking, but does not show the behavioral consequences of causing an accident. Rasmussen also proposed a Skill-, Rule- and Knowledge-Based Behavior (SRK-BB) (Rasmussen, 1983). SRK-BB is intended to classify the behavior of a given event into S, R, and K, and is widely applied as a classification method for actual field applications. However, there is still a lot of research on the relation between SBB and accident that will be shown by the result of action (Rasmussen and Vicente, 1989).

The purpose of this study is to classify the deficient abilities of seafarers into SRK and identify the SRK by the type of accident and ship.

The data used in the experiment were obtained from marine accident reports of the Korea Maritime Safety Tribunal (KMST). KMST's marine accident data describes the causes and consequences of marine accidents and the detailed circumstances at that time. These data are provided to the general public as the form of a written verdict and summarized written verdicts (KMST, 2016; KMST, 2017). The written verdicts (2005 ~ 2014) were collected, and 1,606 accident records suitable for this study were extracted and applied to the study. For the 1,606 accidents, the cumulative frequency of occurrence of SRK for each type of accident and type of ship was calculated and applied as experimental data.

Analysis tools were a mixture of F-test and t-test using two-way ANOVA (Analysis of Variance). Experimental results show that using the cumulative frequency of SRK can identify about 70 % of seafarer's abilities reflected in marine accidents.

This paper is organized as follows. Section 2 explains the study approach procedure, and describes the data collection and classification method. Section 3 represents the ANOVA and t-test results for SRK distribution. Section 4 summarizes the study results.

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2. Method

2.1 Approaching Procedures

Figure 1 shows the research approach procedure. In Step 1, collect the marine accident data and classify into corresponding categories. Step 2 examines how to apply the classified data to ANOVA and t-test. Step 3 represents the analyzed cumulative frequency of accident types and ship types. In step 4, the significance of the F-value and the t-value was examined.

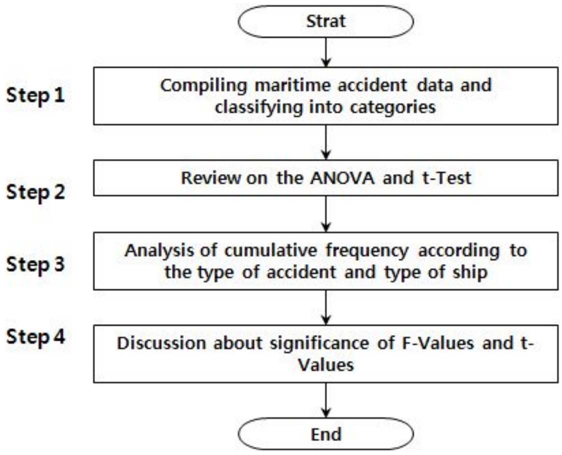


Fig. 1. Study approaching procedures.

Table 1. The number of summarized written verdicts (A) and the number of recorded case for marine accidents (B)

Year	A	B
2005	217	212
2006	189	183
2007	173	169
2008	130	128
2009	166	162
2010	190	186
2011	120	114
2012	164	160
2013	134	132
2014	166	160
Total	1,649	1,606

2.2 Experimental Data Collection and Classification

Experimental data used a total of 1,606 accident records which are extracted from the summarized written verdicts (2005～2014). Table 1 shows the number of compiled data.

Since the accident record as shown in Table 1 is written in a sentence, all the contents corresponding to the sentence must be converted into numbers for statistical analysis. The following procedure was adopted to construct quantified data consisting of numbers.

At first, the classification methods were examined before converting to numbers. The three variables (Skill, Rule, Knowledge) used as classification parameters, and its definitions are as follows.

- Knowledge (K): In case of accidents caused by lack of knowledge among seafarer's ability, they are classified as K.
- Rule (R): Classified as R in the case of accidents caused by non-compliance with the rules or not following prescribed procedures.
- Skill (S): In case of accidents caused by lack of experience among seafarer's abilities, they are classified as S.

Next, conditions for data acquisition were examined. The conditions for constructing the quantified data are as follows.

- One accident can be caused by more than one ship. In this study, limitation was limited to two and they are called vessels A and B.
- There can be multiple causes for an accident. In this study, SRK is classified as one major cause of accidents per ship. Classification methods were subject to the researcher's supervision.

The quantification data was constructed through the following four steps.

Step 1. Classification of accident records

In Step 1, classify the accident data into the following types of character data by applying the above conditions.

〈 {Data number}; {Year}; {Accident type}; {Ship type (A)}; {Ship type (B)}; {Cause (A)}; {Cause (B)} 〉,

where { } denotes a set of data having a letter or number, and 〈 〉 denotes a set of data.

Step 2. Transferring into the numerical data

In Step 2, the character data of Step 1 was converted into numbers by using variables and indexes of Tables 2. The form of quantified data is as follows (Kaplan and Garrick, 1981; Sancaktar, 1982).

$$\langle Yr_i, Ac_i, Sh_i^A, Sh_i^B, SRK_i^A, SRK_i^B \rangle,$$

where Yr_i, Ac_i, Sh_i^A, Sh_i^B, SRK_i^A and SRK_i^B indicate the year, accident type, type of ship A, type of ship B, SRK for ship A, and SRK for ship B, respectively, recorded in the accident record data of $i\,(i=1,\cdots,I)$.

An example of SRK classification is as follows. The following character data are assumed.

< {data number, 1}; {Year, 2006}; {Accident Type, collision}; {Ship type (A), merchant}; {Ship type (B), fishing}; {Cause (A), inadequate watch-keeping}; {Cause (B), rule violation} >

The quantification results using Table 2 are as follows.

$\langle\ Yr_1=2, Ac_1=1, Sh_1^A=1, Sh_1^B=5, SRK_1^A=1, SRK_1^B=2\ \rangle$

Since Cause (A) (inadequate watch-keeping) and Cause (B) (rule violation) corresponds to Knowledge and Rule, SRK_1^A and SRK_1^B are corresponds to 3 and 2 in Table 2, respectively.

Step 3. Calculation of unit data having 1 or 0

In Step 3, the quantified data constructed in Step 2 is constructed by using the following Eq. (1) to obtain data I having a number 1 or 0.

$$I_{i,j,k,m,n}=1 \ \text{if} \begin{cases} j=Yr_i \\ k=Ac_i \\ m=Sh_i^A \text{ or } Sh_i^B \\ n=SRK_i^A \text{ or } SRK_i^B \end{cases} \quad (1)$$

$$I_{i,j,k,m,n}=0 \ \text{if} \ \ others$$

Table 2. List of variables and indices to construct numerical data

Variables Index	Yr j	Ac k	Sh m	$cSRK$ n
1	2005	Collision	Merchant	Knowledge
2	2006	Contacts	Passenger	Rule
3	2007	Grounding	Special purpose	Skill
4	2008	Capsizing	Towing	-
5	2009	Fire/Explosion	Fishing	-
6	2010	Sinking	Others	-
7	2011	Machinery Failure	-	-
8	2012	Causalities	-	-
9	2013	-	-	-
10	2014	-	-	-

Step 4. Construction of cumulative frequency data

In Step 4, two types of cumulative frequency data were constructed using the data as shown in Step 3. The cumulative frequency of SRK for each type of accident is calculated by the following Eq. (2), and the cumulative frequency of SRK for each type of vessel is calculated by the following Eq. (3).

$$CFA_{j,k,n}=\sum_{i=1}^{I} I_{i,j,k,n}^{A}+\sum_{i=1}^{I} I_{i,j,k,n}^{B} \quad (2)$$

where I^A and I^B represent I data for vessel A and vessel B, respectively.

$$CFS_{j,m,n}=\sum_{i=1}^{I} I_{i,j,m,n}^{A}+\sum_{i=1}^{I} I_{i,j,m,n}^{B} \quad (3)$$

2.3 Two-Way Analysis of Variance

Two-way ANOVA (Analysis of Variance) and t-test were used for SRK distribution analysis. The target of two-way ANOVA is to find out weather data from several groups have a common mean. The two-way ANOVA form of the model can be expressed as Eq. (4) (MATLAB, 2008).

$$y_{a,b,c}=\mu+\alpha_b+\beta_a+\gamma_{a,b}+\varepsilon_{a,b,c} \quad (4)$$

where, with respect to the two equations Eq. (2) and Eq. (3), $y_{a,b,c}$ is the results of Eq. (2) or Eq. (3) with the raw index a (k in Eq. (2) or m in Eq. (3)), the column index b (n in the two equations) and repetition index c (J in the two equations). μ is a constant matrix of the overall mean Eq. (2) or Eq. (3). α_b is a matrix whose columns are the deviation of each cumulative frequency that are attributable to the SRK. β_a is a matrix whose rows are the deviations of each cumulative frequency that are attributable to the k in Eq. (2) or m in Eq. (3). $\gamma_{a,b}$ is a matrix of interaction between a and b. $\varepsilon_{a,b,c}$ is a matrix of random distribution.

On the other hand, since the two-way ANOVA is an analysis using the variance among multiple group data, post-hoc comparison analysis is required for analysis within the group. Post-hoc comparisons were performed using t-test.

3. Experimental Result and Discussion

3.1 Distribution Analysis to the Type of Accident

First of all, the sum of the cumulative frequency was examined before two-way ANOVA. Table 3 summarizes the sum of the cumulative frequency of SRK by accident type for the 10 years (2005~2014) calculated using the following Eq. (5).

$$SFA_{k,n}=\sum_{j=1}^{J} CFA_{j,k,n} \quad (5)$$

In Table 3, the sum of the cumulative frequencies is 38.8 % for Knowledge, 43.9 % for Rule, and 17.2 % for Skill.

The statistical significance of cumulative frequency was assessed by two-way ANOVA of factors of accident type and SRK. Table 4 shows the analysis results using $CFA_{j,k,n}$.

Significant main effects of accident type [$F(7,216) = 215.15$, $p < 0.01$], SRK [$F(2,216) = 42.41$, $p < 0.01$] and interaction [$F(14,216) = 37.67$, $p < 0.01$] were observed. The p-Value for all of factors is less than $p < 0.01$. This is a strong indication that the cumulative frequency varies from one SRK to another and one accident type to another. And there was strong interaction between the two factors. This means that there is a strong interconnection between SRKs by type of accident.

Table 3. The sum of the cumulative frequency during ten years by the type of accident for each SRK

Accident type	Knowledge (K)	Rule (R)	Skill (S)
Ac1	467	602	118
Ac2	45	14	17
Ac3	82	45	15
Ac4	53	11	29
Ac5	59	13	77
Ac6	47	23	37
Ac7	4	46	38
Ac8	1	101	3
Sum (percentile)	758 (38.8%)	855 (43.9%)	334 (17.2%)
Total		1,947	

Ac1, collision; Ac2, contacts; A3, grounding; Ac4, capsizing, Ac5, fire/explosion; Ac6, sinking; Ac7, machinery failure; Ac8, causalities.

Table 4. The two-way ANOVA of the frequency count of SRK by the type of accident

Source	SS	df	MS	F	p-Value
SRK	1919.28	2	959.64	42.42	<0.01**
Accident type	34070.86	7	4867.27	215.15	<0.01**
Interaction	11929.33	14	852.09	37.67	<0.01**
Error	4886.5	216	22.62		
Total	52805.96	239			

SS, sum of squares; df, degree of freedom, MS, mean squares; F, F-statistic.
**p < 0.01.

Table 5 shows the results of post hoc comparison using a paired t-Test of the hypothesis H that two paired samples come from distributions with equal means. H=0 indicates that the null hypothesis can not be rejected at the 5 % ($p = 0.05$) significance level and H=1 indicates that the null hypothesis can be rejected at the 5 % level.

The results in Table 5 illustrated in Fig. 2, in which x-axis indicates the competence categories of SRK of different accident type and y-axis indicates the cumulative frequency count of SRK.

In Table 5, among the total 24 SRK pairs, there are 17 pairs of H=1, representing 70.8 % and H=0 of 7 pairs, representing 29.2 %. Therefore, it can be seen that the distribution of SRK also shows a significant difference in the group.

For example, in the case of Acc3 (grounding), all three pairs show H=1. That is, SRK for Acc3 indicates that Acc3 can be represented with significant difference. In the case of Acc1 (collision), which has the greatest number of accidents, the relationship between K and R can not be represented because the K-R pair is H=0, and the other two pairs can be represented. This feature is shown in Fig. 3 which is illustrates the separation of Fig. 2 by type of accident.

Table 5. The post hoc comparison of the frequency count of SRK by the type of accident

	SRK	Mean	Variance	SRK Pair	H	t-Test	p-Values
Acc1	K	46.7	104.23	K-R	0	-2.12	0.06
	R	60.2	283.07	R-S	1	9.37	<0.01**
	S	11.8	43.07	S-K	1	-13.4	<0.01**
Acc2	K	4.5	5.17	K-R	1	4.29	<0.01**
	R	1.4	0.71	R-S	0	-0.63	0.54
	S	1.7	1.34	S-K	1	-2.83	<0.05*
Acc3	K	8.2	9.96	K-R	1	4.53	<0.01**
	R	4.5	2.72	R-S	1	5.03	<0.01**
	S	1.5	1.17	S-K	1	-6.62	<0.01**
Acc4	K	5.3	5.34	K-R	1	6.68	<0.01**
	R	1.1	1.21	R-S	0	-2.11	0.06
	S	2.9	6.10	S-K	1	-3.27	<0.01**
Acc5	K	5.9	6.32	K-R	1	5.81	<0.01**
	R	1.3	0.46	R-S	1	-5.05	<0.01**
	S	7.7	15.57	S-K	0	0.93	0.38
Acc6	K	4.7	7.57	K-R	1	2.71	<0.05*
	R	2.3	3.12	R-S	1	-2.41	<0.05*
	S	3.7	4.46	S-K	0	-1.07	0.31
Acc7	K	0.4	0.49	K-R	1	-3.95	<0.01**
	R	4.6	12.71	R-S	0	0.73	0.48
	S	3.8	5.29	S-K	1	5.49	<0.01**
Acc8	K	0.1	0.10	K-R	1	-6.67	<0.01**
	R	10.1	22.32	R-S	1	7.14	<0.01**
	S	0.3	0.46	S-K	0	0.80	0.44

*p < 0.05, **p < 0.01.

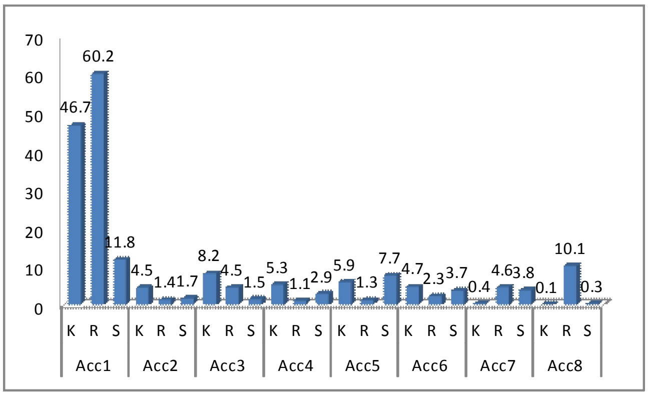
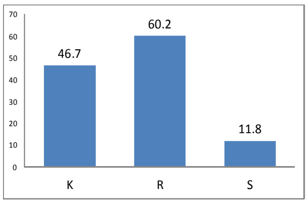
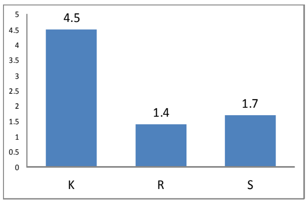


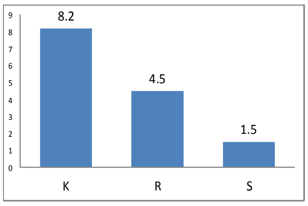
Fig. 2. The illustration of frequency count of SRK classification by the type of accident.



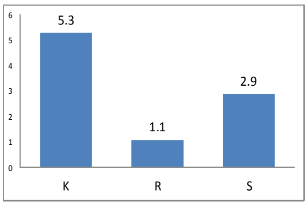
(a) Collision (Acc1)



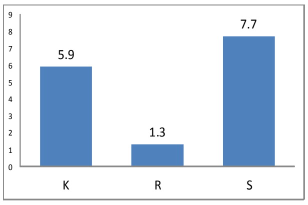
(b) Contact (Acc2)



(c) Grounding (Acc3)

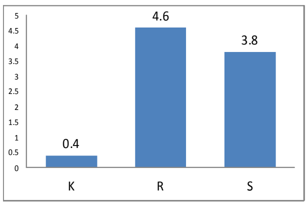


(d) Capsizing (Acc4)

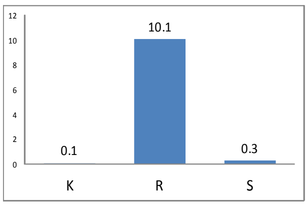


(e) Fire/Explosion (Acc5)

(f) Sinking (Acc6)



(g) Machinery failure (Acc7)



(h) Casualties (Acc8)

Fig. 3. Separated illustration of frequency count of SRK classification according to each type of accident.

3.2 Distribution Analysis to the Type of Ship

The sum of the cumulative frequency was examined before ANOVA. Table 6 summarizes the sum of the cumulative frequency of SRK by vessel type for the 10 years (2005~2014) calculated using the following Eq. (6).

$$SFS_{m,n} = \sum_{j=1}^{J} CFS_{j,m,n} \tag{6}$$

In Table 6, the sum of the cumulative frequencies is 39.2 % for Knowledge, 45.4 % for Rule, and 15.5 % for Skill. The results are similar to those of Knowledge 38.8 %, Rule 43.9 % and Skill 17.2 % as shown in Table 3. That is, the SRK distribution is included in the marine accident with a similar distribution regardless of the type of accident or type of ship.

Table 6. Summarized the sum of the cumulative frequency from 2005 to 2014 by the type of ship for each SRK

Ship type	Knowledge (K)	Rule (R)	Skill (S)
Sh1	182	233	57
Sh2	30	40	19
Sh3	78	118	24
Sh4	164	133	65
Sh5	516	611	221
Sh6	72	72	26
Sum (percentile)	1,042(39.2%)	1,207(45.4%)	412(15.5%)
Total		2,661	

Sh1, merchant; Sh2, passenger; Sh3, special purpose; Sh4, towing; Sh5, fishery; Sh6, others.

The statistical significance of frequency was assessed by two-way ANOVA of factors of ship type and SRK. Table 7 shows the analysis results using $CFS_{j,m,n}$.

Significant main effects of ship type [$F(5, 162) = 221.13$, $p < 0.01$], SRK [$F(2, 162) = 90.44$, $p < 0.01$] and interaction [$F(10, 162) = 15.92$, $p < 0.01$] were observed. The p-Value for all of the sources is less than $p < 0.01$. This is a strong indication that the cumulative frequency varies from one SRK to another, one ship type to another. And, there is a strong interaction between two factors, which means that SRK distribution is related to the type of ship. In other words, SRK is not independent by type of ship, but has a strong linkage with each other.

Table 8 shows the results of post hoc comparison using a paired t-Test of the hypothesis that two paired samples come from distributions with equal means. The results in Table 8 illustrated in Fig. 4.

In Table 8, out of the total 18 SRK pairs, there are 12 pairs of H=1, representing 66.7 %, and H=0 is 6, representing 33.3 %. Therefore, it can be seen that the distribution of SRK also shows a significant difference in the group. For example in the case of Sh5 (Fishery ship), the relationship between K and R can not be represented because the K-R pair is H=0, and the other two pairs can be represented. This feature is shown in Fig. 5 which is shows the separation of Fig. 4 by type of accident.

Table 7. The two-way ANOVA of the frequency count of SRK by the type of ship

Source	SS	d f	MS	F	p-Value
C-SRK	5867.50	2	2933.75	90.44	<0.01**
Ship type	35866.65	5	7173.33	221.13	<0.01**
Interaction	5165.30	10	516.53	15.92	<0.01**
Error	5255.10	162	32.44		
Total	52154.55	179			

**p < 0.01.

Table 8. The post hoc comparison of the frequency count of SRK by the type of ship

	SRK	Mean	Variance	SRK Pair	H	t-Test	p-values
Sh1	K	18.2	15.96	K-R	0	-1.60	0.14
	R	23.3	79.34	R-S	1	5.81	<0.01**
	S	5.7	3.34	S-K	1	-13.38	<0.01**
Sh2	K	3.0	3.11	K-R	0	-1.73	0.12
	R	4.0	4.22	R-S	1	2.79	<0.05*
	S	1.9	4.10	S-K	0	-2.01	0.08
Sh3	K	7.8	13.96	K-R	1	-3.35	<0.01**
	R	11.8	17.07	R-S	1	6.83	<0.01**
	S	2.4	5.38	S-K	1	-4.12	<0.01**
Sh4	K	16.4	20.04	K-R	0	1.67	0.13
	R	13.3	26.01	R-S	1	4.41	<0.01**
	S	6.5	10.94	S-K	1	-5.45	<0.01**
Sh5	K	51.6	109.16	K-R	0	-1.78	0.11
	R	61.1	157.21	R-S	1	9.41	<0.01**
	S	22.1	91.43	S-K	1	-9.15	<0.01**
Sh6	K	7.2	6.844	K-R	0	0	1.00
	R	7.2	13.07	R-S	1	4.36	<0.01**
	S	2.6	2.71	S-K	1	-4.87	<0.01**

*p < 0.05.
**p < 0.01.

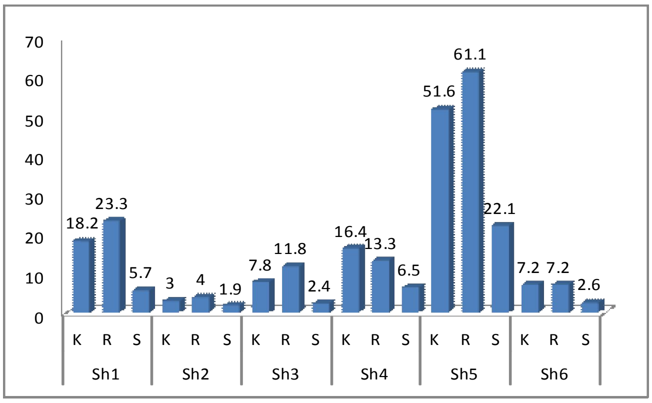
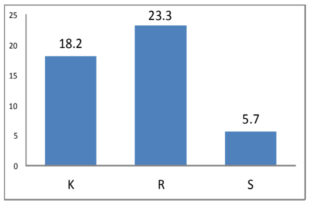
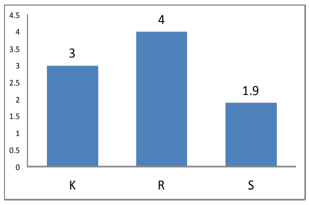


Fig. 4. The illustration of frequency count of SRK classification by the type of ship.



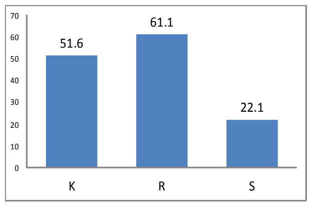
(a) Merchant ship (Sh1)



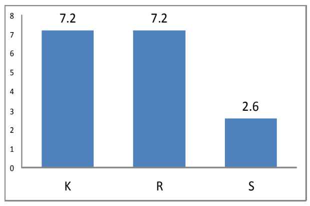
(b) Passenger ship (Sh2)

(c) Specialized ship (Sh3)

(d) Towing/towed (Sh4)



(e) Fishery ship (Sh5)



(f) Others (Sh6)

Fig. 5. Separated illustration of frequency count of SRK classification according to each type of ship.

4. Conclusions

In this study, seafarer's ability to cause marine accidents was classified as SRK (Skill, Rule, Knowledge). The analysis data used the cumulative frequency of SRK classified by types of accident and ship. Analysis tools were two-way ANOVA and t-test. The results of analyzing SRK cumulative frequency for 8 types of accidents and 6 types of vessels are as follows.

First, two-way ANOVA results showed that the cumulative frequency of SRK at the significance level of at least 5 % ($p = 0.05$) in both accident type and vessel type can identify the SRK of seafarer.

Second, strong interaction between SRK and types of accident and ship showed that SRK affects each other.

Third, as a result of the t-test of accident types classified into 24 SRK pairs, 29.2 % of the pairs adopting the null hypothesis that the mean of the two groups were the same, and 70.8 % of the pairs rejected.

Fourth, as a result of t-test of ship types classified by 18 SRK pairs, 33.3 % of the pairs adopting the null hypothesis and 66.7 % of the pairs rejected.

Overall, the validity of the identification of seafarer's ability using the cumulative frequency of SRK is about 70 %. And that it is necessary to develop a method that can maximize the accuracy of identification in the future.

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