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Marine Accident Analysis by Using Pairwise Comparison

Yunus Emre ŞENOL[1] , Bekir ŞAHİN[1,2], Serdar KUM[1]

[1] Istanbul Technical University, Department of Maritime Transportation Management Engineering
[2] Karadeniz Technical University, Department of Maritime Transportation Management Engineering

HIGHLIGHTS

- The estimation of fraction defectives is a complete judgemental process and subject to bias based on the limitations of human judgment and cognitive interpretations.
- We aim to make recommendations for court experts rating the defects of each vessel's actions.
- Empirical results indicated that fraction defectives can be manipulated by the limitations of human judgment and cognitive bias.

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Contact:
Yunus Emre ŞENOL
senolyunusemre@gmail.com
Bekir ŞAHİN
bsahin@itu.edu.tr
Serdar KUM
kumse@itu.edu.tr
Tel: +90 (538) 460 43 00

ABSTRACT

This paper investigates the process of marine accident analysis for the official interpretation to define the rate of defects of vessels in the intended case and proposes the pairwise comparison approach which is frequently used in AHP method. The assessment of marine accidents is a complicated and sophisticated problem which needs a professional and fair judgment based on the existing evidences and navigational specs. However, human judgment is limited and it is usually problematic to evaluate several aspects of a case. The pairwise comparison method is first suggested to simplify decision making process for ranking or selecting an item among the alternatives and it is an essential part of analytic hierarchy process. By utilizing the pairwise comparison, the defect rate of a snapshot of marine accident is calculated in a stepwise approach.

1. Introduction

The analysis of marine accidents is a sophisticated process to elicit the role of parties involved in the related incident. On the other hand, marine accident analysis is usually a subjective assessment since the interpretation of rules and regulations may have contrasting outcomes. Therefore, it is thought to be complicated progress to ensure justice. In the conventional approach, marine accidents are investigated to assign proper fraction defectives for both parties (i.e. ships). The estimation of fraction defectives is a complete judgemental process and subject to bias based on the limitations of human judgment and cognitive interpretations. The motivation behind this paper is to develop an alternative process to improve objective decision making in marine accident analysis. For the intended purpose, a structured decision making method, analytic hierarchy process (AHP), is preferred based on its superiority derived from the decomposition of the problem, organising complexity, compromising expert consultation.

We aim to make recommendations for court experts rating the defects of each vessel's actions. The purpose of this study is to help experts rating in a judicious approach to prevent unfair ratings for similar accidents occurring in the future. We analyse a simulated marine accident with the contributory causes, conditions and circumstances. The particulars of the imaginary vessels are given below:

Table 1 *Vessels details*

Particulars	Alpha(A)	Bravo(B)
Flag	Turkey	UK
Type	Multi-purpose Cargo	General Cargo
Built	1980	1978
Length Overall	193 m	79m
Gross Tonnage	21350gt	1776
Service Speed	18 knots	14.4 knots

Turkish registered multi-purpose cargo vessel Alpha collided with general cargo vessel Bravo in the vicinity of the Mediterranean Sea. Both vessels suffered major structural damage; however, there were no injuries or pollution and each vessel managed to proceed into port without assistance.

Recorded conditions on the day of the accident were:

- Sunrise – 0457
- Height of tide at the time of the accident – 1.1m
- Visibility – 40-50 m. restricted, foggy
- Wind – west-south-west 4-6 knots

Major indicative rules are gathered from pre-surveys which are completed by the court experts. The investigations are based on the COLREG (International Regulations For Preventing Collusions at Sea, 1972).

The investigation shows several factors contributed to the accident:

For Alpha:

A lack of maintenance of a proper look-out(Rule-5)

Lack of minimising the speed for circumstances and conditions of restricted visibility.(Rule 19/b-c)

Lack of an alteration of course to starboard rather than to port.(Rule 14)

Sub-standard VHF communications, sound signals (Rule-35)

For Bravo:

Lack of handling and conducting the manoeuvres on time to avoid the collusion risks. (Rule 8/b-c)

Lack of minimising the speed for circumstances and conditions of restricted visibility. (19/b-c)

Sub-standard VHF communications, sound signals (Rule 35)

Extenuating circumstances:

Intense fog and both radars of the vessels are on.

1.1. Accident Example:

Table 2 *Time and Actions for M/V Alpha and M/V Bravo*

Time	M/V Alpha	M/V Bravo
10.00	Navigates at 285°, 10 knots speed.	Navigates at 70° 12 knots speed, monitors the M/V A on the radar.
10.01	No alteration of the course	Changes the route to the starboard, still ina collusion position.
10.02	Dead slow ahead (*) and 285° keeps rotation.	The distance between ships is 1.47 miles, 10° starboard, then hard to starboard.
10.03	Detection of the collusion risk with the Vessel B while the distance is 100 meters, master commands full	Continues turning with hard to starboard.
10.04	Collusion while turning to port.	Collusion occurs while turning to starboard.

(*) Master of the motor vessel A claims that he gave a command of dead slow ahead.

1.2. Simulation of Scenario Collusion:

At 10.00, M/V Alpha navigates at 285° with 10 knots, on the other hand, M/V Bravo is heading 070° with the forward speed through the water is 12 knots. The reported distance between the vessels is 4.54 nautical miles. The master of M/V Bravo realised that ships are in head-on situation and there would possibly be a touch with the other vessel soon. (Figure 1)

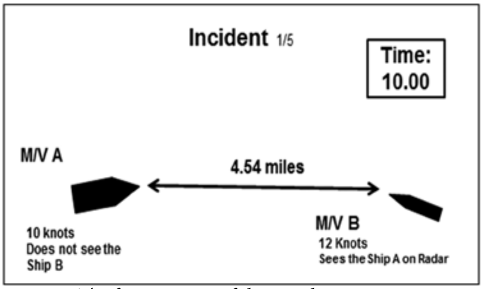

Figure 1 *The first position of the vessels encounter*

At 10.01, M/V Bravo makes a small alteration (10°) to the starboard and is still aware of the other vessel. However, M/V A does not alter the course and speed. The observed distance is 2.84 nm as it is shown on the Figure 2.

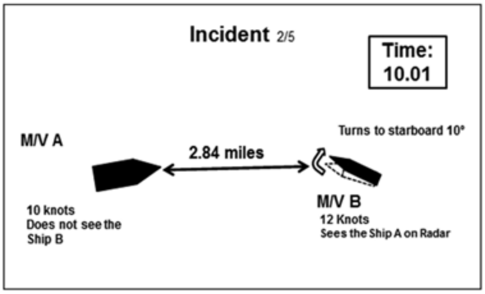

Figure 2 The second snapshot of the position

At 10.02, the distance between the motor vessels is 1.47 nm and M/V Bravo alters the course with the command of hard to starboard. Seafarers of

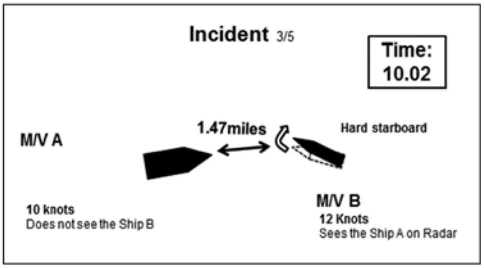

Figure 3 The position of two vessels while the distance is 1.47 miles

M/V Bravo fails to communicate with the other vessel and they are unable to warn M/V Bravo by sound signals.

Also, M/V Alpha is observed making no action to avoid the collusion risk and no alternation of the course and speed. Figure 3 shows the third snapshot of the incident. The master of M/V Bravo has declared that he gave a command of dead slow ahead at the court. However, due to there is no evidence it is omitted.

On the Figure 4, time time is at 10.03, one of the seafarers declares the collusion risk while

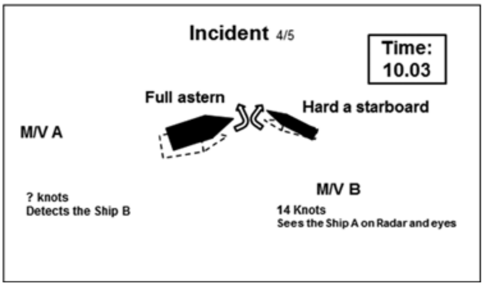

Figure 4 At time 10.03 the positions of the vessels

the distance between vessels is 100 meters, master of M/V Alpha detects the other vessel and there is no data about the speed of the vessel at that time. Master gives a full astern command and alters the course slightly to the port. M/V B sees the other vessel M/V A both on the radar and by eyes.

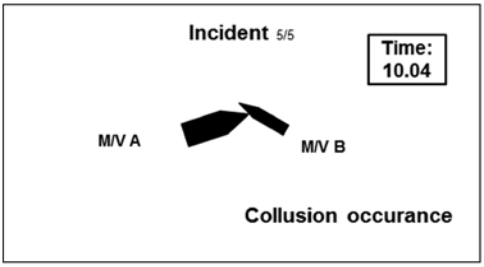

Figure 5 The position of collusion occurrence

At 10.04, the collusion occurs as shown on the Figure 5. The damage to M/V A was limited to her bow. M/V B was holed in way of a bunker tank. Also, there was no pollution.

1.3. COLREG Rules Regarding The Accident Between M/V Alpha and M/V Bravo

Rule 5 - Look-out

Every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision.

Rule 19 - Conduct of vessels in restricted visibility

(a) This Rule applies to vessels not in sight of one another when navigating in or near an area of restricted visibility.

(b) Every vessel shall proceed at a safe speed adapted to the prevailing circumstances and conditions of restricted visibility. A power-driven vessel shall have her engines ready for immediate manoeuvre.

Rule 35 - Sound signals in restricted visibility

In or near an area of restricted visibility, whether by day or night, the signals prescribed in this Rule shall be used as follows:

(a) A power-driven vessel making way through the water shall sound at intervals of not more than 2 minutes one prolonged blast.

Rule 14 - Head-on situation

(a) When two power-driven vessels are meeting on reciprocal or nearly reciprocal courses so as to involve risk of collision each shall alter her course to starboard so that each shall pass on the port side of the other.

(b) Such a situation shall be deemed to exist when a vessel sees the other ahead or nearly ahead and by night she would see the mast head lights of the other in a line or nearly in a line and or both sidelights and by day she observes the corresponding aspect of the other vessel.

(c) When a vessel is in any doubt as to whether such a situation exists she shall assume that it does exist and act accordingly.

Rule 8 - Action to avoid collision

(b) Any alteration of course and/or speed to avoid collision shall, if the circumstances of the case admit, be large enough to be readily apparent to another vessel observing visually or by radar; a succession of small alterations of course and/or speed should be avoided.

(c) If there is sufficient sea-room, alteration of course alone may be the most effective action to avoid a close-quarters situation provided that it is made in good time, is substantial and does not result in another close-quarters situation.

After the investigation, experts have decided an average violation for M/V Alpha as Rule-5 is % 40, Rule 19/b-c is % 10, Rule 14 is % 5 and Rule 35 is % 15 the total fraction defective is unrealistically %70

For M/V Bravo, the same experts have decided an average violation for M/V Bravo as Rule 8/b-c is % 15, Rule 19/b-c is %5 Rule 35 % 10 and the total fraction defective is %30

2. Methodology Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a decision making method which treats both qualitative and quantitative criteria. It is able to deal with multiple goals; it can also handle the fraction defectives of a marine accident. AHP basically involves three steps: hierarchy structure, ratio of priorities and aggregation of the local weights into a global priority that measures the impact of all factors. The alternative rates of global weight give the fraction defectives.

Then, the following can be done manually or automatically by the AHP software. The steps written below are implemented:

1. Combinations of the pair-wise comparison matrix
2. Calculating the priority vector for a rule such as COLREG Rule 5 and then overall priority;
3. Calculation of the CI, consistency index,
4. Calculation of the consistency ratio;
5. Checking the consistency of the pair-wise comparison matrix to aware whether the experts comparisons were dependable or not.

Inputs of AHP are gathered from multiple sources such as experts, experienced captains, judges and academicians.

We made a survey and asked them to critise this accident and then rate the fraction defectives for each step. After their first time critisation, they rated the survey COLREG rule based step by step. Then, they filled out the relative scale measurement which is shown on the table 3.

Table 3 *Pair-wise comparison scale for AHP preferences*

Numerical Rating	Verbal Judgements of Preferences
9	Extremely preferred
7	Very strongly preferred
5	Strongly preferred
3	Moderately preferred

For AHP method, criteria and alternatives as used as inputs and the matrix produces the relative weights of elements. Fraction defectives are classified the into five sub-groups (0-20, 20-40, 40-60, 60-80 and 80-100) in addition to 0. The corresponding vector of weights is and the matrix is given below

$$A=\begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ \vdots \\ A_n \end{array}\begin{array}{c} \begin{array}{cccc} A_1 & A_2 & A_3 & A_n \end{array} \\ \begin{pmatrix} w_1/w_1 & w_1/w_2 & w_1/w_3 \cdots w_1/w_n \\ w_2/w_1 & w_2/w_2 & w_2/w_3 \cdots w_2/w_n \\ w_3/w_1 & w_3/w_2 & w_3/w_3 \cdots w_3/w_n \\ \vdots & \vdots & \vdots \quad\quad \vdots \\ w_n/w_1 & w_n/w_2 & w_n/w_3 \cdots w_n/w_n \end{pmatrix} \end{array}$$

The relative weights are obtained by multiplication of A and W, where W = (w1, w2, . . , wn) (1)

$$A*W = n*W$$

(1) n is the number of the elements, n and W are eigenvalue of the matrix algebra and eigenvector of matrix A.

Due to experts are not able to produce the accurate weights of matrix, the estimation of is obtained as shown below:

$$\hat{A}*\hat{W} = \lambda_{\max}*\hat{W}$$

(2) Where is observed matrix, λmax is the largest eigenvalue of , is the right eigenvector which is the estimation of W (weights i.e. priority vector).

Consistency Index (CI) is calculated from the formula of:

$$CI = \frac{\lambda_{\max} - n}{n-1}$$

(3) λmax is the largest eigenvector value.

Then, Consistency Ratio (CR) is ;

$$CR = \frac{CI}{RI} \leq 0.1$$

(4) Random Consistency Index (RI) is an average index of randomly generated weights which is shown in Table 4.

Table 4 *Random index*

n	1	2	3	4	5	6	7	8	9	10
RI	0,00	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49

2.1. Application of Fraction Defective Management by using AHP

The table 5 and 6 show the pairwise comparisons among fraction defectives on rule 5 for M/V A and rule 8/b-c for M/V B. As the value of CR is less than 0.1, the judgments are acceptable. Similarly, the pairwise comparison matrices and priority vectors for the remaining rules for M/V A and M/V B are calculated respectively. Priority vector (PV) is written to the right side of the table.

Table 5 *Pairwise comparisons among fraction defectives on rule 5 for Ship A(CR=0.03).*

	0	0-20	20-40	40-60	60-80	80-100	Local PV
0	1,00	0,79	0,85	0,77	0,56	0,68	0,12
0-20	1,26	1,00	0,52	0,49	0,36	0,40	0,09
20-40	1,17	1,93	1,00	0,59	0,67	0,81	0,15
40-60	1,30	2,03	1,70	1,00	0,90	0,44	0,17
60-80	1,80	2,81	1,50	1,11	1,00	1,92	0,25
80-100	1,48	2,52	1,23	2,28	0,52	1,00	0,21

According to the empirical results, fraction defectives between 60 and 100 are found with higher contribution to Ship A`s cumulative fraction defective. For Ship B, it is around 0-40 (Table 6).

Table 6 *Pairwise comparisons among fraction defectives on rule 8/b-c for Ship B (CR=0.07).*

	0	0-20	20-40	40-60	60-80	80-100	Local PV
0	1,00	1,29	1,15	0,77	0,61	3,43	0,17
0-20	0,77	1,00	1,52	1,29	3,24	3,35	0,23
20-40	0,87	0,66	1,00	1,59	3,73	3,93	0,22
40-60	1,30	0,77	0,63	1,00	1,51	1,63	0,15
60-80	1,64	0,31	0,27	0,66	1,00	1,21	0,10
80-100	0,29	0,30	0,25	0,61	0,83	1,00	0,07

The priority vectors of criteria are found by using criteria comparison matrix. Based on these results, rule 5 is indicated as the most important factor in the analysis (Table 7). For Ship B, rule 8bc and 35 are indicative for analysing accident.

Table 7 *Global Weights of Rules for Alpha*

	5	19/b-c	14	35	
PV of Rules	*0.32*	*0.22*	*0.28*	*0.17*	Global PV
0	0.12	0.08	0.10	0.09	0,10
0-20	0.09	0.08	0.08	0.08	0,09
20-40	0.15	0.14	0.17	0.17	0,16
40-60	0.17	0.15	0.13	0.14	0,15
60-80	0.25	0.33	0.35	0.30	0,31
80-100	0.21	0.22	0.16	0.23	0,20

Table 8 Global Weights of Rules for Bravo

PV of Rules	*0.41*	*0.17*	*0.40*	Global PV
0	0,18	0,11	0,15	0,43
0-20	0,24	0,13	0,10	0,48
20-40	0,24	0,23	0,22	0,69
40-60	0,16	0,14	0,14	0,44
60-80	0,11	0,22	0,21	0,54
80-100	0,07	0,17	0,17	0,42

Final results are calculated by using the proposed AHP approach. The fraction defective of ships are declared as 70% and 30% for Alpha and Bravo respectively in prior consultation. By using AHP approach, experts are asked for prioritisation of each criterion and sub-groups of fraction defective in stepwise process. After the analysis, former results are changed to 54% and 46% respectively. Around 16% of former estimation is biased in posterior outcome. Results explicitly indicate that the traditional holistic analysis approach misleads experts.

Table 9 *Final Results*

Motor Vessels	Average of Experts' ratings before the survey	Fraction Defective in AHP
Rule 5	40%	17.13%
Rule 19/b-c	10%	12.09%
Rule 14	5%	15.37%
Rule 35	15%	9.41%
M/V Alpha	**70%**	**54%**
Rule 8/b-c	15%	19.08%
Rule 19/b-c	5%	8.15%
Rule 35	10%	18.76%
M/V Bravo	**30%**	**46 %**

3. Conclusıon

Fraction defective management involves complex decision making situations that require professional judgment and methods to make fair decisions. The paper utilised AHP method for analysing fraction defective on the marine accidents. An example of motor vessel incident was investigated to demonstrate AHP application in marine accidents. Marine Accident fraction defective involves COLREG rules and fractionate in percentages that are determined by experts and captains as well as the academicians.

Empirical results indicated that fraction defectives can be manipulated by the limitations of human judgment and cognitive bias. The proposed approach provides a support tool for decision makers to classify problem and defines final outcome by compromising the responses given by experts. The proposed approach is suggested to improve the investigations of marine accidents.

4. References

*Bulut E. & Duru O. & Aydogdu V. 2010. Comparative Analysis for the Selection of Hazardous Area in the Strait of Istanbul, The First Global International Conference on Innovation in Marine Tech, Istanbul

*Saaty, T.L., The analytic hierarchy process. New York: McGraw- Hill, 1980.

*Saaty, T.L., Axiomatic foundations of the analytic hierarchy process. Management Science, 32(7), N, pp. 841-855. 1986.

*Convention on the International Regulations for Preventing Collisions at Sea, 1972, IMO

*http://www.navcen.uscg.gov/ Navigation Rules, U.S. Coast Guard Navigation Center, Alexandria, VA, 2013

*http://www.maib.gov.uk/home/index.cfm