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A MCDM Approach with Fuzzy AHP Method for Occupational Accidents on Board

Ü. Özdemir
Mersin University, Mersin, Turkey

İ. Altinpinar & F.B. Demirel
Karadeniz Technical University, Trabzon, Turkey

ABSTRACT: Occupational accidents on board criteria determining is a challenging procedure in shipping industry as the ideal safety ship management strategy depends on many factors involving in shipping transportation There are many legislations, agreements and practices to obtain series of security measures in order to ensure safety and security of seafarers. Causes of on-board occupational accidents need to be evaluated in a correct manner to regulate more functional practices and also to lower the on-board accident rates. However, causes of on-board accidents can be extremely complex. Therefore, scientific methods should be used to evaluate the causes and to determine the measures to be taken. The evaluation of the parameters is of great importance for the future of the maritime sector and in terms of development. In this study, factors have been identified that lead to seafarers' occupational accidents on board and we tried to present alternative solutions which can be applied on this issue. Severity of the reasons that led to the accidents and their relationships with each other are identified to be able to sort through the alternative solutions with a model using the fuzzy AHP (Analytic Hierarchy Process) method approach. Results of the study revealed that the most important criteria for the occupational accidents on board criteria selection are respectively; human factors, lack of management, ship-borne troubles, cargo troubles and environmental factors

1 INTRODUCTION

Ships operate in a highly risky milieu; typically, the people on board adapt a set routine of shift work disrupted by arrival at, working in, and sailing from port. Recently, international maritime authorities have performed significant contributions to improve safety at sea in the shipping transportation industry. But, there is no remarkable decrease in total number of the shipping accidents. From the economical perspective, ships are very important commodities as they offer jobs for people and enhance the financial activities by transporting goods and passengers from one node to another. This is a presence which involves living in the place of work for prolonged periods, creating a unparalleled form of working life which almost no doubt increases the risk of human error. Marine traffic, which is a natural consequence of growing world trade, not only increased the number of ship accidents but also caused more frequent in-ship occupational accidents (Özdemir and Güneroğlu 2015, Uğurlu 2016). There is no doubt that maintaining the seafarers' safety is utterly important. According to the International Labour Organization (ILO), seafarer is any person who works in any position on board a seagoing ship or vessel engaged in commercial maritime navigation, whether publicly or privately owned, other than a ship of war. Being a seafarer includes professionally difficulties in addition to the harsh environmental factors. Unlike other professions, they spend 24 hours a day at work. Therefore, when dangerous occupations are listed, the risk of accident is rather high for seafarers (Roberts, 2002). There are many different reasons for the occupational accidents on board. Hanson's study carried out a survey that showed that mortal injuries among Danish seafarers were 11.5 times higher than average rates among the Danish male workers ashore between 1986 and 1993 (Hansen, 1996). Accidents on ships may pose great risks for personnel and the environment, according to the nature of the accident (Portela 2005, Uğurlu et al. 2016). Accident can be described as an unexpected event that results in a personal injury or loss of property, or both. We see that ship related occupational accidents can be inspected under three main headings. These can be listed as auxiliary causes, sudden causes and other causes (Hansen 1996, Hansen et al. 2002). Certain operations on board may cause extremely dangerous working conditions. Inadequate safety of ship operations are not only inclined by the material precautions but also human factors such as seafarers' behaviors, habits, lack of attentions and occupational educations (Roberts 2000, Martins and Maturana 2010, Uğurlu et al. 2016). Most of marine accidents are caused by some form of human error as well as incidents (Havold 2000, Rothblum 2000, Toffoli et. al. 2005, Hetherington et al. 2006, Grech et. al. 2008, Talley 2009, Özdemir and Güneroğlu 2015). Previous researches demonstrate that for each serious accident in the maritime industry, or in any other area, there are a larger number of incidents, a big number of near-misses and huge number of safety-critical events and unsafe acts (Grech et. al. 2008). Example of workers' unsafe acts include the determination to proceed with work in unsafe conditions, disregarding standard safety procedures such as not wearing safety equipment, working while intoxicated, occupational illiteracy, working with insufficient sleep and fatigue (Abdelhamid and Everett 2000). Personal injuries are much worse when they are on board, due to the fact that seafarer's health care opportunities are poorer than those ashore. A critical conflict in the treatment of seafarer at sea is that medical care on-board is applied by a medical health officer who is not medical professional (Oldenburg et al. 2010).

Maritime accidents usually occur due to failure of a decision as combination of coincidental incidents or processes, as a general rule by negligence of one or more independent components that are required to action accurately for the successful finalizations of decision flow (Özdemir and Güneroğlu 2015). Main reasons of ship related accidents can be listed as; human factors (psychological, physical, human relations, team work, communication); machinery/equipment factors (incorrect machinery and equipment layout, absent or defective protectors, inadequate standardization, inadequate control and maintenance, inadequate engineering services); environmental factors (inadequate knowledge, improper working methods, improper working environment) and management factors (inadequate management organization, incomplete rules and regulations, inadequate security management plan, educational inadequacies, inadequate health controls, employment of incompetent personnel, etc.) (O'Neil 2003, Portela 2005, Hetherington and Flin 2006, Özdemir and Güneroğlu 2015, Uğurlu 2016)

In this study, we used a quantitative application to examine the reasons of work related accidents in ships and tried to discover alternative solutions for the matter. Work related accidents on ships have several interconnected reasons. For the solutions of such problems in which various factors and criteria must be analysed and evaluated, using a "fuzzy multi-criteria decision-making model" (FMCDM) can be a positive approach. In this study, we determined the criteria that cause work related accidents and offered an appropriate methodology for the solution of the problem by using a fuzzy multi-criteria decision-making model. Fuzzy AHP (Analytic Hierarchy Process) is used to determine and rank the accident-related criteria according to their importance.

2 METHODOLOGY

The problem of the causes of occupational accident selection criteria on ship is considered as a multi-dimensional complex issue that can be resolved by a MCDM approach. In such a complex problem, the availability of many choices and their relative impact on the final solution are always risky as they may be misleading the decision maker if there is not a reliable tool in hand (Özdemir and Güneroğlu 2015, Uğurlu 2015, Güneroğlu et. al 2016). In this study, causes of occupational accident selection criteria' weighting was implemented using Fuzzy AHP following Buckley (1985) by pairwise comparisons of the experts' scores were applied for ranking and evaluating the criteria.

The steps of the applied technique and related case study are presented in following sub-sections.

2.1 *Fuzzy AHP*

The first step of implemented methodology is endured on Buckley's AHP technique. Actaully, this technique is a magnified version of the original AHP technique by Saaty (2006) and instead of classic rational numbers, it uses fuzzy comparison ratios. The notable virtue of the Buckley's Fuzzy AHP is the expansion of the statements to Fuzzy environment with relatively easy efforts as well as the guarantee of one absolute value. Complex, laborious and error-prone computational requirements are the main disadvantages of the same technique. The Fuzzy AHP technique by Buckley (1985) can be summarized as followed (Buckley, 1985; Kafalı et al., 2014; Özdemir and Güneroğlu,2017);

The first step of the technique contains defining the main criteria that potentially affects the problem under investigation by experts and decision makers. Afterwards, in order to convert the expert evaluations to the fuzzy numbers, a predefined linguistic scale is used. Then, expert evaluations were received as pairwise comparisons that converted to the fuzzy numbers with in matrix form as shown in Eq.1,

$$\tilde{A}^k = \begin{bmatrix} 1 & \tilde{A}_{12} & \tilde{A}_{1m} \\ \tilde{A}_{21} & 1 & m \\ \cdot & \cdot & \cdot \\ & \cdots & \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \tilde{A}_{m1} & \tilde{A}_{m2} & 1 \end{bmatrix} \quad (1)$$

where "$\tilde{A}^k$" is the response matrix by each expert. Linguistic scale and corresponding fuzzy numbers used in the Buckley's technique were given in Table 1 (Xu and Yager 2008, Kafalı et al. 2014).

Then all data received as result of experts' evaluations is compiled by using weighted mean formula as given in Eq.2,

$$\tilde{A}_{xy} = \frac{Z_1 A_{xy}^1 + Z_2 A_{xy}^2 + \ldots + Z_k A_{xy}^k}{Z_1 + Z_2 + \ldots + Z_k} \quad (2)$$

In Eq.2 "$\tilde{A}_{mn}$", is the joined comparison value of the critieria "x" and "y"; "Z_k" is the weighted value of "k."expert; "A_{xy}^k" is the comparison value of "k." expert evaluations corresponding to "x" and "y" criteria. The decision matrix formed by weighted means of all experts' scores can be shown in following matrix form (Eq.3)

$$\check{A} = \begin{bmatrix} 1 & \tilde{A}_{12} & \cdots & \tilde{A}_{1m} \\ \tilde{A}_{21} & 1 & \cdots & \tilde{A}_{2m} \\ \vdots & & & \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{A}_{m1} & \tilde{A}_{m2} & \cdots & 1 \end{bmatrix} \quad (3)$$

After obtaining the decision matrix, the weight of each criterion can be calculated in two steps. The first step is computing the geometric mean of each row in decision matrix, as shown in Eq.4

$$\check{b}_i = \left(\widetilde{a_{i1}} \otimes \widetilde{a_{i2}} \otimes \ldots \otimes \widetilde{a_{in}}\right)^{1/n} \quad (4)$$

where "n" stands for total number of criteria, "$\widetilde{a_{in}}$" is the fuzzy comparison value between two criteria "i." and "n." and "b_i" is the fuzzy geotmetric mean of the all compared criteria. As a second step, a fuzzy weight of each criterion is calculated by applying Eq.5.

$$\widetilde{w_i} = \widetilde{b_i} \otimes \left(\widetilde{b_1} + \widetilde{b_2} + \ldots + \widetilde{r_n}\right)^{-1} \quad (5)$$

where, "$\widetilde{w_i}$" is the fuzzy weight of criterion "i.".

The remaining part of the Buckley's FuzzyAHP technique requires conversion of the fuzzy numbers to corresponding absolute values and calculation of relative weights among all criteria.

where,"$\check{B}$" is referred to triangular fuzzy number, defuzzification of "B" can be applied using Eq.6.

$$\check{B} = \frac{\widetilde{b_1} + \widetilde{b_2} + \widetilde{b_3}}{3} \quad (6)$$

For better evaluation of the obtained values, normalization is applied on the main criteria as it is in Eq.7,

$$\left(w_i^R\right)^N = \frac{w_i^N}{\sum_{i=1}^{n} w_i^N} \quad (7)$$

where "$\left(w_i^R\right)$N"is referred to normalized weight of each criteria and "n" is the total number of the criteria. Similarly, normalization of sub-criteria is also performed for each elements of the matrix.

Finally, relative fuzzy and absolute weights of main and sub-criteria are computed by multiplying main and related each sub-criteria in the matrix as shown in Eq.8 and Eq.9.

$$\left(\tilde{w}_i^R\right)^{SN} = \left(\tilde{w}\right)^N \otimes \left(\tilde{w}_i\right)^{SN} \quad (8)$$

where, "$\left(\tilde{w}_i^R\right)$SN" is the fuzzy relative weight of "i." sub-criterion, "$\left(\tilde{w}\right)$N" is the fuzzy weight of the related main criterion and "$(\tilde{w}_i)$SN" is the fuzzy weight of the same sub-criterion.

$$\left(w_i^R\right)^{SN} = \left(w^R\right)^N \mathrm{X} \left(w_i^R\right)^{SN} \quad (9)$$

In Eq.9, "$\left(w_i^R\right)$SN" is the normalized relative absolute weight of the "i." sub-criterion, "$\left(w^R\right)$N" is the normalized absolute weight of the related main criterion and "$\left(w_i^R\right)$SN" is the normalized absolute weight of the same sub-criterion.

3 CASE STUDY

With an aim of obtaining data sets by establishing criteria within the framework of research model; ship crews, company officials, academicians, analysts and casualties/casualties' relatives were interviewed. Also, safety reports were evaluated and criteria were established by considering the agreements and conventions published for maritime safety. As a result of the evaluations made, it was decided that 5 main criteria shown in Table 1, would be studied.

Maritime management is comprised of 9 people (Oceangoing master/3, ship casualties/3, academician/3) and these people have experiences about ship's crew. Questionnaire forms of compiled criteria shown in Table 1 were applied to the participants with an aim of obtaining opinions of decision makers. Paired comparison matrixes of each expert related to all the criteria were obtained in the form of verbal statements as a result of the evaluation of all the criteria. Due to the fact that all the questionnaire data, which were collected from the experts, were in verbal forms, they need to be converted to triangular fuzzy numbers in accordance with fuzzy number equivalents of linguistic scale, which was specified before (Xu and Yager, 2008; Özdemir and Güneroğlu, 2017; Özdemir and Çetin, 2017). The values in Table 2 were used in these conversions.

Table 1. Criteria determined for the study.

#	Criteria
1	Environmental factors (Sea condition, weather condition etc.) - C1
2	Lack of management (Lack of ship rules, failure to take measures, lack of management, lack of communication etc.) – C2
3	Shipborne Troubles (Ship age, ship condition, condition of equipment, equipment inadequacy, poor lighting etc.) - C3
4	Human Factor (Lack of training, unawareness, carelessness, occupational willies, fatigue, dangerous movements etc.) – C4
5	Cargo Troubles (inappropriate loading, dangerous cargoes etc.) - C5

Incorporated fuzzy decision matrixes of the data, which were obtained as a result of paired comparison of main criteria by using formula 10 and 11, were calculated as in Table 3.

$$\tilde{C}_{ij} = \left(1/N\right) \otimes \left(\tilde{c}_{ij}^{1} \oplus \tilde{c}_{ij}^{2} \oplus \ldots \oplus \tilde{c}_{ij}^{N}\right) \tag{10}$$

$$\tilde{D}_{ij} = \left(1/N\right) \otimes \left(\tilde{d}_{ij}^{1} \oplus \tilde{d}_{ij}^{2} \oplus \ldots \oplus \tilde{d}_{ij}^{N}\right) \tag{11}$$

Table 2. Linguistic terms used for Buckley's Fuzzy AHP (Kafalı et al. 2014, Özdemir and Güneroğlu 2016, Özdemir and Güneroğlu 2017, Özdemir and Çetin 2017)

Linguistic Terms	Fuzzy Number
Slightly more important (Row)	(1, 3, 5)
Strongly more important (Row)	(3, 5, 7)
Highly more important (Row)	(5, 7, 9)
Absolutely more important (Row)	(7, 7, 9)
Equally important	(1, 1, 3)
Absolutely more important (Column)	(0.111, 0.111, 0.143)
Highly more important (Column)	(0.111, 0.143, 0.200)
Strongly more important (Column)	(0.143, 0.200, 0.333)
Slightly more important (Column)	(0.200, 0.333, 1.000)

The step after calculating incorporated fuzzy decision matrixes calculations was the calculation of criterion weights according to Buckley approach and it is carried out in the second step. As a first step, geometric average of each line of incorporated fuzzy decision matrixes is calculated. This process is expressed in formula 4. In the second step, geometric average of matrix is calculated and then its fuzzy weight value is calculated with the help of formula 5. This process was applied for all main and sub-criteria. Weighted fuzzy decision matrix, which was calculated for main criteria, was shown in Table 4.

According to Buckley approach, the next step is conversion of fuzzy values into absolute values. According to this, defuzzification and normalization processes are carried out. Formula 6 was used for this calculation. Formula 7 was benefited in order to evaluate absolute weights in a better way. The results, in which calculated defuzzification process was included for the criteria, were shown in Table 4 and normalization results were shown in Table 5.

Table 3. Aggregated fuzzy decision matrix for the criteria

	C1	C2	C3	C4	C5
C1	1.000	0.125	0.324	0.621	1.458
	1.000	2.354	1.000	0.388	2.642
	1.000	3.652	2.024	0.547	2.033
C2	0.256	1.000	0.387	0.254	2.010
	0.745	1.000	2.457	0.541	2.354
	2.354	1.000	1.874	2.456	2.247
C3	0.385	0.845	1.000	0.451	1.687
	1.845	1.354	1.000	0.365	1.347
	2.214	2.410	1.000	1.354	4.024
C4	1.651	2.874	0.343	1.000	2.410
	1.033	3.120	1.687	1.000	3.025
	0.333	1.018	2.374	1.000	4.024
C5	0.897	0.985	0.852	1.241	1.000
	0.624	0.458	0.349	0.314	1.000
	1.025	1.303	1.541	0.652	1.000

Table 4. Weighted fuzzy decision matrix for criteria (a), defuzzified criteria weights (b).

(a)	Weighted Fuzzy Decision Matrix		
C1	0.034	0.398	0.403
C2	0.204	0.452	0.182
C3	0.024	0.065	0.035
C4	0.287	0.078	0.802
C5	0.136	0.304	0.246
(b)	Defuzzified criteria weights		
C1	0.026	0.228	0.542
C2	0.125	0.309	0.021
C3	0.203	0.065	0.520
C4	0.028	0.122	0.033
C5	0.077	0.201	0.217

Table 5. Normalized criteria weights

Criteria	Normalization (Crisp)	Percentage Value (%)
C1(5)	0.1248	12,48
C2(2)	0.2438	24,38
C3(3)	0.1878	18,78
C4(1)	0.2598	25,98
C5(4)	0.1838	18,38
Total	1.000	100

4 RESULTS

According to the results of the study, the reasons that occupational accident on board are specified as follows in order of priorities: human factors (C4), lack of management (C2), shipborne Troubles (C3), Cargo Troubles (C5), and Environmental factors (C1). According to the results of the study, criteria of human factors such as lack of training, unawareness, carelessness, occupational willies, fatigue, dangerous movements etc., which is ranked in the first place, that main reasons of occupational accident on board were experienced. When the criteria are examined generally, we see that C2 and C4 are directly human-induced while C3 and C5 are indirectly effected by human error. C1 stands out as the distinctive criteria that differentiates the maritime occupation from other occupational fields. Safety culture affects behavioral pattern of people against dangerous situations (Cox and Flin 1998, Cooper 2000, Dursun 2013). Reiman ve Oedewald (2002) collected the criteria of 'good safety culture' in the literature under the main headings such as: security policies; apparent sagacity of management for security; democratic applications and competencies; positive values with security tendencies; open definitions of responsibilities and necessities; security priority operations; balance of security and production; competent workers and education; high motivation and work satisfaction; mutual trust and fair approach between management and workers; update of quality, rules and regulations; regular machinery maintenance; proper and regular reporting of every incident and interpretation; healthy information flow from different managerial levels and positions; adequate funds and constant development; proper design and business relations with authority. Perception of safety culture of individuals is an important factor in the accidents that originate from such human errors. Enhancing the perception of safety culture will contribute to prevent accidents that results from human induced errors. Several studies and accidents reports have warned of the difficulties encountered by crews who are constantly working on ships of different sizes, with different equipment, and carrying different cargoes. Mariners often do not understand how the automation works or under what set of operating conditions it was designed to work effectively.

Dealing with this research enables the following contributions to the shipping accident analysis and prevention literature that improving the structure of the existing MCDM model and extending the application of combine MCDM to occupational accident on board. When the previous studies about privateering are considered, it is thought that this study will significantly contribute to the literature and future studies due to the lacking number of quantitative studies about work accidents on ship, which are accepted as a major problem for maritime industry.

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