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STRATEGIC APPROACH MODEL FOR INVESTIGATING THE CAUSE OF MARITIME ACCIDENTS

ABSTRACT

It is commonly accepted that the majority of maritime causalities are caused by human factors/errors. The role of human factor in maritime accident and the possible reasons of this argument can be quantitatively evaluated based on expert knowledge and multiple criteria decision-making (MCDM) methodology. To investigate what makes the first "human factor" in ship accidents, a hybrid approach was applied in this study. Two methods, the decision-making trial and evaluation laboratory (DEMATEL) and the analytical network process (ANP) were proposed to evaluate the importance level of the human factors in maritime casualties. Quantitative evaluations of the human errors in maritime operations can greatly improve the decision-making process and reduce potential risks. As a result of this study, the top three priorities in the evaluation systems were found as: 'ability, skills, knowledge' (8.94%), 'physical condition' (8.77%), 'weather - sea conditions' (8.21%) and the least important criterion was 'cargo characteristics' (2.21%).

KEY WORDS

maritime accident; multiple criteria decision-making; decision-making trial and evaluation laboratory; analytical network process;

1. INTRODUCTION

Despite all the advances achieved in the field of marine technology and transportation in recent years, the number of maritime accidents occurring on a world-wide basis has not been reduced to an acceptable level [1]. Evaluations that have been performed in shipping industry clearly indicate that the human factor is still the dominating pin point of the maritime accidents [2]. Recently, international maritime authorities have performed significant contributions to improve safety at sea in the shipping transportation industry [3]. 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 [4]. In fact, there is no available technique that completely eliminates the risk factor for both ships and passengers at sea but there should be a way to diminish the risk factor to a lower level by analyzing, evaluating and studying the problem [5]. This is very important for the economy and environmental sustainability of the maritime trading or coastal countries where the high maritime accident risk became an acute problem [6]. The negative effects of maritime accident can be summarized as loss of lives at sea, environmental pollution mainly due to oil spill and economic results that may deteriorate the international logistic flow [2, 7]. It has been very well documented that the main reason in a maritime accident is the "human factor". Therefore, studying the human factor and accident analysis has recently become a popular research topic among the maritime professionals and scientists. Within this frame, the whole maritime system is a manmade system that relies on real professionals but interestingly the center of the problem is again the "human" themselves [8]. In fact, there are many studies on the role of human factor in maritime accidents and incidents [9]. The related work pointed out that 75% to 96% of maritime causalities are linked to human error engaged with professional maritime transportation [2, 5, 10, 11, 12, 13, 14, 15, 16, 17]. As reported by [18], human error contributes to 89-96% of collisions, 75% of fires and explosions, 79% of towing vessel groundings, 84-88% of tanker accidents, 75% of allusions. Furthermore, many authorities such as "The Australian Transport Safety Bureau", "Transport Safety Board of Canada", "The Maritime Safety Authority of New Zealand", "The Marine Accident Investigation Branch of United Kingdom" or "The National Transportation Safety Board of U.S.A." reported via internet that human error is the most important factor in maritime accidents.

Maritime accidents usually occur due to breaking of a decision process as combination of failures in sub-blocks by negligence of one or more independent components that are required to act accurately for the successful finalizations of decision flow [19]. According to the IMO (International Maritime Organization) A. 849(20) Code, human error is affected by factors such as "*people factors*", "*organization on board*", "*working and living conditions*", "*ship factors*", "*shore-side management*", "*external influences*", "*environment*" and their 44 sub-criteria of errors related to ship accidents. The determination process of human errors in maritime accident should have the technical capability of handling complicated multidimensional factors with scientifically acceptable methodology. Therefore, determination of maritime accidents caused by human errors is a kind of multiple criteria decision-making (MCDM) problem and requires MCDM methods to solve it. Although the human error on maritime accident is a kind of MCDM problem, there are limited MCDM studies which focus on what are the main causes for human errors on maritime accidents. Consequently a hybrid MCDM method can be followed to handle the problem appropriately.

In this study, a combined method is proposed for analyzing human error in maritime accidents. The method combines decision-making trial and evaluation laboratory (DEMATEL) and analytical network process (ANP). Moreover, the proposed method utilizes DEMATEL technique to explain the relationships between various criteria based on expert knowledge as DEMATEL is a comprehensive method for building and analyzing a structural model to explain causal relationships between complex factors. DEMATEL method can transform the relations between cause and effect of criteria into a structural process by applying a set of criteria [20; 21]. In general, the DEMATEL method is used to illustrate the relations between different criteria and reach the main factor/criteria to explain the impact of a factor [22]. The DEMATEL method is established on digraphs, which can transform involved factors into cause and effect groups [21]. This method has also been individually used in many activities such as safety problems [20], transportation [20], supply chain management [24] and automotive industry [25]. The other technique involved in the proposed methodology is the analytic network process (ANP). ANP is widely applied to cope with the problems of interdependence and feedback among criteria, sub-criteria and alternatives [26]. ANP method works by classifying the criteria of an entire system to form a supermatrix by pair-wise comparisons and search an answer for the question "*How much importance does one criterion have compared to another criterion, with respect to our interests or preferences?*" [27]. The most important property of ANP is that it does not ignore the dependencies among the factors used in evaluation process which allows the ANP to obtain better results [25]. A hybrid model that combines ANP and DEMATEL can be very effective in solving very complex interrelations involved in maritime accidents and extract the main causes attributed to human factors. In this study a hybrid MCDM method [22] is proposed to research "*what causes the human factor?*" in maritime casualties. This hybrid model is used in many situations such as airline safety procedures [20], management strategies [25], location selection for high technology firms [23] and solid waste management [21].

Based on several aspects of shipping accidents, it is believed that the interdependence between criteria that affect an incident should not be overlooked. The proposed method accounts for the dependence among different criteria by evaluating the weights and ranges for each factor. Many models have been established that discuss Human Factors in accidents, e.g. Reason's Swiss Cheese Model [28], Human Factors Analysis and Classification System (HFACS) [29], Classifications of Socio-Technical Systems involved in safety control [30], Systems-Theoretic Accident Model and Processes [31]. Therefore, there are many techniques available for risk analysis and traditional decision-making methods as "*FTA (Fault Tree Analysis), ETA (Event Tree Analysis), Leader-participation, Grey Relational Analysis (GRA), and so on*". These models are generally based on an assumption of independence among criteria affecting the process. On the other hand, an individual criterion is not always exactly independent. Moreover, it should be stressed that using an additive model which ignores the interrelations among criteria is not always successful in explaining the real world problems because of the changing interdependence levels among various criteria. Therefore, this study proposed a hybrid MCDM model combined with DEMATEL and ANP to solve the dependence level and feedback problems and it may help decision-makers to make an optimal decision. Reliable and rational results could be obtained in determining the human element as a factor in maritime accidents. Therefore, such a hybrid MCDM approach can be very effective in solving the causes of human-related errors in maritime accidents. Within this frame, the scientific contribution of the current study is based on the proposed hybrid methodology to find the different factor loads on an accident caused by human error. Consequently, compared to traditional methods, it is believed that the proposed technique is capable of eliminating interdependencies among different factors.

2. MATERIALS AND METHODOLOGY

In order to investigate the human factor in maritime accidents, a hybrid MCDM method combined with DEMATEL and ANP was used. Firstly, the formulation of the problem was established including the main goals and evaluation clusters. The criteria set for human error on maritime accidents were determined according to IMO A. 849(20) Code as in *Table 1*. The criteria involved in the human error selection were chosen according to DEMATEL method. The critical relation between every node, influences on human error and the network effect were determined. The DEMATEL method analysis was used to obtain the initial direct-relation matrix with using pair-wise comparisons in total relational matrix with D+R, D-R values and to build a critical relative graph of criteria as a cluster. The relative graph supports a network structure for analyzing the main criteria of human errors on maritime accidents. The network effect is based on DEMATEL technique in order to construct an objective supermatrix of ANP. Consequently, ANP evaluates the dependence and feedback within a cluster and among different clusters. Weights of each cluster related to the criteria are computed by ANP.

2.1 The decision-making trial and evaluation laboratory (DEMATEL)

DEMATEL method is used to illustrate the relations between criteria and to reach the main factor/criterion to symbolize the impact of factor [25]. The DEMATEL method is established on digraphs which can transform the involved factors into cause and effect groups [21, 22, 23]. This method has proven to be very effective in solution complex systems of causal relationships in recent years [33]. The DEMATEL method is briefly described as follows according to [20, 22, 23, 34].

Step 1: Direct-relation matrix is calculated in this step. It is assumed that there are "*L*" experts in the study and "*n*" criteria related to the problem. Firstly, measuring the relationship between criteria requires that the comparison scale be designed as pair-wise comparison scale with five levels, where scores ranging from 0 to 4 represent "no influence" to "very high influence", respectively. Experts are asked to indicate the direct influence degree between criterion "*u*" and criterion "*v*", as indicated by " Z_{uv} ". The initial direct-relation matrix $Z = [Z_{uv}] \| Y |$ is determined from pair-wise comparisons in terms of influences and directions between criteria. Then, as a result of these evaluations, the initial data can be obtained as the direct-relation matrix that is a " $k \times k$ " matrix "*Z*", in which a Z_{uv} is denoted as the degree to which criterion "*u*" affects criterion *v*. The scores by each expert will give us " $n \times n$ " non-negative answer matrix " $X^k = [X^k_{uv}]_{n \times x}$ ", with " $1 \le k \le L$ ". Thus, " $X^1, X^2, \ldots, X^L$ " are the answer matrices for each of the "*L*" experts, and each element of " X^k " is an integer denoted by " X^k_{uv} ". The diagonal elements of each answer matrix " X^k " are all set to zero. We can then compute the " $n \times n$ " average matrix "*Z*" for all expert opinions by averaging "*L*" experts' scores as follows:

$$[Z_{uv}]_{n \times n} = x = \frac{1}{L} \sum_{k=1}^{L} [X^k_{uv}]_{n \times n} \tag{1}$$

Step 2: In this step the direct-relation matrix is normalized. On the basis of direct-relation matrix "*Z*", the normalized direct-relation matrix "*M*" can be obtained using Equation 2 and Equation 3;

$$M = Z \times L \tag{2}$$

$$L = \frac{1}{\max 1 \le u \le n \sum_{v=1}^{n} Z_{uv}}, u, v = 1, 2, \ldots, n \tag{3}$$

Step 3: After the normalized direct-relation matrix "*M*" is obtained, the total relation matrix *K* can be derived by using Equation (4), in which "*H*" is an identity matrix.

$$K = M \times (H - M)^{-1} \tag{4}$$

Step 4: The sum of rows and the sum of columns are specifically depicted as "*D*" and "*R*" within the total-relation matrix "*K*" through Equations (5) to (7).

$$K = [kuv] \quad u, v = 1, 2, 3, \ldots, n \tag{5}$$

$$D = (Du) = \left(\sum_{v=1}^{n} kuv \right) \tag{6}$$

$$R = (Rv) = \left(\sum_{u=1}^{n} kuv \right) \tag{7}$$

The DEMATEL method analysis was used to obtain the initial direct-relation matrix by using pair-wise comparison of total relation matrix values and build a critical relative graph of criteria in the cluster effect. "*Du*" is the "*i*"-th sum of the row in matrix "*K*". Then, "*Du*" denotes the sum of influence dispatching from factor *v* to other factors. *Rv* shows the column sum of "*v*"-th column of matrix "*K*". "*Rv*" is the sum of the influence that factor "*u*" is receiving from other factors. The sum of row sum and column sum $(D + R)$ shows the index representing the strength of influence both dispatching and receiving. Furthermore, if $(D-R)$ is positive, then factor "u" is dispatching the influence to other factors, and if $(D-R)$ is negative, then factor "u" is receiving the influence from other factors.

Step 5: In this step, a threshold value is determined to form a digraph. Since matrix "K" provides information on how one factor affects another, it is necessary for a decision maker to set up a threshold value for removing some negligible effects. For this reason, only the effects greater than the threshold value are chosen and shown in digraph. In this study, the threshold value was set up by computing the average of the elements in Matrix "K". The digraph can be obtained by mapping the $(D+R, D-R)$ data.

2.2 Analytical network process (ANP)

The ANP method is a modified form of AHP [35] that copes with the problem of interdependence and feedback between criteria [32]. According to [35] computing a supermatrix is a convenient way for overcoming interdependencies among different clusters, which is known as ANP method in literature [36]. The advantages of ANP contain the capability for including dependencies and feedbacks using a hierarchical decision network as well as representing and analyzing interactions, and synthesizing their reciprocal effects by following a logical procedure [26, 37].

ANP evaluates the weights of each element using a supermatrix. The influence of each element on another one in that the network can be represented in the form of a supermatrix. The following supermatrix "B" consists of many sub-matrices (B_{ij}; $i,j = 1,2,\ldots,n$) that are used to derive the priorities of the system [35]. The general form of the supermatrix can be described as follows according to [20, 22, 23, 35].

$$B = \begin{matrix} & & c_1 & c_2 & c_3 & \dots & c_n \\ & & d_{11} & d_{12} & d_{13} & \dots & d_{nm} \\ C_1 & d_{11} & B_{11} & B_{12} & B_{13} & \dots & B_{1n} \\ C_2 & d_{12} & B_{21} & B_{22} & B_{23} & \dots & B_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ C_n & d_{nm} & B_{n1} & B_{n2} & B_{n3} & \dots & B_{nn} \end{matrix} \quad (8)\ [20; 22]$$

where "C_n" denotes the n-th cluster, "d_{nm}" denotes the m-th element in n-th cluster, and "B_{uv}" is the principal eigenvector of the influence of the elements compared in the v-th cluster to the u-th cluster. In addition, if the v-th cluster has no impact on the u-th cluster, then "B_{uv}" takes the form as $B_{uv} = [0]$.

A step-wise procedure was followed by investigating the human factor in maritime accidents. First, the DEMATEL method was used to derive the network relationship map. As the next step, the total-influence matrix "K" and threshold value "α" are derived to generate a new matrix. The values of the clusters in matrix "K" are reset to zero if their values are less than the decided threshold value. This is because, if an element has a value lower than "α" in matrix "K" then the effect of this element on the cluster can be omitted for simplifying the outcomes. The "α" value is generally decided by decision-makers or experts. The new matrix is called α-cut total-influence matrix "$K\alpha$", as in Equation (9).

$$K_\alpha = \begin{bmatrix} k_{11}^\alpha & \dots & k_{1v}^\alpha & \dots & k_{1n}^\alpha \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ k_{u1}^\alpha & \dots & k_{uv}^\alpha & \dots & k_{un}^\alpha \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ k_{n1}^\alpha & \dots & k_{nv}^\alpha & \dots & k_{nn}^\alpha \end{bmatrix} \rightarrow d_1 = \sum_{v=1}^{n} k_{1v}^\alpha \quad (9)$$

where if $K_{UV} < \alpha$, then $K_{UV} = 0$, else $k^\alpha uv = k_{uv}$, and k_{uv} is in the total influence matrix K. The α-cut total-influence matrix "K_α" needs to be normalized by applying the following equation:

$$d_1 = \sum_{v=1}^{n} k^\alpha uv \quad (10)$$

Therefore, α-cut total-influence matrix could be normalized and represented as "K_s".

$$K_s = \begin{bmatrix} k_{11}^\alpha/d_1 & \dots & k_{1v}^\alpha/d_1 & \dots & k_{1n}^\alpha/d_1 \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ k_{u1}^\alpha/d_u & \dots & k_{uv}^\alpha/d_u & \dots & k_{un}^\alpha/d_u \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ k_{n1}^\alpha/d_n & \dots & k_{nv}^\alpha/d_n & \vdots & k_{nn}^\alpha/d_n \end{bmatrix} = \begin{bmatrix} k_{11}^s & \dots & k_{1v}^s & \dots & k_{1n}^s \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ k_{u1}^s & \dots & k_{uv}^s & \dots & k_{un}^s \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ k_{n1}^s & \dots & k_{nv}^s & \dots & k_{nm}^s \end{bmatrix} \quad (11)$$

This study adopts the normalized α-cut total-influence matrix "K_s" (hereafter "*the normalized matrix*") and the unweighted supermatrix "B" using Equation (11) to calculate the weighted supermatrix "B_b". Equation (12) shows this influence level of the values as the basis of the normalization for determining the weighted supermatrix.

$$B_b = \begin{bmatrix} k_{11}^s \times B_{11} & \dots & k_{21}^s \times B_{12} & \dots & k_{1n}^s \times B_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ k_{u1}^s \times B_{21} & \dots & k_{uv}^s \times B_{22} & \dots & k_{un}^s \times B_{un} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ k_{n1}^s \times B_{n1} & \dots & k_{nv}^s \times B_{n2} & \dots & k_{nn}^s \times B_{nn} \end{bmatrix} \quad (12)$$

As a final step, the limit of the weighted supermatrix is taken by raising it to a sufficiently large power "k", as in Equation (13), until the supermatrix is converged and becomes a long-term stable supermatrix to get the global priority vectors or weights.

$$\lim_{k \to \infty} B^k \quad (13)$$

The overall priorities are also obtained by applying Equation (13).

3. EMPIRICAL STUDY

An empirical example for the most important criteria selection for the human errors in maritime accidents is illustrated to demonstrate the proposed method to be more rational and suitable in this section. A decision-making team was invited to answer the questionnaire. The computations of DEMATEL and ANP methods are based on an expert team consisting of six persons providing scores and judgments. The establishment of the network relationship among criteria that influence each other for the human error selection involves a decision-making team which includes 2 academicians, 2 experienced officers and 2 captains with long working experience. The criteria and sub-criteria have been determined according to the IMO (International Maritime Organization) A. 849(20) Code, these major influencing criteria and sub-criteria involved in human error selection are given in *Table 1*. Then, the decision-making team E1, E2, . . . E6 is invited to determine the network relationships and give the performance scores for each expert in terms of all criteria in the evaluation of hierarchical structure, respectively. A

Table 1 - Criteria and sub-criteria for the human error selection

Criteria	Sub-criteria
External influences and environment (C1)	Weather and sea conditions (C11) Port and transit conditions (C12) Traffic density (C13) Ice conditions (C14) Organizations representing ship owners and seafarers (C15) Regulations, surveys and inspections (C16)
Shore-side management (C2)	Policy on recruitment (C21) Safety policy and philosophy (C22) Management commitment to safety (C23) Scheduling of leave periods (C24) General management policy (C25) Port scheduling (C26) Contractual and/or industrial arrangements... (C27) Assignment of duties (C28) Ship-shore communication (C29)
Ship Factor (C3)	Design (C31) State of maintenance (C32) Equipment (C33) Cargo characteristics... (C34) Certificates (C35)
People Factor (C4)	Ability, skills, knowledge (C41) Personality (C42) Physical condition (C43) Activities prior to accident/occurrence (C44) Assigned duties at time of accident/occurrence (C45) Actual behavior at time of accident/occurrence (C46) Attitude (C47)
Organization on board (C5)	Division of tasks and responsibilities (C51) Composition of the crew (C52) Manning level (C53) Workload/complexity of tasks (C54) Working hours/rest hours (C55) Procedures and standing orders (C56) Communication (C57) On-board management and supervision (C58) Organization of on-board training and drills (C59) Teamwork, including resource management (C510) Planning (C511)
Working and living conditions (C6)	Level of automation (C61) Ergonomic design of working, living conditions(C62) Adequacy of living conditions (C63) Opportunities for recreation (C64) Adequacy of food (C65) Level of ship motion, vibrations, heat and noise (C66)

questionnaire was used to find out influential relations from each expert for ranking each criterion on the appropriate human error with a four-point scale ranging from 0 to 4, representing from 'No influence (0),' to 'Very high influence (4),' respectively. For each pair-wise comparison, the decision-making team has to determine the intensity of the relative importance between two criteria.

The computation of using DEMATEL technique is based upon these six experts' opinions. So, there are 6 dimensions by 6×6 matrices. Using the 6×6 pair-wise comparisons, the total average scores for each expert's opinion were calculated .Then, the average initial direct matrix "*Z*" is obtained based on Equation (1) as in *Table 2*.

Normalized initial direct-relation matrix "*M*" is calculated through Equations (2) and (3). Sequentially, the total relation matrix "*K*" is also derived utilizing Equation (4) shown in *Table 3*.

Total sum of effects given and received by each criterion is seen in *Table 3* using Equations (6) and (7).

Table 4 provides the direct and indirect effects of six dimensions. Finally, the threshold value (0.7218) used for computing the average of each element in Matrix "*K*". The digraph of six dimensions was demonstrated and the network relationship map of DEMATEL method was obtained as shown in *Figure 1*.

Table 4 shows that "*external influences and environment*" is the most important dimension with the largest (D + R) value of 9.217 whereas "*organization on board*" is the least important dimension with the weight of 6.659. The importance of dimensions can be determined by the (D + R) values. Positive (D-R) values for "*shore-side management*", "*ship factor*" and "*working - living conditions*" can be evaluated as net causes in terms of cause-effect relationship because of the positive values of (D-R). On the contrary, "*external influences and environment*", "*people factor*" and "*organization on board*" are net receivers due to negative (D - R) values. Furthermore, "*working and living conditions*", "*shore-side management*", and "*ship factor*" are the most important dimensions considering

Table 2 - Initial direct matrix Z

Criteria	External influences and environment	Shore-side management	Ship factor	People factor	Organization on board	Working and living conditions
External influences and environment	0	0.348	0.315	0.421	0.210	0.329
Shore-side management	0.304	0	0.185	0.256	0.189	0.165
Ship factor	0.215	0.289	0	0.287	0.121	0.324
People factor	0.278	0.201	0.325	0	0.341	0.292
Organization on board	0.168	0.214	0.203	0.320	0	0.242
Working and living conditions	0.185	0.165	0.258	0.125	0.345	0

Table 3 - Total influential relation matrix K

Criteria	External influences and environment	Shore-side management	Ship factor	People factor	Organization on board	Working and living conditions	Rv
External influences and environment	0.686	1.156	0.985	1.216	0.412	1.029	5.484
Shore-side management	0.890	0.712	0.328	0.551	0.384	0.385	3.25
Ship factor	0.623	0.625	0.527	0.659	0.289	0.986	3.709
People factor	0.725	0.589	1.126	0.587	0.695	0.658	4.38
Organization on board	0.387	0.603	0.624	0.703	0.587	0.603	3.507
Working and living conditions	0.421	0.487	0.584	0.325	0.785	0.587	3.189
Du	3.733	4.172	4.174	4.085	3.152	4.248	

Table 4 - Sum of influences given and received for each criterion

Criteria	Du+Rv	Du-Rv
External influences and environment	9.217	-1.757
Shore-side management	7.422	0.922
Ship factor	7.883	0.465
People factor	8.465	-0.295
Organization on board	6.659	-0.355
Working and living conditions	7.437	1.059

the causal relations for investigation of human error (*Figure 1*). Specifically, "*working and living condition*" directly affect "*organization on board*" and "*people factor*" because of the fact that "*ship factor*", "*external influences and environment*" and "*people factor*" have impacts on "*working and living conditions*". Six dimensions are influenced or mutually influenced by any pair of dimensions except "*organization on board*" and "*working and living conditions*". In summary, "*working and living conditions*" is the most important dimension followed by "*shore-side management*" and then "*ship factor*".

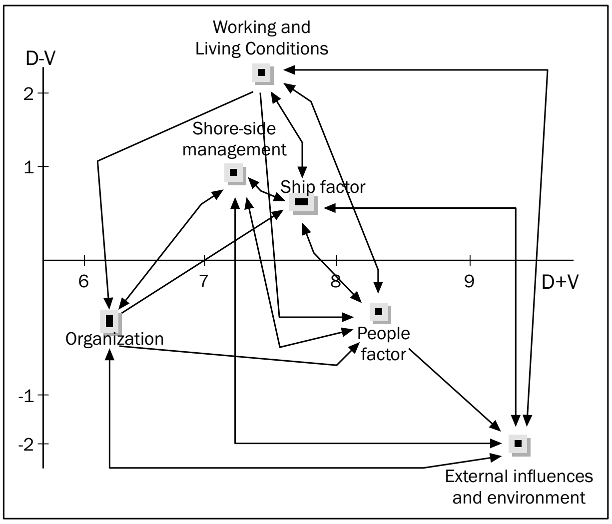

Figure 1 - Network relationship map of impacts for the human error selection

3.1 Calculating the weights of criteria by ANP

In this study, the normalized matrix "K_z", which is based on DEMATEL method results, is combined to the procedure of the ANP method. The interactive network link of the clusters that are under influence of human factor was found by applying DEMATEL. As the next step, the major human error selection criteria are investigated using the ANP method. Then, the total influence matrix is calculated by using Equations (8, 9)

Table 5 - Normalized total influence matrix Ks

	External influences and environment	Shore-side management	Ship factor	People factor	Organization on board	Working and living conditions
External influences and environment	0.0815	0	0.8067	0.8752	0	0.3214
Shore-side management	0.8425	0	0	0.0728	0	0.4924
Ship factor	0.0841	0.4125	0.1387	0.0871	0	0.1427
People factor	0.7587	0.1423	0.4520	0	0.1024	0.0573
Organization on board	0	0	0.0571	0.1587	0.0125	0.0257
Working and living conditions	0.0740	0.0521	0.1935	0.0475	1	0.412

Table 6 - The unweighted supermatrix

	C11	C12	C13	C14	C15	C16	C41	C42	C43	C44	C45	C46	C47	C31	C32	C33	C34	C35
C11	0	0.036	0.174	0.016	0	0.614	0.009	0.012	0.180	0.604	0.030	0.328	0.112	0.010	0.644	0.002	0.033	0.318
C12	0	0.012	0.058	0.321	0.042	0	0.011	0.047	0.047	0	0.051	0.010	0.008	0.050	0	0	0.069	0.009
C13	0.401	0.072	0.051	0.112	0.513	0	0.241	0.003	0.003	0.644	0	0.241	0.012	0	0.401	0.239	0.203	0.644
C14	0.081	0.018	0.062	0.008	0.050	0.033	0.318	0.007	0.047	0.328	0.419	0.318	0.271	0.419	0	0.030	0.042	0.328
C15	0.180	0.021	0	0.012	0.052	0.069	0.009	0.285	0.180	0.644	0.030	0.009	0.112	0.644	0	0.051	0	0
C16	0.047	0.074	0	0.271	0.019	0.203	0.644	0	0.047	0.328	0.051	0.644	0.180	0.328	0.033	0.117	0.008	0.644
C41	0.003	0.037	0	0.328	0.028	0.048	0.328	0.029	0	0.010	0.117	0.328	0.047	0.117	0.069	0.419	0.012	0.328
C42	0.047	0	0.042	0.008	0	0.030	0.117	0.031	0.401	0.050	0.008	0	0.003	0.008	0.203	0.019	0.644	0.618
C43	0.048	0.002	0.033	0	0.032	0.051	0.008	0	0	0	0.048	0.029	0.047	0.048	0.048	0.028	0.008	0.328
C44	0.030	0.052	0.041	0	0.052	0.048	0.048	0.278	0.042	0.419	0.644	0.031	0.180	0.644	0.644	0	0.012	0
C45	0.051	0.019	0.017	0.029	0.012	0.030	0.057	0.004	0	0.644	0	0	0	0	0.328	0.032	0.271	0.051
C46	0.072	0.028	0.032	0.031	0.009	0.051	0.072	0.008	0.008	0.008	0.401	0.278	0	0.401	0.010	0.052	0.344	0
C47	0	0	0.069	0	0.011	0	0.322	0.048	0.012	0.012	0	0.033	0	0.081	0.050	0.019	0.051	0.419
C31	0.021	0.032	0	0.278	0.241	0.419	0.411	0.644	0.271	0.271	0.042	0.041	0	0.180	0	0	0	0.030
C32	0.033	0.381	0.038	0.004	0.318	0.644	0.003	0	0	0.328	0.513	0.017	0.644	0.047	0.644	0.021	0.419	0.011
C33	0.018	0.213	0.013	0.059	0.464	0.328	0.038	0.401	0.042	0.008	0.050	0.032	0.328	0	0	0	0.030	0.050
C34	0	0	0.023	0.291	0.021	0.117	0.043	0.117	0.513	0	0.052	0.401	0.271	0.411	0.042	0.032	0.020	0.052
C35	0.028	0.082	0.035	0.017	0.310	0	0	0.398	0.278	0.005	0	0	0.328	0.003	0.033	0.011	0.081	0.011

Table 7 - The weighted supermatrix

	C11	C12	C13	C14	C15	C16	C41	C42	C43	C44	C45	C46	C47	C31	C32	C33	C34	C35
C11	0	0.008	0.023	0.019	0	0.018	0.033	0.271	0.028	0.021	0.001	0.050	0.009	0.012	0.031	0.048	0.029	0.012
C12	0	0.042	0.044	0.030	0.030	0	0.069	0.019	0.010	0	0.023	0.008	0.049	0.008	0	0	0.005	0.041
C13	0.072	0.025	0.037	0.011	0.051	0	0.203	0.080	0.008	0.018	0	0.048	0.068	0	0.009	0.012	0.008	0.010
C14	0.066	0.002	0.018	0.050	0.017	0.016	0.042	0.047	0.048	0.032	0.112	0.057	0.030	0.032	0	0.062	0.042	0.040
C15	0.045	0.003	0	0.008	0.008	0.021	0.033	0.003	0.044	0.023	0.008	0.018	0.011	0.052	0	0.078	0	0
C16	0.024	0.002	0	0.048	0.048	0.012	0.011	0	0.008	0.011	0.012	0.003	0.050	0.012	0.012	0.038	0.049	0.045
C41	0.018	0.001	0	0.057	0.001	0.008	0.050	0.042	0	0.001	0.069	0.002	0.052	0.009	0.071	0.043	0.033	0.031
C42	0.023	0	0.017	0.008	0	0.012	0.008	0.033	0.004	0.002	0.028	0	0.011	0.011	0.012	0.027	0.011	0.066
C43	0.044	0.021	0.008	0	0.112	0.071	0.048	0	0	0	0.008	0.017	0.010	0.002	0.061	0.030	0.046	0.045
C44	0.037	0	0.048	0	0.008	0.028	0.057	0.008	0.025	0.050	0.009	0.002	0.047	0	0.002	0	0.053	0
C45	0.018	0.044	0.057	0.025	0.012	0.008	0.018	0.012	0	0.008	0	0	0	0	0.047	0.021	0.027	0.034
C46	0.053	0.008	0.072	0.002	0.271	0.009	0.003	0.075	0.002	0.048	0.018	0.003	0	0.057	0.008	0.044	0.059	0
C47	0	0	0.117	0	0.012	0	0.002	0.012	0.003	0.057	0	0.009	0	0.008	0.048	0.052	0.063	0.032
C31	0.042	0.008	0	0.041	0.080	0.009	0.004	0.083	0.002	0.008	0.002	0.011	0	0.050	0	0	0	0.052
C32	0.033	0.048	0.002	0.018	0.047	0.011	0.033	0	0	0.050	0.013	0.038	0.008	0.023	0.001	0.028	0.047	0.012
C33	0.027	0.057	0.003	0.009	0.003	0.041	0.041	0.032	0.008	0.023	0.003	0.042	0.048	0	0	0	0.019	0.009
C34	0	0	0.002	0.044	0.047	0.018	0.017	0.052	0.048	0	0.021	0.001	0.057	0.021	0.008	0.046	0.033	0.011
C35	0.011	0.017	0.002	0.028	0.080	0	0	0.012	0.057	0.014	0	0	0.008	0.011	0.007	0.033	0.014	0.002

Table 8 - Limiting supermatrix

	C11	C12	C13	C14	C15	C16	C41	C42	C43	C44	C45	C46	C47	C31	C32	C33	C34	C35
C11	0.0821	0.0821	0.0821	0.0821	0.0821	0.0821	0.0821	0.0821	0.0821	0.0821	0.0821	0.0821	0.0821	0.0821	0.0821	0.0821	0.0821	0.0821
C12	0.0619	0.0619	0.0619	0.0619	0.0619	0.0619	0.0619	0.0619	0.0619	0.0619	0.0619	0.0619	0.0619	0.0619	0.0619	0.0619	0.0619	0.0619
C13	0.0769	0.0769	0.0769	0.0769	0.0769	0.0769	0.0769	0.0769	0.0769	0.0769	0.0769	0.0769	0.0769	0.0769	0.0769	0.0769	0.0769	0.0769
C14	0.0187	0.0187	0.0187	0.0187	0.0187	0.0187	0.0187	0.0187	0.0187	0.0187	0.0187	0.0187	0.0187	0.0187	0.0187	0.0187	0.0187	0.0187
C15	0.0321	0.0321	0.0321	0.0321	0.0321	0.0321	0.0321	0.0321	0.0321	0.0321	0.0321	0.0321	0.0321	0.0321	0.0321	0.0321	0.0321	0.0321
C16	0.0431	0.0431	0.0431	0.0431	0.0431	0.0431	0.0431	0.0431	0.0431	0.0431	0.0431	0.0431	0.0431	0.0431	0.0431	0.0431	0.0431	0.0431
C41	0.0894	0.0894	0.0894	0.0894	0.0894	0.0894	0.0894	0.0894	0.0894	0.0894	0.0894	0.0894	0.0894	0.0894	0.0894	0.0894	0.0894	0.0894
C42	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721
C43	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877
C44	0.0575	0.0575	0.0575	0.0575	0.0575	0.0575	0.0575	0.0575	0.0575	0.0575	0.0575	0.0575	0.0575	0.0575	0.0575	0.0575	0.0575	0.0575
C45	0.0712	0.0712	0.0712	0.0712	0.0712	0.0712	0.0712	0.0712	0.0712	0.0712	0.0712	0.0712	0.0712	0.0712	0.0712	0.0712	0.0712	0.0712
C46	0.0659	0.0659	0.0659	0.0659	0.0659	0.0659	0.0659	0.0659	0.0659	0.0659	0.0659	0.0659	0.0659	0.0659	0.0659	0.0659	0.0659	0.0659
C47	0.0597	0.0597	0.0597	0.0597	0.0597	0.0597	0.0597	0.0597	0.0597	0.0597	0.0597	0.0597	0.0597	0.0597	0.0597	0.0597	0.0597	0.0597
C31	0.0624	0.0624	0.0624	0.0624	0.0624	0.0624	0.0624	0.0624	0.0624	0.0624	0.0624	0.0624	0.0624	0.0624	0.0624	0.0624	0.0624	0.0624
C32	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762
C33	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125
C34	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021
C35	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285

and the normalized total influence matrix " K_s " is computed by using Equation (10) shown in *Table 5*.

Network relation map showed that "*external influences and environment*" is a key factor. The cluster effect of the current survey is formed by three main criteria which are "*external influences and environment, people factor and ship factor*". Therefore, sub-criteria of major factors in cluster effect are compared. The normalized direct-relation matrix was obtained within three major factors and sub-criteria by Equation (2). Then, an unweighted supermatrix can be obtained by using Equation (11) as in *Table 6*. By applying Equation (12), the weighted supermatrix is determined as shown in *Table 7*.

By calculating the limiting power of the influential cluster-weighted supermatrix, Equation (13) is applied until a steady-state condition has been achieved. Finally, the weights of each sub-criterion can be obtained as shown in *Table 8*.

4. RESULTS AND DISCUSSION

According to the weights of each sub-criterion, the factor clusters with very high contribution impact appeared in the first stage. In order to eliminate factors that have little or almost no impacts on ship accidents, the distance between priority weights is a convenient technique. Each row in *Table 8* represents the weight of each criterion. Quantitative empirical data analysis revealed that human errors in maritime accidents can be ranked as follows: C41, C43, C11, C13, C32, C42, C45, C46, C31, C12, C47, C44, C16, C15, C35, C14, C33, and C34. The top three factors are C41, C43 and C11 with total weight ratios as 8.94%, 8.77% and 8.21%, respectively. Moreover, criteria that are considered most important by expert opinions are found to be "*ability, skill and knowledge*" of the seaman, whereas the least important one is the "*cargo characteristics*". Interestingly, "*physical condition*" and dynamic "*weather and sea states*" are also found to be very effective in occurrence of accidents.

Findings of the current study indicate that after determination of weight matrix of all criteria, the most effective factors can be decided by the proposed methodology. The hybrid MCDM methodology has been proven very helpful in the decision-making processes of a management strategy. MCDM technique is widely used in airline safety, site selection problems, e-learning educational programs and market management procedures as reported by [20, 21, 22, 23, 25, 33]. Specifically, human error in shipping accidents was also investigated by [17]. This study proposed a quantitative methodology based on fuzzy analytical hierarchy process for determining the most important human factors. Similar to our findings of the current study, the authors found that skill-based factors are placed in the first category. Our results showed that ability, skills, knowledge and physical conditions are very important for determining of human factor in maritime accidents. However, it is also stressed in literature that crews who constantly change the working environment tend to encounter difficulties because of different cargo types, ship type and ship size as well as changing technological and handling devices on board. Moreover, recent automation technologies require necessary training and experience to be effectively used on-board for not causing an unwanted incident.

According to the second level of the influential criteria of the main factors, "*external influences and environment*" highly affect the accident occurrence at sea with related sub-criteria such as weather and sea conditions (C11) and traffic density (C13). Naturally, marine environment is under the influence of dynamic very harsh oceanographic conditions. Currents, winds, waves and fog create a dangerous working environment for a sailing ship by increasing the risk factor as the weather system deviates from the normal conditions. Therefore, ship stability plays an important role in avoiding a potential accident if all environmental conditions are taken into account at a certain limit during the feasibility project. Otherwise, the result can be catastrophic and may lead to ship facing greater risk [18].

From the main criteria, the "*ship factor*" (C3) influences human errors onboard ship with 7.62%, depending on the "*maintenance state*" (C32) of the ship. More clearly, the maintenance state refers to some important factors such as crew fatigue, emergency equipment and repairs, lack of working back-up systems and some other poor maintenance issues. Poor maintenance can also lead to problems such as fires or explosions. Besides, poor equipment design is reported as the main factor in one-third of marine accidents [38]. Therefore, it is necessary to seek onboard equipment that does not interfere but supports the operations by fitting into the entire equipment suite [18].

The results of the study can be used in preventive measures during operational or managerial efforts by considering the priority weight of each factor affecting the accident case. The most important result of the current study is the quantitative ranking of human-related factors which makes the human element the focal point of the maritime accidents. In fact, in some other studies, poor crew competence, inadequate communication, lack of proper maintenance and safety measures and seamanship training are reported as main factors of a maritime accident incidence [3, 17, 39, 40], whereas our approach puts the "*skill, knowledge and ability*" at the first level. The proposed approach can be used to reduce the human-induced maritime accidents number by decreasing inherent potential error, optimizing onboard workflow and improving the crisis management in case of emergency situation by taking into account quantitative results of the maritime accident causes.

5. CONCLUSION

This paper proposed a hybrid MCDM approach for identifying and ranking the influential criteria of human errors in maritime casualties. Although the human error in maritime accident is a kind of MCDM problem, there is a limited MCDM study which focuses on maritime accidents.

The results of this study show that the most important reasons concerning people factor are "*ability, skills, knowledge*" (8.94%), and "*physical conditions*" (8.77%). These are the top two priorities in the evaluation system suggested in this paper. Maritime accidents are still the main problem of the worldwide maritime industry. Leading international maritime authorities and agencies seek for solutions of the problem. However, for a number of years, people factors have been recognized by IMO as the major safety factors in maritime accidents. This study indicates that the maritime system is a human-induced system, and human errors are part of the maritime workflow. Therefore, in order to improve our knowledge on maritime operations and reduce associated marine accident incidents to an acceptable level, there should be a focus on the types of human errors causing risks onboard a ship and try to enhance the technological infrastructure of merchant ships.

The current study enables the following contributions to the literature on shipping accident analysis caused by human errors. The study suggests extending of the existing MCDM model by following a hybrid MCDM approach for investigating the human related maritime accidents. The proposed methodology can effectively deal with any type of problem with interdependent changing factors. In addition to the human error problem, the model can be applied to some other maritime problems with interdependence or feedback effects. This approach also provides a relatively easy and very convenient technique for strategic decision-making problems.

The proposed methodology is expected to help to reduce the human factor in maritime casualties. The decision-makers and maritime authorities should follow the findings of the current study as they are based on analytical approach when dealing with risk assessment or technological improvements of onboard instruments. It is very important to know what factors trigger an accident caused by human error onboard a ship. Finally, the results can be useful for improving safety measures in shipping industry as well as guiding to upcoming maritime regulations.

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ÖZET

STRATEJİK BİR MODEL YAKLAŞIMI İLE DENİZ KAZA SEBEPLERİNİN ARAŞTIRILMASI

Denizlerde meydana gelen kazaların büyük bir bölümünün insan kaynaklı hatalardan kaynaklandığı bilinmektedir. Deniz kazlarının oluşumunda insan faktörünün önemi ve buna neden olan unsurlar uzman görüşleri ve Çok Kriterli Karar Verme (ÇKKV) yöntemleri kullanılarak belirlenebilir. Bu çalışmada, gemi kazalarında insan faktörünü öne çıkaran etkiler bütünleşik bir karar verme yaklaşımı ile belirlenmiştir. Analitik Ağ Süreci (AAS) ve DEMATEL yöntemlerinin birlikte kullanılması ile hangi kriterlerin insan kaynaklı deniz kazalarının meydana gelmesinde etkili olduğu araştırılmıştır. İnsan hatalarının kantitatif olarak ortaya konması denizcilik operasyonlarında karar verme sürecinin geliştirilmesine katkı sağlayabileceği gibi bu operasyonlar sırasında oluşabilecek risklerin azaltılmasına da yardımcı olabilir. Çalışmanın sonucu olarak deniz kazalarında insanın hata yapmasında rol oynayan en önemli nedenlerin % 8,94'lük oran ile "yetenek, beceri, bilgi"; % 8.77 oran ile "fiziksel kondisyon-durum", % 8.21'lik oran ile "hava ve deniz durumu" olduğu tespit edilmiştir. Buna karşın, en önemsiz sebebin ise % 2.21'lik oran ile "yük karakteristiği" olduğu belirlenmiştir.

ANAHTAR KELİMELER

deniz kazası; çok kriterli karar verme yöntemi; deneyimsel karar verme ve değerlendirme; analitik ağ süreci;

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