APPLICATION OF INTERVAL TYPE-2 FUZZY SETS DEMATEL METHODS IN MARITIME TRANSPORTATION: THE CASE OF SHIP COLLISION

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SUMMARY

Accident analyse in marine industry is one of the critical issues for safety practitioners to prevent loss of life. Although considerable efforts were undertaken to prevent marine accident, numerous researches revealed that marine accidents are still on-going. In order to minimize accidents in the marine transportation, this paper presents a proactive decision-making tool which is integrating Decision-Making Trail and Evaluation Laboratory (DEMATEL) method with interval type-2 fuzzy sets (IT2FSs). As the DEMATEL enables to analyse cause and effect relationship in decision-making, the IT2FSs overcome ambiguity and vagueness of linguistic assessment of decision-makers through the DEMATEL. Thus, significant accident causal factors and their effects can be analysed on the basis of cause-effect diagram. The application of proposed approach is demonstrated with a real ship collision case. Beside its theoretical contribution, the proposed approach provides practical benefits to ship owners and operators to perceive cause and effect relationship and to avoid marine accident.

1. INTRODUCTION

Maritime transportation has been growing significantly over the last decades since more than about 80% of volume of international cargo trade is carried by ships (UNCTAD, 2015[48]). The statistics show that the world ship fleet grew by 3.5% during the last year (UNCTAD, 2015[48]) since the carriage of cargo by ship is considered as one of the safer and economical method comparing to the others. On the other hand, ship accident at sea may severely damage to the marine environment in case oil spill pollution occurred. Therefore, maritime authorities have been seeking alternative solutions to minimize ship accidents, in particular accidents that may result with environmental disaster. In this context, there are a set of conventions and regulations adopted such as SOLAS (International Convention for the Safety of Life at Sea), COLREG (The International Regulations for Preventing Collisions at Sea), STCW (International Convention on Standard of Training Certification, and Watchkeeping for Seafarers) and etc. Specifically, the SOLAS becomes a prominent convention concerning the safety improving at sea. The primary aim of the convention is to provide minimum standards for the equipment, construction, and operation of ships (IMO, 2015[28]; Akyuz and Celik, 2014a[6]). Likewise, the COLREG was accepted by International Maritime Organisation (IMO) by the aim of providing a set of rules to avoid ship collision at sea. It is the one of three most significant complementing key conventions of the IMO. Despite significant regulatory improvements were adopted by regulatory body in recent decades, maritime accidents are still on-going (Gaonkar et al., 2011[23]; Akyuz, 2015a[4]).

According to the EMSA annual overview of marine accident causality report, collision/contact is placed on the top since it represents more than 35% of the total number of ship accidents around European Union seas (EMSA, 2015[19]). Therefore, considerable researches have been undertaken in recent years to minimize marine accidents, particularly collision incidents at sea. A number of ship collision studies focused on damages to ship hull and structure (Talley, W.K., 1996[46]; Tabri, 2012[45]; Haris and Amdhl, 2012[26]; Papanikolaou et al., 2013[42]; Storheim and Amdahl, 2014[43]). In general; structural design, extend of damage, ship stability and strength of hull plating are discussed in mentioned studies in the event of collision. Risk assessment in ship collision is also highly cited topics in the literature. There are a couple of well-designed studies to assess risk and sustainability associated with ship collision accidents (Qu and Li Suyi, 2011[44]; Karahalios, 2014[31]; Dong and Frangopol, 2015[20]; Goerlandt et al., 2015[24]; Ugurlu et al., 2015[47]). On the other hand, there are some other studies associated with the ship accident investigation and analysing such as analytical HFACS approach which was proposed by Celik and Cebi (2009)[12]. The aim of the authors is to identify the role of human errors in shipping accidents. Similarly, the HFACS-Coll was introduced to perform a systemic analyse for the role of human and organisational factors (Chauvin et al., 2013[17]). Moreover, another model based approach was presented by Mullai and Paulsson (2011)[41] to create a conceptual framework for analysis of marine accidents. The authors mainly utilise statistical data to transform into useful information. Furthermore, a robust accident analyse and investigation tool was proposed to classify the causal factors in marine accident (Chen et al., 2013[16]). The paper presents a comprehensive framework addressed to IMO guidelines with respect to the human factor significant. A hybrid marine accident analysis and prevention tool, namely called HFACS-CM, was introduced to exercise an elaborative analyse for role of the human factor in marine accident (Akyuz and Celik, 2014b[5]). Likewise, a hybrid marine accident analysis technique has recently been introduced in order to investigate marine accident analytically by combining Accident Analyse Mapping (AcciMap) and Analytical Network Process (ANP) methods (Akyuz, 2015a[4]).

Marine accident analyse are quite critical for preventing loss of life and marine environment pollution. In this context, this paper prompts a methodological approach to analyse marine accident on the basis of cause and effect relationship in decision-making. The proposed approach combines the DEMATEL and IT2FSs methods in order to present a proactive marine accident analysing tool. The proposed approach is demonstrated with a real-case collision accident application to prevent similar accident in advance.

Within this scope, the research is organised as follows. This section explains motivation of the study and presents brief literature review about marine accident analysis in industry. The next section describes research methodologies and the proposed approach. Section three provides a real-case collision accident application as a demonstration of the proposed approach. The final section involves conclusion and contribution of the study into marine industry.

2. METHODOLOGY

In order to design a conceptual framework for marine accident analysing perspective, this paper takes benefit of interval type-2 fuzzy sets and DEMATEL methods. Accordingly, next parts will define both methodologies and their integration.

2.1 INTERVAL TYPE-2 FUZZY SETS

Type-2 fuzzy set is as an extension of the concept of a type-1 fuzzy set (Karnik and Mendel, 2001[32], Mendel, 2007a[38]) which was proposed and developed by Zadeh (1975)[50]. Indeed, an interval type-2 fuzzy set is a special case of a general type-2 fuzzy set and the most frequently used type-2 fuzzy sets (Mendel, 2007b[39]) because of its convenience (Mendel et al. 2006[40]) and less complexity calculation exercise by comparison general type-2 fuzzy sets. It includes for more uncertainty. Hence, produce more exact and robust consequences. Therefore, it is comprehensively implemented in various application areas (Mendel, 2009[37]). Different literature review for IT2FSs is presented as follows: industrial applications, design and optimization of interval type-2 fuzzy controllers, optimization of the type-2 fuzzy systems based on bio-inspired methods, classification, and MCDM approaches based on IT2FSs and etc. (Akyuz and Celik, 2016[2]; Melin and Castillo, 2013[36]; Dereli et al. 2011)[18].

The fundamental definitions of the type-2 fuzzy sets and IT2FSs are presented from Mendel et al. (2006)[40], Celik et al. (2013, 2014, 2015)[14,13,15], Kahraman et al. (2014)[30], Aydın et al. (2015)[8].

Definition 1: A type-2 fuzzy set $\tilde{\tilde{A}}$ in the universe of discourse X can be illustrated by a type-2 membership function $\mu_{\tilde{\tilde{A}}}$, given as follows:

$$\tilde{\tilde{A}} = \left\{ ((x,u), \mu_{\tilde{\tilde{A}}}(x,u)) \middle| \begin{array}{l} \forall x \in X, \\ \forall u \in J_X \subseteq [0,1] \end{array}, 0 \le \mu_{\tilde{\tilde{A}}}(x,u) \le 1 \right\}$$

where J_X states an interval in [0, 1]. Moreover, the type-2 fuzzy set $\tilde{\tilde{A}}$ also can be illustrated as below;

$\tilde{\tilde{A}} = \int_{x\in X} \int_{u \in J_X} \mu_{\tilde{\tilde{A}}}(x,u) / (x,u)$ where $J_X \subseteq [0,1]$ and $\iint$ express union over all admissible x and u.

Definition 2: Let $\tilde{\tilde{A}}$ be a type-2 fuzzy set in the universe of discourse X showed by the type-2 membership function $\mu_{\tilde{\tilde{A}}}$. If all $\mu_{\tilde{\tilde{A}}}(x,u) = 1$, then $\tilde{\tilde{A}}$ is called as an interval type-2 fuzzy set. An interval type-2 fuzzy set $\tilde{\tilde{A}}$ can be considered as a special case of a type-2 fuzzy set and it is expressed as below;

$\tilde{\tilde{A}} = \int_{x\in X} \int_{u \in J_X} 1 / (x,u)$ where $J_X \subseteq [0,1]$

Definition 3: The type-1 fuzzy sets membership functions constitute both upper and the lower membership function of an interval type-2 fuzzy set. In order to deal with fuzzy multiple attributes group decision-making issue in which reference points as well as level of the upper and lower membership functions of IT2FSs are utilized to address type-2 fuzzy sets, this paper adopts IT2FSs. As illustrated in Figure 1,

$$\tilde{\tilde{A}}_i = \left(\tilde{A}_i^U, \tilde{A}_i^L\right) = \left(\begin{array}{l} \left(a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U; H_1\left(\tilde{A}_i^U\right), H_2\left(\tilde{A}_i^U\right)\right), \\ \left(a_{i1}^L, a_{i2}^L, a_{i3}^L, a_{i4}^L; H_1\left(\tilde{A}_i^L\right), H_2\left(\tilde{A}_i^L\right)\right) \end{array} \right),$$

whilst $\tilde{A}_i^U$ and $\tilde{A}_i^L$ are type-1 fuzzy sets, $a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U, a_{i1}^L, a_{i2}^L, a_{i3}^L$ and a_{i4}^L are the reference points of the interval type-2 fuzzy $\tilde{\tilde{A}}_i$; $H_j\left(\tilde{A}_i^U\right)$ gives the membership value of the element $a_{i(j+1)}^U$ in the upper trapezoidal membership function $\tilde{A}_i^U$ and $1 \le j \le 2$, $H_j\left(\tilde{A}_i^L\right)$ states the membership value of the element $a_{i(j+1)}^L$ in the lower trapezoidal membership function $\tilde{A}_i^L$; $1 \le j \le 2$, $H_j\left(\tilde{A}_i^L\right)$ $H_1\left(\tilde{A}_i^U\right) \in [0,1]$, $H_2\left(\tilde{A}_i^U\right) \in [0,1]$, $H_1\left(\tilde{A}_i^L\right) \in [0,1]$, $H_2\left(\tilde{A}_i^L\right) \in [0,1]$ and $1 \le i \le n$.

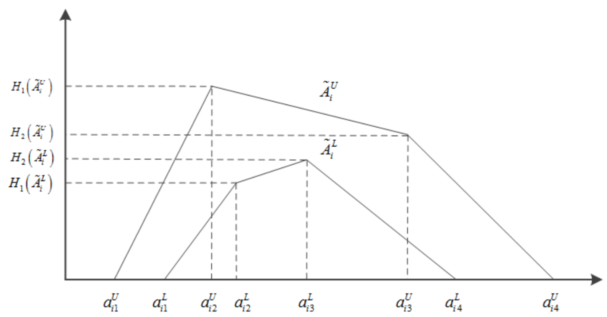

Figure 1. The trapezoidal membership function.

Some of algorithmic operations among the two IT2FSs are demonstrated as follows.

The addition operation:

$$\tilde{\tilde{A}}_1=\left(\tilde{A}_1^U,\tilde{A}_1^L\right)=\begin{pmatrix}\left(a_{11}^U,a_{12}^U,a_{13}^U,a_{14}^U;H_1\left(\tilde{A}_1^U\right),H_2\left(\tilde{A}_1^U\right)\right),\\ \left(a_{11}^L,a_{12}^L,a_{13}^L,a_{14}^L;H_1\left(\tilde{A}_1^L\right),H_2\left(\tilde{A}_1^L\right)\right)\end{pmatrix}$$

$$\tilde{\tilde{A}}_2=\left(\tilde{A}_2^U,\tilde{A}_2^L\right)=\begin{pmatrix}\left(a_{21}^U,a_{22}^U,a_{23}^U,a_{24}^U;H_1\left(\tilde{A}_2^U\right),H_2\left(\tilde{A}_2^U\right)\right),\\ \left(a_{21}^L,a_{22}^L,a_{23}^L,a_{24}^L;H_1\left(\tilde{A}_2^L\right),H_2\left(\tilde{A}_2^L\right)\right)\end{pmatrix}$$

$$\tilde{A}_1\oplus\tilde{A}_2=\left(\tilde{A}_1^U,\tilde{A}_1^L\right)\oplus\left(\tilde{A}_2^U,\tilde{A}_2^L\right)$$
$$=\begin{pmatrix}\begin{pmatrix}a_{11}^U+a_{21}^U,a_{12}^U+a_{22}^U,a_{13}^U+a_{23}^U,a_{14}^U+a_{24}^U;\\ \min\left(H_1\left(\tilde{A}_1^U\right),H_1\left(\tilde{A}_2^U\right)\right),\min\left(H_2\left(\tilde{A}_1^U\right),H_2\left(\tilde{A}_2^U\right)\right)\end{pmatrix},\\ \begin{pmatrix}a_{11}^L+a_{21}^L,a_{12}^L+a_{22}^L,a_{13}^L+a_{23}^L,a_{14}^L+a_{24}^L;\\ \min\left(H_1\left(\tilde{A}_1^L\right),H_1\left(\tilde{A}_2^L\right)\right),\min\left(H_2\left(\tilde{A}_1^L\right),H_2\left(\tilde{A}_2^L\right)\right)\end{pmatrix}\end{pmatrix}$$

The subtraction operation:

$$\tilde{A}_1\Theta\tilde{A}_2=\left(\tilde{A}_1^U,\tilde{A}_1^L\right)\Theta\left(\tilde{A}_2^U,\tilde{A}_2^L\right)$$
$$=\begin{pmatrix}\begin{pmatrix}a_{11}^U-a_{24}^U,a_{12}^U-a_{23}^U,a_{13}^U-a_{22}^U,a_{14}^U-a_{21}^U;\\ \min\left(H_1\left(\tilde{A}_1^U\right),H_1\left(\tilde{A}_2^U\right)\right),\min\left(H_2\left(\tilde{A}_1^U\right),H_2\left(\tilde{A}_2^U\right)\right)\end{pmatrix},\\ \begin{pmatrix}a_{11}^L-a_{24}^L,a_{12}^L-a_{23}^L,a_{13}^L-a_{22}^L,a_{14}^L-a_{21}^L;\\ \min\left(H_1\left(\tilde{A}_1^L\right),H_1\left(\tilde{A}_2^L\right)\right),\min\left(H_2\left(\tilde{A}_1^L\right),H_2\left(\tilde{A}_2^L\right)\right)\end{pmatrix}\end{pmatrix}$$

The multiplication operation:

$$\tilde{A}_1\otimes\tilde{A}_2=\left(\tilde{A}_1^U,\tilde{A}_1^L\right)\otimes\left(\tilde{A}_2^U,\tilde{A}_2^L\right)$$
$$=\begin{pmatrix}\begin{pmatrix}a_{11}^U\times a_{21}^U,a_{12}^U\times a_{22}^U,a_{13}^U\times a_{23}^U,a_{14}^U\times a_{24}^U;\\ \min\left(H_1\left(\tilde{A}_1^U\right),H_1\left(\tilde{A}_2^U\right)\right),\min\left(H_2\left(\tilde{A}_1^U\right),H_2\left(\tilde{A}_2^U\right)\right)\end{pmatrix},\\ \begin{pmatrix}a_{11}^L\times a_{21}^L,a_{12}^L\times a_{22}^L,a_{13}^L\times a_{23}^L,a_{14}^L\times a_{24}^L;\\ \min\left(H_1\left(\tilde{A}_1^L\right),H_1\left(\tilde{A}_2^L\right)\right),\min\left(H_2\left(\tilde{A}_1^L\right),H_2\left(\tilde{A}_2^L\right)\right)\end{pmatrix}\end{pmatrix}$$

The arithmetic operations:

$$k\tilde{\tilde{A}}_1=\begin{pmatrix}\left(k\times a_{11}^U,k\times a_{12}^U,k\times a_{13}^U,k\times a_{14}^U;H_1\left(\tilde{A}_1^U\right),H_2\left(\tilde{A}_1^U\right)\right),\\ \left(k\times a_{11}^L,k\times a_{12}^L,k\times a_{13}^L,k\times a_{14}^L;H_1\left(\tilde{A}_1^L\right),H_2\left(\tilde{A}_1^L\right)\right)\end{pmatrix}$$

$$\frac{\tilde{\tilde{A}}_1}{k}=\begin{pmatrix}\left(\frac{1}{k}\times a_{11}^U,\frac{1}{k}\times a_{12}^U,\frac{1}{k}\times a_{13}^U,\frac{1}{k}\times a_{14}^U;H_1\left(\tilde{A}_1^U\right),H_2\left(\tilde{A}_1^U\right)\right),\\ \left(\frac{1}{k}\times a_{11}^L,\frac{1}{k}\times a_{12}^L,\frac{1}{k}\times a_{13}^L,\frac{1}{k}\times a_{14}^L;H_1\left(\tilde{A}_1^L\right),H_2\left(\tilde{A}_1^L\right)\right)\end{pmatrix}$$

2.2 DEMATEL

The DEMATEL was developed to analyse complex and interacted decision making problems (Gabus and Fontela, 1972[21]). It has been commonly accepted as one of the useful method to define cause and effect relationship between the criteria (Cebi, 2013a[10]; Lin and Tzeng, 2009[34]). The theory lies behind the method is based on the graph theory whose aim is to investigate and clarify problems by visualization. Moreover, the technique provides a practical tool to reveal not only interdependence relations between the criteria but also values of influential effects (Gül et al., 2014[25]; Akyuz and Celik, 2015[3]). The basic steps of DEMATEL technique are briefly explained as follows.

Step 1: An initial direct-relation matrix is established for pair wise comparison of the criteria. To achieve this purpose, decision-makers are determined for evaluation (Cebi, 2013b[11]). The decision-makers assess effects among the each pair of criteria by adopting linguistic statements. Thus, assessments are converted to actual values. In this context, the direct-relation matrix is acquired. $A = [a_{ij}]$,

where A is a nxn non-negative matrix, a_{ij} denotes the direct impact of factor i on factor j; and when $i = j$, the diagonal elements $a_{ij} = 0$.

Step 2: In this step, normalization is performed for initial direct-relation by comparing the criteria. The normalized direct-relation matrix, which is called $D = [d_{ij}]$, can be acquired through an equation (1). All elements in the matrix D are complying with $0 \leq d_{ij} \leq 1$, and all principal diagonal elements are equal to zero.

$$D=\frac{1}{\underset{1\leq i\leq n}{max}\sum_{j=1}^{n}a_{ij}} \tag{1}$$

Step 3: The aim of this step is to calculate a total-relation matrix *(T)* by applying equation (2) where I represents nxn identity matrix. The element t_{ij} represents the indirect effects that criterion i have on criterion j, so that the matrix T gives the total relationship among the each pair of criteria.

$$T=D(I-D)^{-1} \tag{2}$$

Step 4: The sum of rows and columns of matrix T is computed. In order to accomplish this purpose, r_i and c_j

are obtained according to the equation (3) and (4). In the equations, since r_i represents all direct and indirect influence given by criterion i to all other factors, c_j gives the degree of influenced impact.

$$r_i = \sum_{1 \le j \le n} t_{ij} \quad (3)$$

$$c_j = \sum_{1 \le i \le n} t_{ij} \quad (4)$$

When $i = j$, $r_i + c_j$ presents all effects which are given and received by criterion i. The $r_i + c_j$ shows both criterion i's impact on the entire system and other system criteria impact on criteria i. Thus, the indicator $r_i + c_j$ can present the degree of importance that criterion i plays in the total system. In contrast, the difference of the two, $r_i - c_j$ shows the net effect that criterion i has on the system. Particularly, if the value of $r_i - c_j$ is positive, the criteria i is a net cause, exposing net causal effect on the system. While $r_i - c_j$ is negative, the criteria is a net result clustered into effect group (Yang et al., 2008[49]; Lee et al., 2009[33]).

Step 5: The objective of the final step is to create a cause and effect relation diagram with respect to the $r_i + c_j$ and $r_i - c_j$. Thus, a comprehensive interrelationship between the criteria is visualized through the diagram.

2.3 PROPOSED APPROACH: IT2FSs AND DEMATEL

In this section, the IT2FSs are combined with the DEMATEL technique to create a proactive marine accident analysing tool. The proposed approach takes benefits of both IT2FSs and DEMATEL. Since DEMATEL technique enables to analyse cause and effect interrelationship in decision-making, the IT2FSs overcome ambiguity and vagueness of linguistic assessment of decision-makers through the DEMATEL. The main steps of the IT2FDEMATEL is presented as follows (Hosseini and Tarokh, 2013[27]; Abdullah and Zulkifli, 2015[1]).

***Step 1 - Select a group of exp*erts**: In the first step, it is liaised with a group of experts who have sufficient knowledge and experiences about the topic.

S***tep 2 - Identify critical accident factors and build up IT2FSs scale:*** The purpose of this step is to determine critical accident factors of accident in order to perform a comprehensive accident analysis and investigation. Thereafter, linguistic variables are build up in accordance with five scale on the basis of the linguistic statements and Table 1 shows the linguistic variable and relevant IT2F numbers (Abdullah and Zulkifli, 2015[1]).

Table 1. Corresponding relationship between linguistic variables and IT2FNs.

Linguistic variables	IT2FN
Very high influence (VH)	((0.8;0.9;0.9;1;1;1),(0.85;0.9;0.9;0.95;0.9;0.9))
High influence (H)	((0.6;0.7;0.7;0.8;1;1),(0.65;0.7;0.7;0.75;0.9;0.9))
Low influence (L)	((0.4;0.5;0.5;0.6;1;1),(0.45;0.5;0.5;0.55;0.9;0.9))
Very low influence (VL)	((0.2;0.3;0.3;0.4;1;1),(0.25;0.3;0.3;0.35;0.9;0.9))
No influence (No)	((0;0.1;0.1;0.1;1;1),(0;0.1;0.1;0.05;0.9;0.9))

Step 3 - Obtain evaluation scores of the group decision makers: In this step, a pair wise comparison is obtained on the basis of the linguistics variables. An initial direct-relation IT2FS matrix *($\tilde{E}$)* of a group of p experts is constructed. Therefore, p pair-wise comparison IT2FSs matrices $\tilde{E}^1; \tilde{E}^2; \ldots; \tilde{E}^p$ are obtained. Assume that $\tilde{e}_{ij}$ is ij_{th} entry of initial-direct-relation IT2FS matrix. The aggregated initial direct-relation IT2FS matrix *($\tilde{E}$)* is obtained from equation (5).

$$\tilde{e}_{ij} = \frac{\tilde{E}_{ij}^1 + \tilde{E}_{ij}^2 + \cdots + \tilde{E}_{ij}^p}{p} \quad (5)$$

Step 4 - Establish normalized direct-relation IT2FS matrix: According to the initial direct-relation matrix, a normalized direct-relation IT2FS matrix is calculated. The following calculation (6) is applied respectively.

$$E_x = \begin{bmatrix} 0 & \cdots & e_{1n} \\ \vdots & \ddots & \vdots \\ e_{n1} & \cdots & 0 \end{bmatrix} \quad (6)$$

Where $x = (UMF; LMF) = ((a;\ b;\ c;\ d);\ (i;\ j; k; l))$. As a result, there are eight $n \times n$ matrices. $n \times n$ matrix is required for the calculation since it contains multiplication of matrices between matrix E and identity matrix. The row of matrix E must be matched with column of identity matrix.

$$E_a = \begin{bmatrix} 0 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & 0 \end{bmatrix}, E_b = \begin{bmatrix} 0 & \cdots & b_{1n} \\ \vdots & \ddots & \vdots \\ b_{n1} & \cdots & 0 \end{bmatrix}, \ldots, E_l = \begin{bmatrix} 0 & \cdots & l_{1n} \\ \vdots & \ddots & \vdots \\ l_{n1} & \cdots & 0 \end{bmatrix}$$

E_d contains the forth element of $UMF(\tilde{E})$. All f_{ij} are normal IT2FSs. Hence, E_d contains the greatest elements in the initial-direct-relation matrix. Then, the linear scale transformation is conducted to transform the causal factors into comparable scales. The normalized direct-relation matrix can be obtained as:

$$\tilde{\tilde{F}} = \begin{bmatrix} 0 & \cdots & \tilde{f}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{f}_{n1} & \cdots & 0 \end{bmatrix} \quad (7)$$

$$\tilde{f}_{ij} = \frac{\tilde{e}_{ij}}{\gamma} = \left(\frac{E_a}{\gamma}, \frac{E_b}{\gamma}, \frac{E_c}{\gamma}, \frac{E_d}{\gamma}, \frac{E_i}{\gamma}, \frac{E_j}{\gamma}, \frac{E_k}{\gamma}, \frac{E_l}{\gamma}\right) \quad (8)$$

$$\gamma = max\left(\sum_{j=1}^{n} E_{d_{ij}}\right) \quad (9)$$

Step 5 - Determine total-relation IT2FS matrix: A total-relation IT2FS matrix is calculated by ensuring of $\lim_{\omega\to\infty} F^{\omega} = 0$ after getting normalized direct-relation IT2FS matrix, Then, the crisp case of the total-relation IT2FS matrix is defined as follows.

$$\tilde{\tilde{T}} = \lim_{\omega\to\infty}\left(\tilde{F} + \tilde{F}^2 + \cdots + \tilde{F}^{\omega}\right) \quad (10)$$

$$\tilde{\tilde{T}} = \begin{bmatrix} \tilde{t}_{11} & \cdots & \tilde{t}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{t}_{n1} & \cdots & \tilde{t}_{nn} \end{bmatrix} \quad (11)$$

where $\tilde{t}_{ij=} = \left((a';\ b';\ c';\ d');\ (i';\ j';k';l')\right)$

$$Matrix[a'] = F_a\, x\, (I - F_a)^{-1} \quad (12)$$
$$Matrix[b'] = F_b\, x\, (I - F_b)^{-1} \quad (13)$$
$$Matrix[c'] = F_c\, x\, (I - F_c)^{-1} \quad (14)$$
$$Matrix[d'] = F_d\, x\, (I - F_d)^{-1} \quad (15)$$
$$Matrix[i'] = F_i\, x\, (I - F_i)^{-1} \quad (16)$$
$$Matrix[j'] = F_j\, x\, (I - F_j)^{-1} \quad (17)$$
$$Matrix[k'] = F_k\, x\, (I - F_k)^{-1} \quad (18)$$
$$Matrix[l'] = F_l\, x\, (I - F_l)^{-1} \quad (19)$$

Step 6 - Analyse structural model: The $\tilde{\boldsymbol{r}}_{\boldsymbol{i}} + \tilde{\boldsymbol{c}}_{\boldsymbol{j}}$ and $\tilde{\boldsymbol{r}}_{\boldsymbol{i}} - \tilde{\boldsymbol{c}}_{\boldsymbol{j}}$ values are computed after calculating matrix $\tilde{\tilde{T}}$. The $\tilde{r}_i$ and $\tilde{c}_j$ denote the sum of the rows and columns of matrix $\tilde{T}$ respectively. As the $r_i + c_j$ represents the importance of factor *i*, $r_i - c_j$ gives net effect of factor *i*.

Step 7 - Defuzzify $\tilde{\boldsymbol{r}}_{\boldsymbol{i}} + \tilde{\boldsymbol{c}}_{\boldsymbol{j}}$ and $\tilde{\boldsymbol{r}}_{\boldsymbol{i}} - \tilde{\boldsymbol{c}}_{\boldsymbol{j}}$: This step shows how $\tilde{\boldsymbol{r}}_{\boldsymbol{i}} + \tilde{\boldsymbol{c}}_{\boldsymbol{j}}$ and $\tilde{\boldsymbol{r}}_{\boldsymbol{i}} - \tilde{\boldsymbol{c}}_{\boldsymbol{j}}$ values are defuzzified by using COA (centre of area) technique. The aim of this technique is to obtain the best non-fuzzy performance value. In the proposed approach, the following COA method is used to defuzzify and rank the IT2FSs (Kahraman et al., 2014[30]).

$$Defuzzified\left(\tilde{\tilde{A}}_i\right) = \frac{\left[\frac{\left(a_{i4}^U - a_{i1}^U\right) + \left(H_1\left(\tilde{A}_i^U\right) * a_{i2}^U - a_{i1}^U\right) + \left(H_2\left(\tilde{A}_i^U\right) * a_{i3}^U - a_{i1}^U\right)}{4} + a_{i1}^U + \frac{\left(a_{i4}^L - a_{i1}^L\right) + \left(H_1\left(\tilde{A}_i^L\right) * a_{i2}^L - a_{i1}^L\right) + \left(H_2\left(\tilde{A}_i^L\right) * a_{i3}^L - a_{i1}^L\right)}{4} + a_{i1}^L\right]}{2}$$

Step 8 - Construct cause-effect relation diagram: The cause and effect interrelationship diagram is constructed by mapping the dataset of $r_i + c_j$ and $r_i - c_j$.

3. APPLICATION

In order to demonstrate the proposed approach, a real ship collision case is selected since consequences of collision can pose potential harm to human life, marine environment, ship structure, ship equipment and cargo on-board. The real ship collision case is taken from the marine accident investigation branch (MAIB).

3.1 PROBLEM STATEMENT

The collision may emerge either to strike another ship or floating object. It may sometimes be a fix object. Due to the high risks caused by collision at sea, it has always been a serious concern in marine and environmental safety practitioners. The reason of that it may severely damage to the human life and marine environment. In light of the official reports, collision is one of the most frequent ship causality in the total number of ship accidents (EMSA, 2015[19]). The collision has serious environmental impact of oil spills, in particular where big size tanker ships are involved (Calle and Alves, 2015[9]). Moreover, there would be loss of human life according to severity of impact. The financial consequences may also impose a burden to ship owner due to ship total loss or fine (Gard, 2006[22]). Therefore, avoiding of collision accident is considerably significant concerns not only for maritime authorities but also safety practitioners. A comprehensive accident analysis for ship collision is needed to reveal critical accident factors of collision on the basis of technical and operational aspects. Specifically, analysing of cause and effect correlations among the accident factors may assist to enhance motivation towards avoiding accident in advance.

3.2 NARRATIVE: A REAL-CASE SHIP COLLISION ACCIDENT

The real ship collision accident occurred at the open waters while two vessel were transiting. Due to the commercial reason, the authors masked the ship owners and vessels names. The weather condition was good and sea state was calm at the time of accident. The condition of visibility was quite good (MAIB, 2013[35]). The vessel A's chief officer saw the vessel B almost ten minutes before the event. However, he assumed that it was an overtaking vessel and would probably keep clear from the vessel A. The vessel B's master was alone on the bridge and distracted by the other tasks. Both vessel did not expect to collide each other but made a close quarter passing. Even though both vessels altered their course, there was not enough time and distance to take necessary avoiding action. Thereafter, two vessels severely collided at open waters. At the end of collision, the vessel A suffered extensive damage to the aft starboard side. Her engine room flooded and accommodation space heavily damaged. Likewise, vessel B severely damaged on her bow. Fortunately, there were no injuries or loss of lives. About 18 tonnes of diesel oil and lubricating spilled into the sea and some minor marine pollution was observed. In the light of the MAIB accident investigation report, a comprehensive research has been performed to identify causal factors of collision accident. Accordingly, Table 2 provides technical and operational critical factors of collision accident (CAF).

3.3 ANALYSIS OF EXPERTS

Since there are no evidential data, expert judgements can be an alternative solution for evaluation. The primary benefits of expert judgement are to obtain a rapid assessment of the state of knowledge about a particular aspect of criteria. In order to get input data, it was connected with a prestigious shipping company. The fleet of company consists of more than forty container ships varying from 800 TEU to 2,800 TEU cargo capacity. The elaborative survey was conducted with the technical superintendents and DPAs who have enough experiences on-board ship as Master and chief-officer for a long years as well as shore based managers. Table 3 shows marine experts' detail. The marine experts were asked to evaluate cause and effect inter-relationship among the critical accident factors on the basis of linguistic statements.

Table 2. Critical technical and operational accident factors of collision.

Code	Critical accident factors
CAF1	Fail to keep a proper look out
CAF2	Lack of taking appropriate action stipulated by COLREG to avoid the collision
CAF3	Not to perform chart correction properly
CAF4	Action to avoid collision is made on assumption.
CAF5	Not calling Master although clear instruction was given by ship management company
CAF6	OOW did not assess the situation initially
CAF7	Watch alarm (Dead man alarm) was not set by the Master
CAF8	OOW was distracted by other tasks rather than keeping a lookout
CAF9	Lack of maintaining high standards of watchkeeping at all times
CAF10	Late action was performed to avoid collision
CAF11	Relaying on electronic information only (scanty radar information)
CAF12	Lack of effective radio communication between the vessels
CAF13	Loss of situational awareness within the bridge team management
CAF14	OOW did not assess risk of collision sufficiently
CAF15	OOW did not take rest enough before in charge of bridge watch

Table 3. Marine experts' profile details.

Marine Expert	Position	Educational level	Years in marine and shore-based experienced	Age
1	Superintendent	Undergraduate	13	39
2	Superintendent	Undergraduate	18	45
3	Senior DPA	Gradate	16	40
4	Junior DPA	Undergraduate	9	32
5	Superintendent	PhD.	14	44

3.4 APPLICATION OF PROPOSED APPROACH

In the view of experts' judgements, the proposed approach is applied to analyse cause and effect interrelationship of the collision accident. The technical and operational factors of collision accident have been presented marine experts for evaluation. The experts evaluated the interrelationship among the critical accident factors through the use of fuzzy linguistic variable on the basis of IT2F numbers. The linguistic variables and corresponding IT2FSs are presented in Table 1. Accordingly, Table 4 illustrates the linguistic assessments of five marine experts. Since there are five marine experts to evaluate the cause and effect interrelation ship, the linguistic assessments are reduced to one by getting arithmetic means of them. After taking experts' assessments, initial direct IT2FSs matrix, which is illustrated in Table 5. Then, normalized direct-relation IT2FSs matrix is computed by using Eqs. (6)-(9). Table 6 shows normalized initial direct relation IT2FSs matrix. Furthermore, a total-relation IT2FSs matrix can be calculated by applying Eqs. (10)-(19). In this context, Table 7 presents the total-relation IT2FSs matrix accordingly. The IT2FSs values of $\tilde{\tilde{r}}_i$, $\tilde{\tilde{c}}_j$, $\tilde{\tilde{r}}_i + \tilde{\tilde{c}}_j$ and $\tilde{\tilde{r}}_i - \tilde{\tilde{c}}_j$ are calculated before defuzzification. Table 8 provides IT2FSs values of of $\tilde{\tilde{r}}_i$, $\tilde{\tilde{c}}_j$, $\tilde{\tilde{r}}_i + \tilde{\tilde{c}}_j$ and $\tilde{\tilde{r}}_i - \tilde{\tilde{c}}_j$. Thereafter, the crisp values of r_i, $c_{j,}$, $r_i + c_j$ and $r_i - c_j$ are calculated by using COA method. Table 9 shows the crisp values of r_i, $c_{j,}$, $r_i + c_j$ and $r_i - c_j$. The aim of obtaining crisp values of the r_i, $c_{j,}$, $r_i + c_j$ and $r_i - c_j$ is to build up cause-effect interrelation diagram.

Table 4. Linguistic assessment of five marine experts

	CAF1					**CAF2**					**CAF3**					**CAF4**					**CAF5**				
	E1	*E2*	*E3*	*E4*	*E5*	*E1*	*E2*	*E3*	*E4*	*E5*	*E1*	*E2*	*E3*	*E4*	*E5*	*E1*	*E2*	*E3*	*E4*	*E5*	*E1*	*E2*	*E3*	*E4*	*E5*
CF1	No	No	No	No	No	VH	H	L	H	VH	No	No	VL	L	No	H	VH	H	L	H	VL	No	L	L	VL
CF2	VL	L	No	L	VL	No	No	No	No	No	No	VL	L	No	No	H	H	L	VH	H	VL	L	No	L	VL
CF3	No	VL	No	VL	No	VL	L	H	VL	L	No	No	No	No	No	H	L	VH	H	H	No	VL	L	No	No
CF4	VL	L	VL	No	VL	H	L	H	VH	H	VL	L	VL	No	VL	No	No	No	No	No	L	L	VL	H	VL
CF5	No	VL	No	L	No	L	VL	L	No	L	VL	VL	L	L	No	L	H	L	VL	L	No	No	No	No	No
CF6	L	L	VL	H	VL	H	L	H	VH	H	No	No	VL	VL	L	H	H	VH	VH	H	VH	H	VH	L	VH
CF7	VL	VL	No	L	VL	No	No	VL	L	VL	No	VL	No	No	VL	VL	L	VL	No	VL	No	VL	No	VL	L
CF8	VH	H	VH	H	VH	H	VH	VH	H	H	VL	L	L	VL	VL	H	L	H	VH	H	L	VL	L	VL	L
CF9	VH	H	VH	H	VH	H	VH	H	L	VH	H	VH	H	VH	H	VH	H	H	VH	H	L	H	VL	L	L
CF10	VL	L	VL	VL	L	VL	L	VL	No	VL	No	VL	No	No	L	No	No	VL	No	No	H	VH	H	VH	H
CF11	H	H	VH	L	H	L	VL	L	L	VL	No	VL	No	L	No	H	VH	H	VH	L	No	VL	No	VL	No
CF12	No	N	VL	No	VL	H	VH	H	VH	H	No	L	No	VL	No	L	VL	VL	L	H	VL	L	VL	No	VL
CF13	H	VH	H	H	VH	L	VL	L	VL	L	H	VH	H	VH	H	L	VL	L	H	VL	H	VH	H	VH	L
CF14	VL	L	VL	VL	L	H	VH	H	VH	L	No	VL	L	No	No	VH	VH	H	H	VH	VL	L	VL	VL	No
CF15	VH	H	VH	H	H	H	H	VH	H	VH	H	VH	H	VH	L	VH	H	L	VH	H	L	VL	L	VL	VL

	CAF6					**CAF7**					**CAF8**					**CAF9**					**CAF10**				
	E1	*E2*	*E3*	*E4*	*E5*	*E1*	*E2*	*E3*	*E4*	*E5*	*E1*	*E2*	*E3*	*E4*	*E5*	*E1*	*E2*	*E3*	*E4*	*E5*	*E1*	*E2*	*E3*	*E4*	*E5*
CF1	H	VH	H	L	H	No	VL	No	No	No	No	VL	No	No	VL	VL	L	VL	VL	L	H	H	L	VH	H
CF2	VL	VL	No	HL	VL	VL	L	VL	No	VL	No	No	No	VL	VL	VH	H	H	VH	L	H	VH	H	H	L
CF3	VL	VL	L	No	VL	No	VL	L	No	VL	VL	L	VL	No	VL	L	L	VL	L	H	VL	No	L	VL	VL
CF4	VL	L	VL	No		VL	L	VL	No	VL	No	VL	No	VL	L	H	VH	H	H	L	VH	H	VH	H	H
CF5	No	No	VL	VL	No	H	VH	H	H	VH	VL	L	VL	No	VL	L	L	H	L	VL	H	VH	H	H	VH
CF6	No	No	No	No	No	No	VL	No	VL	No	VL	L	VL	VL	No	VL	VL	L	No	VL	VH	H	VH	VH	H
CF7	No	VL	VL	No	No	No	No	No	No	No	H	H	VH	H	VH	H	VH	H	H	L	VL	L	VL	L	VL
CF8	VH	H	H	VH	VH	L	L	VL	H	L	No	No	No	No	No	H	H	VH	VH	L	VH	H	VH	H	VH
CF9	H	VH	H	HL	VH	H	VH	H	H	VH	L	VL	L	No	L	No	No	No	No	No	L	No	VL	L	L
CF10	VL	L	No	VL	L	No	No	NO	VL	L	NO	No	VL	VL	No	L	H	L	VL	L	No	No	No	No	No
CF11	VH	VH	H	H	VH	No	VL	No	No	VL	VL	No	VL	L	VL	H	VH	H	L	VH	H	H	VH	VH	H
CF12	VL	L	No	VL	VL	No	No	L	No	VL	VL	No	VL	No	V	H	H	VH	H	L	VH	H	VH	H	H
CF13	VH	H	VH	H	VH	VL	No	VL	L	VL	H	VH	H	L	VH	VH	H	VH	H	H	L	L	VL	VL	L
CF14	L	VL	L	H	VL	No	No	VL	L	VL	VL	VL	L	No	VL	L	VL	L	No	VL	VH	H	VH	H	VH
CF15	H	H	VH	H	L	No	No	No	VL	L	L	VL	L	No		VH	H	VH	H	H	VH	H	H	L	VH

	CAF11					**CAF12**					**CAF13**					**CAF14**					**CAF15**				
	E1	*E2*	*E3*	*E4*	*E5*	*E1*	*E2*	*E3*	*E4*	*E5*	*E1*	*E2*	*E3*	*E4*	*E5*	*E1*	*E2*	*E3*	*E4*	*E5*	*E1*	*E2*	*E3*	*E4*	*E5*
CF1	L	H	L	L	VL	VL	L	No	VL	L	No	VL	No	No	VL	VH	H	H	VH	L	No	No	No	VL	No
CF2	L	L	VL	H	VL	L	VL	L	L	VL	H	H	VH	L	VH	L	VL	L	L	VL	No	L	No	No	VL
CF3	VH	H	H	VH	H	No	VL	No	No	VL	VL	L	VL	L	No	L	H	VL	L	L	No	VL	L	No	No
CF4	VL	VL	No	VL	L	No	VL	No	L	N	H	VH	H	L	H	H	H	VH	VH	H	VL	L	VL	VL	No
CF5	No	L	VL	No	No	VL	L	L	VL	VL	L	H	VL	L	L	VL	No	VL	L	VL	No	VL	No	L	VL
CF6	H	H	VH	H	H	L	VL	L	L	VL	VL	No	VL	L	No	VH	VH	H	H	VH	No	No	No	VL	L
CF7	No	No	VL	VL	No	VL	No	VL	No	VL	VL	L	VL	No	VL	VL	No	VL	L	VL	VL	VL	No	L	No
CF8	H	VH	L	H	VH	H	VH	H	H	L	L	L	VL	L	VL	VH	VH	H	H	VH	No	No	No	VL	VL
CF9	VL	No	VL	VL	L	H	H	VH	VH	H	VH	VH	H	H	VH	H	VH	H	H	VH	No	VL	No	VL	No
CF10	L	VL	L	VL	H	VL	No	No	VL	L	L	VL	L	No	L	VL	L	VL	L	VL	VL	L	VL	No	VL
CF11	No	No	No	No	No	H	L	H	VL	VH	H	VH	H	H	VH	VH	H	H	VH	VH	No	No	VL	No	No
CF12	VL	L	VL	L	L	No	No	No	No	No	L	VL	L	VL	VL	L	VL	L	VL	L	No	No	VL	VL	No
CF13	VL	L	L	VL	VL	L	VL	L	VL	H	No	No	No	No	No	H	H	VH	H	VH	L	VL	L	VL	VL
CF14	L	VL	L	VL	H	H	VH	H	H	L	L	VL	L	L	VL	No	No	No	No	No	No	No	VL	L	No
CF15	H	VH	H	VH	L	H	VH	VH	H	VL	H	VH	H	H	VH	VH	H	H	L	VH	No	No	No	No	No

Table 5. The initial direct-relation IT2FSs matrix.

	CAF1	...	CAF15
CAF1	((0;0.1;0.1;0.1;1;1),(0;0.1;0.1;0.05;0.9;0.9))	...	((0.04;0.14;0.14;0.16;1;1),(0.05;0.14;0.14;0.11;0.9;0.9))
CAF2	((0.24;0.34;0.34;0.42;1;1),(0.28;0.34;0.34;0.37;0.9;0.9))	...	((0.12;0.22;0.22;0.26;1;1),(0.14;0.22;0.22;0.21;0.9;0.9))
CAF3	((0.08;0.18;0.18;0.22;1;1),(0.1;0.18;0.18;0.17;0.9;0.9))	...	((0.12;0.22;0.22;0.26;1;1),(0.14;0.22;0.22;0.21;0.9;0.9))
CAF4	((0.2;0.3;0.3;0.38;1;1),(0.24;0.3;0.3;0.33;0.9;0.9))	...	((0.2;0.3;0.3;0.38;1;1),(0.24;0.3;0.3;0.33;0.9;0.9))
CAF5	((0.12;0.22;0.22;0.26;1;1),(0.14;0.22;0.22;0.21;0.9;0.9))	...	((0.16;0.26;0.26;0.32;1;1),(0.19;0.26;0.26;0.27;0.9;0.9))
CAF6	((0.36;0.46;0.46;0.56;1;1),(0.41;0.46;0.46;0.51;0.9;0.9))	...	((0.12;0.22;0.22;0.26;1;1),(0.14;0.22;0.22;0.21;0.9;0.9))
CAF7	((0.2;0.3;0.3;0.38;1;1),(0.24;0.3;0.3;0.33;0.9;0.9))	...	((0.16;0.26;0.26;0.32;1;1),(0.19;0.26;0.26;0.27;0.9;0.9))
CAF8	((0.72;0.82;0.82;0.92;1;1),(0.77;0.82;0.82;0.87;0.9;0.9))	...	((0.08;0.18;0.18;0.22;1;1),(0.1;0.18;0.18;0.17;0.9;0.9))
CAF9	((0.72;0.82;0.82;0.92;1;1),(0.77;0.82;0.82;0.87;0.9;0.9))	...	((0.08;0.18;0.18;0.22;1;1),(0.1;0.18;0.18;0.17;0.9;0.9))
CAF10	((0.28;0.38;0.38;0.48;1;1),(0.33;0.38;0.38;0.43;0.9;0.9))	...	((0.2;0.3;0.3;0.38;1;1),(0.24;0.3;0.3;0.33;0.9;0.9))
CAF11	((0.6;0.7;0.7;0.8;1;1),(0.65;0.7;0.7;0.75;0.9;0.9))	...	((0.04;0.14;0.14;0.16;1;1),(0.05;0.14;0.14;0.11;0.9;0.9))
CAF12	((0.2;0.3;0.3;0.36;1;1),(0.23;0.3;0.3;0.31;0.9;0.9))	...	((0.08;0.18;0.18;0.22;1;1),(0.1;0.18;0.18;0.17;0.9;0.9))
CAF13	((0.68;0.78;0.78;0.88;1;1),(0.73;0.78;0.78;0.83;0.9;0.9))	...	((0.28;0.38;0.38;0.48;1;1),(0.33;0.38;0.38;0.43;0.9;0.9))
CAF14	((0.28;0.38;0.38;0.48;1;1),(0.33;0.38;0.38;0.43;0.9;0.9))	...	((0.12;0.22;0.22;0.26;1;1),(0.14;0.22;0.22;0.21;0.9;0.9))
CAF15	((0.68;0.78;0.78;0.88;1;1),(0.73;0.78;0.78;0.83;0.9;0.9))	...	((0;0.1;0.1;0.1;1;1),(0;0.1;0.1;0.05;0.9;0.9))

Table 6. Normalized initial direct-relation IT2FSs matrix.

	CAF1	...	CAF15
CAF1	((0;0.01;0.01;0.01;1;1),(0;0.01;0.01;0;0.9;0.9))	...	((0;0.01;0.01;0.02;1;1),(0;0.01;0.01;0.01;0.9;0.9))
CAF2	((0.02;0.03;0.03;0.04;1;1),(0.03;0.03;0.03;0.03;0.9;0.9))	...	((0.01;0.02;0.02;0.02;1;1),(0.01;0.02;0.02;0.02;0.9;0.9))
CAF3	((0.01;0.02;0.02;0.02;1;1),(0.01;0.02;0.02;0.02;0.9;0.9))	...	((0.01;0.02;0.02;0.02;1;1),(0.01;0.02;0.02;0.02;0.9;0.9))
CAF4	((0.02;0.03;0.03;0.04;1;1),(0.02;0.03;0.03;0.03;0.9;0.9))	...	((0.02;0.03;0.03;0.04;1;1),(0.02;0.03;0.03;0.03;0.9;0.9))
CAF5	((0.01;0.02;0.02;0.02;1;1),(0.01;0.02;0.02;0.02;0.9;0.9))	...	((0.02;0.02;0.02;0.03;1;1),(0.02;0.02;0.02;0.03;0.9;0.9))
CAF6	((0.03;0.04;0.04;0.05;1;1),(0.04;0.04;0.04;0.05;0.9;0.9))	...	((0.01;0.02;0.02;0.02;1;1),(0.01;0.02;0.02;0.02;0.9;0.9))
CAF7	((0.02;0.03;0.03;0.04;1;1),(0.02;0.03;0.03;0.03;0.9;0.9))	...	((0.02;0.02;0.02;0.03;1;1),(0.02;0.02;0.02;0.03;0.9;0.9))
CAF8	((0.07;0.08;0.08;0.09;1;1),(0.07;0.08;0.08;0.08;0.9;0.9))	...	((0.01;0.02;0.02;0.02;1;1),(0.01;0.02;0.02;0.02;0.9;0.9))
CAF9	((0.07;0.08;0.08;0.09;1;1),(0.07;0.08;0.08;0.08;0.9;0.9))	...	((0.01;0.02;0.02;0.02;1;1),(0.01;0.02;0.02;0.02;0.9;0.9))
CAF10	((0.03;0.04;0.04;0.05;1;1),(0.03;0.04;0.04;0.04;0.9;0.9))	...	((0.02;0.03;0.03;0.04;1;1),(0.02;0.03;0.03;0.03;0.9;0.9))
CAF11	((0.06;0.07;0.07;0.08;1;1),(0.06;0.07;0.07;0.07;0.9;0.9))	...	((0;0.01;0.01;0.02;1;1),(0;0.01;0.01;0.01;0.9;0.9))
CAF12	((0.02;0.03;0.03;0.03;1;1),(0.02;0.03;0.03;0.03;0.9;0.9))	...	((0.01;0.02;0.02;0.02;1;1),(0.01;0.02;0.02;0.02;0.9;0.9))
CAF13	((0.06;0.07;0.07;0.08;1;1),(0.07;0.07;0.07;0.08;0.9;0.9))	...	((0.03;0.04;0.04;0.05;1;1),(0.03;0.04;0.04;0.04;0.9;0.9))
CAF14	((0.03;0.04;0.04;0.05;1;1),(0.03;0.04;0.04;0.04;0.9;0.9))	...	((0.01;0.02;0.02;0.02;1;1),(0.01;0.02;0.02;0.02;0.9;0.9))
CAF15	((0.06;0.07;0.07;0.08;1;1),(0.07;0.07;0.07;0.08;0.9;0.9))	...	((0;0.01;0.01;0.01;1;1),(0;0.01;0.01;0;0.9;0.9))

Table 7. Total-relation IT2FSs matrix.

	CAF1	...	CAF15
CAF1	((0;0.01;0.01;0.01;1;1),(0;0.01;0.01;0.01;0.9;0.9))	...	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
CAF2	((0;0;0;0.01;1;1),(0;0;0;0;0.9;0.9))	...	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
CAF3	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	...	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
CAF4	((0;0;0;0.01;1;1),(0;0;0;0;0.9;0.9))	...	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
CAF5	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	...	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
CAF6	((0;0.01;0.01;0.01;1;1),(0;0.01;0.01;0.01;0.9;0.9))	...	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
CAF7	((0;0;0;0.01;1;1),(0;0;0;0;0.9;0.9))	...	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
CAF8	((0.01;0.01;0.01;0.02;1;1),(0.01;0.01;0.01;0.02;0.9;0.9))	...	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
CAF9	((0.01;0.01;0.01;0.02;1;1),(0.01;0.01;0.01;0.02;0.9;0.9))	...	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
CAF10	((0;0;0;0.01;1;1),(0;0;0;0;0.9;0.9))	...	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
CAF11	((0.01;0.01;0.01;0.02;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	...	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
CAF12	((0;0;0;0.01;1;1),(0;0;0;0;0.9;0.9))	...	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
CAF13	((0.01;0.01;0.01;0.02;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	...	((0;0;0;0.01;1;1),(0;0;0;0;0.9;0.9))
CAF14	((0;0;0;0.01;1;1),(0;0;0;0.01;0.9;0.9))	...	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
CAF15	((0.01;0.01;0.01;0.02;1;1),(0.01;0.01;0.01;0.02;0.9;0.9))	...	((0;0.01;0.01;0.01;1;1),(0;0.01;0.01;0;0.9;0.9))

Table 8. Interval type-2 fuzzy values of $\tilde{\tilde{r}}_i$, $\tilde{\tilde{c}}_j$, $\tilde{\tilde{r}}_i + \tilde{\tilde{c}}_j$ and $\tilde{\tilde{r}}_i - \tilde{\tilde{c}}_j$.

	$\tilde{\tilde{r}}_i$	$\tilde{\tilde{c}}_j$
CAF1	((0.03;0.08;0.08;0.14;1;1),(0.04;0.08;0.08;0.09;0.9;0.9))	((0.04;0.1;0.1;0.17;1;1),(0.06;0.1;0.1;0.11;0.9;0.9))
CAF2	((0.03;0.08;0.08;0.14;1;1),(0.04;0.08;0.08;0.09;0.9;0.9))	((0.06;0.13;0.13;0.23;1;1),(0.08;0.13;0.13;0.15;0.9;0.9))
CAF3	((0.02;0.06;0.06;0.11;1;1),(0.03;0.06;0.06;0.07;0.9;0.9))	((0.02;0.06;0.06;0.11;1;1),(0.03;0.06;0.06;0.07;0.9;0.9))
CAF4	((0.04;0.09;0.09;0.16;1;1),(0.05;0.09;0.09;0.1;0.9;0.9))	((0.07;0.14;0.14;0.24;1;1),(0.09;0.14;0.14;0.16;0.9;0.9))
CAF5	((0.03;0.07;0.07;0.12;1;1),(0.04;0.07;0.07;0.08;0.9;0.9))	((0.03;0.08;0.08;0.14;1;1),(0.04;0.08;0.08;0.09;0.9;0.9))
CAF6	((0.05;0.1;0.1;0.18;1;1),(0.06;0.1;0.1;0.12;0.9;0.9))	((0.04;0.1;0.1;0.17;1;1),(0.06;0.1;0.1;0.11;0.9;0.9))
CAF7	((0.02;0.05;0.05;0.09;1;1),(0.02;0.05;0.05;0.06;0.9;0.9))	((0.02;0.05;0.05;0.09;1;1),(0.02;0.05;0.05;0.06;0.9;0.9))
CAF8	((0.07;0.15;0.15;0.26;1;1),(0.1;0.15;0.15;0.18;0.9;0.9))	((0.02;0.05;0.05;0.09;1;1),(0.02;0.05;0.05;0.06;0.9;0.9))
CAF9	((0.07;0.14;0.14;0.24;1;1),(0.09;0.14;0.14;0.17;0.9;0.9))	((0.06;0.13;0.13;0.23;1;1),(0.08;0.13;0.13;0.16;0.9;0.9))
CAF10	((0.02;0.05;0.05;0.1;1;1),(0.02;0.05;0.05;0.06;0.9;0.9))	((0.08;0.15;0.15;0.28;1;1),(0.1;0.15;0.15;0.19;0.9;0.9))
CAF11	((0.05;0.12;0.12;0.2;1;1),(0.07;0.12;0.12;0.14;0.9;0.9))	((0.04;0.09;0.09;0.16;1;1),(0.05;0.09;0.09;0.1;0.9;0.9))
CAF12	((0.03;0.07;0.07;0.13;1;1),(0.04;0.07;0.07;0.08;0.9;0.9))	((0.04;0.09;0.09;0.16;1;1),(0.05;0.09;0.09;0.1;0.9;0.9))
CAF13	((0.06;0.13;0.13;0.23;1;1),(0.08;0.13;0.13;0.15;0.9;0.9))	((0.04;0.1;0.1;0.18;1;1),(0.06;0.1;0.1;0.12;0.9;0.9))
CAF14	((0.04;0.09;0.09;0.16;1;1),(0.05;0.09;0.09;0.1;0.9;0.9))	((0.07;0.14;0.14;0.25;1;1),(0.09;0.14;0.14;0.17;0.9;0.9))
CAF15	((0.08;0.16;0.16;0.28;1;1),(0.1;0.16;0.16;0.19;0.9;0.9))	((0;0.03;0.03;0.05;1;1),(0.01;0.03;0.03;0.02;0.9;0.9))

	$\tilde{\tilde{r}}_i + \tilde{\tilde{c}}_j$	$\tilde{\tilde{r}}_i - \tilde{\tilde{c}}_j$
CAF1	((0.08;0.17;0.17;0.31;1;1),(0.1;0.17;0.17;0.2;0.9;0.9))	((-0.14;-0.02;-0.02;0.1;1;1),(-0.07;-0.02;-0.02;0.03;0.9;0.9))
CAF2	((0.09;0.21;0.21;0.37;1;1),(0.12;0.21;0.21;0.25;0.9;0.9))	((-0.2;-0.05;-0.05;0.08;1;1),(-0.11;-0.05;-0.05;0.01;0.9;0.9))
CAF3	((0.05;0.12;0.12;0.22;1;1),(0.06;0.12;0.12;0.14;0.9;0.9))	((-0.08;0;0;0.09;1;1),(-0.03;0;0;0.04;0.9;0.9))
CAF4	((0.1;0.22;0.22;0.4;1;1),(0.14;0.22;0.22;0.27;0.9;0.9))	((-0.2;-0.05;-0.05;0.09;1;1),(-0.11;-0.05;-0.05;0.02;0.9;0.9))
CAF5	((0.06;0.14;0.14;0.26;1;1),(0.08;0.14;0.14;0.17;0.9;0.9))	((-0.12;-0.01;-0.01;0.09;1;1),(-0.06;-0.01;-0.01;0.03;0.9;0.9))
CAF6	((0.09;0.2;0.2;0.35;1;1),(0.12;0.2;0.2;0.23;0.9;0.9))	((-0.13;0;0;0.14;1;1),(-0.05;0;0;0.06;0.9;0.9))
CAF7	((0.03;0.1;0.1;0.18;1;1),(0.05;0.1;0.1;0.11;0.9;0.9))	((-0.07;0;0;0.07;1;1),(-0.03;0;0;0.03;0.9;0.9))
CAF8	((0.09;0.2;0.2;0.35;1;1),(0.12;0.2;0.2;0.24;0.9;0.9))	((-0.02;0.1;0.1;0.25;1;1),(0.04;0.1;0.1;0.16;0.9;0.9))
CAF9	((0.13;0.27;0.27;0.48;1;1),(0.17;0.27;0.27;0.32;0.9;0.9))	((-0.16;0.01;0.01;0.18;1;1),(-0.07;0.01;0.01;0.09;0.9;0.9))
CAF10	((0.09;0.21;0.21;0.37;1;1),(0.12;0.21;0.21;0.25;0.9;0.9))	((-0.26;-0.1;-0.1;0.02;1;1),(-0.16;-0.1;-0.1;-0.04;0.9;0.9))
CAF11	((0.09;0.2;0.2;0.36;1;1),(0.12;0.2;0.2;0.24;0.9;0.9))	((-0.11;0.03;0.03;0.16;1;1),(-0.03;0.03;0.03;0.09;0.9;0.9))
CAF12	((0.07;0.16;0.16;0.29;1;1),(0.09;0.16;0.16;0.19;0.9;0.9))	((-0.13;-0.02;-0.02;0.1;1;1),(-0.07;-0.02;-0.02;0.03;0.9;0.9))
CAF13	((0.1;0.22;0.22;0.41;1;1),(0.14;0.22;0.22;0.27;0.9;0.9))	((-0.12;0.03;0.03;0.19;1;1),(-0.04;0.03;0.03;0.1;0.9;0.9))
CAF14	((0.11;0.23;0.23;0.41;1;1),(0.14;0.23;0.23;0.27;0.9;0.9))	((-0.21;-0.05;-0.05;0.09;1;1),(-0.12;-0.05;-0.05;0.01;0.9;0.9))
CAF15	((0.08;0.18;0.18;0.32;1;1),(0.11;0.18;0.18;0.21;0.9;0.9))	((0.03;0.13;0.13;0.27;1;1),(0.08;0.13;0.13;0.18;0.9;0.9))

Table 9. Crisp values of r_i, c_j, $r_i + c_j$ and $r_i - c_j$ >

	r_i	c_j	$r_i + c_j$	$r_i - c_j$
CAF1	0.0763	0.0932	0.170	-0.017
CAF2	0.0759	0.1259	0.204	-0.050
CAF3	0.0594	0.0568	0.116	0.003
CAF4	0.0852	0.1339	0.219	-0.049
CAF5	0.0641	0.0745	0.139	-0.010
CAF6	0.0990	0.0951	0.194	0.004
CAF7	0.0474	0.0480	0.095	-0.001
CAF8	0.1464	0.0480	0.194	0.098
CAF9	0.1365	0.1267	0.263	0.010
CAF10	0.0490	0.1536	0.203	-0.105
CAF11	0.1128	0.0856	0.198	0.027
CAF12	0.0702	0.0859	0.156	-0.016
CAF13	0.1255	0.0965	0.222	0.029
CAF14	0.0835	0.1391	0.223	-0.056
CAF15	0.1553	0.0235	0.179	0.132

3.5 FINDINGS AND DISCUSSION

After obtained r_i, c_j, $r_i + c_j$ and $r_i - c_j$ values, cause and effect interrelation diagram is mapped on the basis of outcomes. Figure 2 depicts the diagram. According to the diagram, the findings can be divided into two groups: causal factors and effect factors.

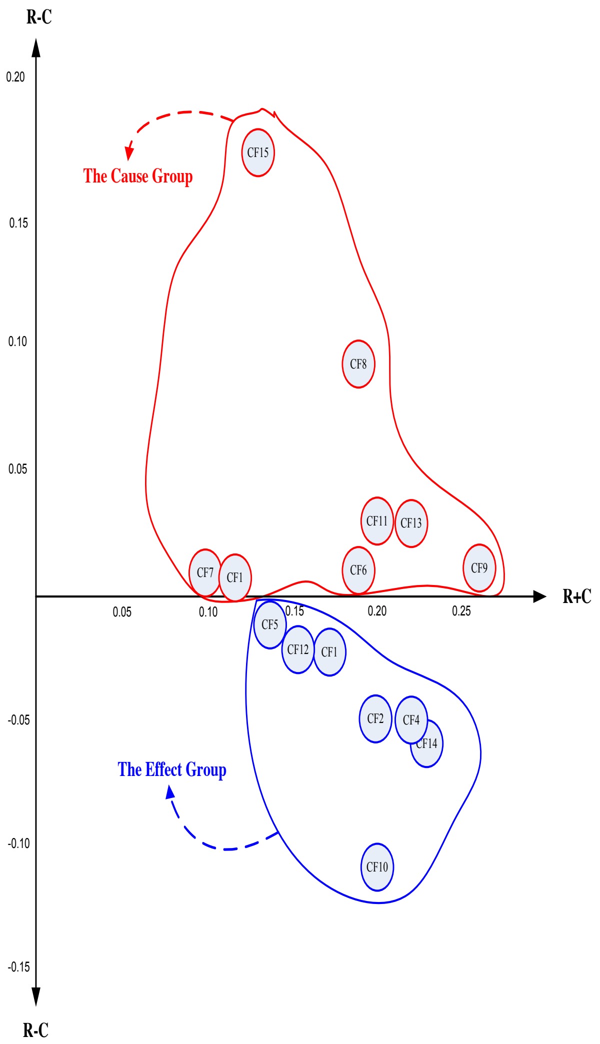

Figure 2. Cause and effect interrelation diagram.

3.5 (a) Causal Factors

To understand actual reason of collision case, causal factors are tackled with priority. According to the cause and effect interrelation diagram, the CAF15 has the highest $r_i - c_j$ value (0.132) among the all factors in cause group. Moreover, it has the highest degree of influential impact index (r_i) value (0.1553). This means CAF15 has considerably high impact on collision accident occurrence. According to the STCW 78 (as per Manila amendments) requirement, each officer shall take enough rest hours before handling bride watch (IMO, 2011[29]). Insufficient rest hours is one of the main contributory factors to collision accident causalities since it may cause poor concentration, lack of focus, distraction, fatigue and memory impairment during bridge watch. In the view of diagram, CAF8 is the second most focal causal factor as it ranks second place among the all causal factors (0.098). It has also second highest r_i value (0.1464) from the point of influential impact degree. Distraction by other tasks rather than keeping a proper look out is quite dangerous manner since concentration is lost and collection and analysis of information is relatively straightforward. On the other hand, CAF13 and CAF11 have relatively moderate effect on collision accident since their $r_i - c_j$ values (0.029 and 0.027) are not very high. The rest of causal factors CAF7, CAF1, CAF6 and CAF9 have almost equal and low impact upon collision accident since their $r_i - c_j$ values are very close to each other.

3.5 (b) Effect Factors

After having reviewed causal factors, the effect factors should be analysed to enhance perception of collision accident causality. The effect factors can be referred as the causal factors which are easily impacted by other causal factors. The causal factor may trigger the effect factor and lead the domino effect in the event of incident. Insignificant causal factors can lead to consequential results. In the view of cause and effect interrelation diagram, CAF14 is the most significant effected factors in course of collision accident as it has the highest $r_i + c_j$ value (0.223) among the all critical factors. Also, an influenced impact index (c_j) value of CAF14 ranks second place among the all factors. It means that CAF14 is considerably affected by the other factors in the event of collision case. Inadequate risk assessment may bring the vessel in very dangerous situation such as collision. Because, OOW cannot perceive the situation properly until close-quarter and cannot perform proper action to avoid collision. Inadequate risk assessment may severely affect other circumstances such as collision preventive manoeuvring, correct radio communication, situational awareness and bride team organisation. CAF4 and CAF2 rank second and third place on the basis of $r_i - c_j$ values. Their (c_j) values are also high among the other critical factors. Therefore, CAF4 and CAF2 are considered as significant effected factors as well. Assumption may cause to increase risk of collision and to prevent taking necessary manoeuvring on time. Lack of taking appropriate action may bring the vessel in collision risk. It may be significantly affected by the other critical factors such as assumption, scanty radar information, inexperience officer on watch, fatigue or insufficient look out. On the other hand, although CAF2 and CAF10 have almost same $r_i - c_j$ values, CAF10 has one of the highest (c_j) values among the effect factors. Therefore, CAF10 is also considered as significant effected factors in course of collision accident.

3.6 MARINE ACCIDENT PREVENTION PLAN

The findings show that a real-case ship collision accident is considerably affected cause and effect interrelation of critical factors. Specifically, critical accident factors CAF15, CAF8 (causal factors), CAF14, CAF4, CAF2 and CAF10 (effect factors) become prominent in the event of collision. Marine accident prevention plan is recommended in the view of marine experts who have sufficient experiences on-board ship as Master and chief-officer and professional execution experiences at shore for a long years. Table 10 shows marine accident prevention plan accordingly.

4. CONCLUSIONS

Marine accident analyse has always been a serious concern in marine safety engineers due to the high risks caused by human errors (Akyuz, 2015b[5]). Specifically, ship collision has become prominent topic in this aspect since the consequences of collision may harm to human life, ship structure, marine environment and cargo on-board. The aim of his study is to propose a hybrid marine accident analysing tool to investigate critical accident factors on the basis of cause-effect relation diagram in decision-making. To achieve these purposes, proposed approach integrates the DEMATEL and IT2FSs methods. The strength of the proposed approach is to analyse accident factors based on the cause-effect interrelationship diagram where importance of each causal factors and their net effects are mapped. Thus, it may provide a useful guideline in defining the technical and operational factors of marine accident since IMO adopted a special code for the investigation of marine casualties and incidents in order to undertake an investigation of any casualty occurring to any of its ships. The outcomes of this paper hopefully support relevant requirement of Code. The experts' observation with respect to the critical factors can be easily interpreted and transformed into meaningful information to avoid marine accident. Since the DEMATEL method reflects cause and effect relationship in decision-making, IT2FSs deals with vagueness of the linguistic assessments of marine experts during marine accident analysing process. To demonstrate the model, a real-case ship collision accident is applied. Thus, critical technical and operational accident factors in the event of collision are analysed by adopting visual causal-effect relation diagram.

Consequently, the proposed approach has not only theoretical benefits to the safety practitioners from a research point of view in marine accident analysis but also practical contributions to the ship owners, technical managers and marine professionals as the proposed approach brings a practical solution to evaluate critical accident factor by mapping. Indeed, a practical software tool (a knowledge-based programming which transforms technical assessments into meaningful outcomes during the evaluation of marine accident factors) is planning to design based on theoretical framework of the approach. The proposed approach can be applicable to the wide range domains such as aviation, railway, petrochemical, construction, etc., where the result of any accidents have severe effects.

Table 10. Marine accident prevention plan.

	Critical accident factors	Accident prevention plan
Causal Factors	CAF15	• Make sure that the Master of ship properly complies with STCW rest hours requirements • Increase internal audit frequency to check if rest hours are being recorded correctly
	CAF8	• Instruct OOW not to do any work such as chart correction, passage plan or etc. during a watch • Insert a CCTV camera on bridge and monitor OOW regularly to control if s/he is distracted by other tasks
Effect Factors	CAF14	• Provide practical and theoretical practice about risk assessment for deck officers before embarking ship • Provide practical training about application of the Collision Avoidance Funnel model
	CAF4	• Instruct OOW to call the Master of ship in case of doubt or assumption • Increase situational awareness to understand importance of proper action to avoid collision
	CAF2	• Provide practical training including simulator application for officers before embarking ship about collision preventing manoeuvring as per COLREG • Request Master of ship to provide visual evidence showing how to take necessary action to avoid collision
	CAF10	• Give clear instruction for OOW to call the Master in case of doubt about action to avoid collision • Provide practical and theoretical applications about proper action on time to avoid collision before embarking ship

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