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Gemi kazanlarının en yaygın kritik operasyonel arızalarının bulanık DEMATEL tekniğiyle değerlendirilme uygulaması

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Application of Fuzzy Dematel Technique to Assess Most Common Critical Operational Faults of Marine Boilers

Araştırma Makalesi / Research Article

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ABSTRACT

Whether it is steam powered or has an internal combustion engine as the main engine of propulsion, a ship without a boiler is unimaginable; somehow a boiler, which is indispensable on ships is needed. Boiler, one of the most important ship auxiliary engines, is used for several purposes that consist of heating of fuel tanks, machinery equipment and accommodation. Many problems can arise in boilers which are designed to work with main engine exhaust gas so that the waste heat can be used in order to match expectations of energy efficiency requirements. When ship systems are analyzed, it is understood that many systems are related to each other. If there is a problem with the boiler many systems will be affected and many problems will be encountered. Therefore, this study provides a fuzzy DEMATEL (Decision Making Trial and Evaluation Laboratory) method to assess most common critical operational faults in marine boilers. The DEMATEL method gives chances to identify and analyses the important faults of marine boiler with respect to cause effect relationship diagram. Likewise, fuzzy sets get through with the uncertainty in decision making and experts comments on DEMATEL. When the results are examined, it is understood that "boiler takes excessive time to reach pressure" is important in terms of the reasons. When the effects are examined, it is seen that the most important effect is "leakage from pipes or valves". The acquired results of the research will contribute to ship boilers operational safety and prevention of dangerous machinery effects.

Keywords: Marine boiler, fuzzy DEMATEL, faults, safety.

Gemi Kazanlarının En Yaygın Kritik Operasyonel Arızalarının Bulanık DEMATEL Tekniğiyle Değerlendirilme Uygulaması

ÖZ

Tahrik sisteminin ana motoru olarak ister buharla çalışan isterse de içten yanmalı motora sahip olan bir geminin, kazansız olması hayal edilemezdir; her şekilde, gemilerde vazgeçilmez bir yardımcı makine olan kazana ihtiyaç vardır. En önemli gemi yardımcı makinelerinden biri olan kazan; yakıt tanklarının, makine ekipmanlarının ve yaşam mahallinin ısıtılmasını içeren çeşitli amaçlarla kullanılmaktadır. Gemi ana makinesi egzoz gazı ile çalışacak şekilde tasarlanmakta ve bu sayede atık ısı, enerji verimliliği gereksinimlerinin beklentilerini karşılayacak şekilde kullanılabilmektedir. Bu sistemlerde kazanlarda birçok sorun ortaya çıkabilir. Gemi sistemleri incelendiğinde, birçok sistemin birbiriyle ilişkili olduğu anlaşılmaktadır. Kazanda bir sorun varsa, birçok sistem etkilenecek ve birçok sorunla karşılaşılacaktır. Bu nedenle, bu çalışma, gemi kazanlarında en yaygın kritik operasyonel hataları değerlendirmek için bulanık bir DEMATEL (Karar Verme Deneme ve Değerlendirme Laboratuvarı) yöntemini sunmaktadır. DEMATEL yöntemi, gemi kazanlarının önemli arızalarını neden etki ilişkisi şemasına göre tanımlama ve analiz etme şansı verir. Benzer şekilde, bulanık kümeler karar verme konusundaki belirsizlikler ve DEMATEL ile ilgili uzman görüşleri üzerine bilgiler vermektedir. Sonuçlar incelendiğinde, "kazanın istenilen basınca ulaşmak için aşırı zaman geçtiği" nedenler açısından önemlidir. Etkiler incelendiğinde en önemli etkinin "borulardan veya valflerden sızıntı" olduğu görülmektedir. Araştırmanın elde edilen sonuçları, gemi kazanlarına operasyonel emniyet ve tehlikeli makine etkilerinin önlenmesine katkıda bulunacaktır.

Anahtar Kelimeler: Gemi kazanları, bulanık DEMATEL, arızalar, emniyet

1. INTRODUCTION

Boilers are closed vessels containing a liquid, generally water, which is converted into steam at any desired ressure designed by applying heat, as understood by marine engineers [1]. Years ago different types of these boilers and control methods were patented [2–4]. Boiler, one of the most important ship auxiliary engines, is used for several purposes that consist of heating of fuel tanks, machinery equipment and accommodation. Basically, it converts the water in the boiler to the high

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temperature steam when the ship is in navigation with the heat of the main engine exhaust gas or the heat obtained by burning the fuel. Although it seem simple, boilers are made up of many structures and affect many systems. From the external view, the structures that are on the boiler can be simply as; hand rail at the top, steam pressure switch and gauge, soot blower, funnel base of main engine (M/E) inlet and outlet, water level controller and gauge, blow of valve(s), fuel oil heater(s), boiler water sampling valve(s) and burner exhaust gas outlet. Likewise, in internal structure, boiler have steam and water drums, some manholes, water tubes, burner etc. Each of these structures is systematically composed of several devices within itself. For example, fuel oil system of boiler have strainers, fuel oil pump, fuel pump motor, control valves, thermocouples, thermostats, solenoid valves for low and high combustion and solenoid shut-off valve. Besides, damper unit, ignition transformers, flame eye and peep hole, nozzles are also system components. In the operation of the boilers, fuel and combustion, air required for combustion, water to be transformed into steam and the treatment of this water, general corrosive problems, vapor pressures and other operational situations are important. There are a few publications and/or books in the literature on ship boilers [5-6], optimal control strategies [7–9] and failures of these boilers [10]. In such cases it is possible to use the fuzzy DEMATEL method. The DEMATEL method enables to identify and analyses the important faults of marine boiler with respect to cause effect relationship diagram. Likewise, fuzzy sets get through with the uncertainty in decision making and experts comments on DEMATEL. When the literature is searched, as for fuzzy DEMATEL technique, it is found that it can be applied to many different areas [11–16]. Wu and Lee [17] searched an effective method that combines fuzzy logic and DEMATEL method to segment required competencies of global managers. Labovská et al. [18] investigated model based hazard identification of an ammonia synthesis chemical reactor. Akyuz and Celik [19] underlined the importance of human errors aboard ships with their reliability analysis for chemical tanker's cargo tank cleaning operations. Patil and Kant [20] proposed a prediction which is based on DEMATEL and fuzzy multi criteria decision making (FMCDM) for knowledge adoption in supply chain. Shahi et al. [21] investigated the cause and effect decision making model of fuzzy DEMATEL for development of nuclear power plant. Baykasoğlu et al. [22] studied on integrating fuzzy DEMATEL and fuzzy hierarchical TOPSIS methods for land transportation companies truck selection. George-Ufot et al. [23] examined several factors into economic, political, environmental and socio - cultural criteria in Nigeria by using fuzzy logic and DEMATEL method. Tadić et al. [24] proposed a novel hybrid model which involve DEMATEL, fuzzy ANP and fuzzy VIKOR for solving complex city logistics concept selection. Furthermore, Liou et al. [25] developed a method that consist of fuzzy logic and DEMATEL method for building safety management system for airlines. When the literature is examined as above, it is seen that these methods have been successfully applied to many different research areas but there are not sufficient studies about ship and marine industry. In this context, apart from prior studies, this paper will remedy the missing part in the literature by adopting fuzzy DEMATEL method for critical operational faults of marine boilers which is one of the most important ship auxiliary engine.

2. RESEARCH METHODS

This study uses fuzzy sets and DEMATEL method to assess most common and important operational faults for ship boilers operation in any type of ships. The next section discusses fuzzy sets and DEMATEL methodologies.

2.1. Fuzzy Sets

Fuzzy logic which is developed by Lotfi A. Zadeh in 1965, is a method for evaluating uncertainty, ambiguity and decision making in human decisions. When the problems of decision making in real transactions are examined, it is seen that many decisions are caused by constraints and uncertain events, which are not known precisely [26]. It is thought to be more advantageous to translate linguistic terms into fuzzy numbers rather than blending opinions, ideas or decisions that arise from the expertise of the individuals or groups. Thus, the problems of group decision-making have essential generated fuzzy numbers to put into effect. A triangular fuzzy number can be expressed as a triplet $\tilde{A} = (l, m, u)$ where l, m and u denotes lower, medium and upper numbers of the fuzzy which is crisp and real numbers $(x \leq y \leq z)$. The membership function of a triangular fuzzy number can be described as below.

$$\mu_{\tilde{A}} = \begin{cases} 0, & x < l \\ (x-l)/(m-l), & l \leq x \leq m \\ (u-x)/(u-m), & m \leq x \leq u \\ 0 & x \geq u \end{cases} \quad (1)$$

Within this framework, Figure 1 shows a triangular fuzzy number. The ersatz relationship among the verbal terms and triangular fuzzy numbers is identified according to the Table 1. Hence, fuzzy ratings and their membership function is exemplified in Figure 2.

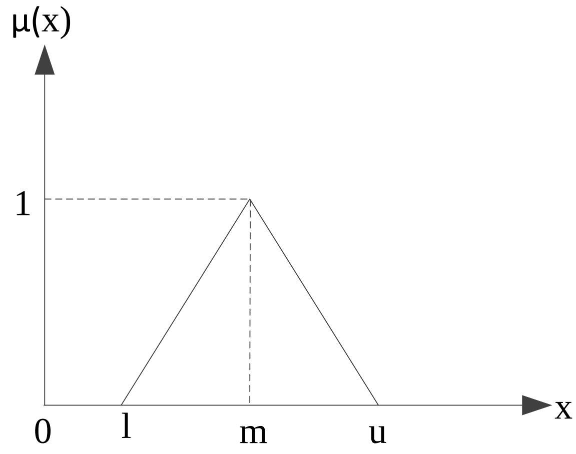

Figure 1. Triangular fuzzy number

Table 1. Ersatz relationship among linguistic terms and fuzzy numbers

Linguistic terms	Triangular fuzzy numbers
No influence (No)	(0, 0, 0.25)
Very low influence (VL)	(0, 0.25, 0.5)
Low influence (L)	(0.25, 0.5, 0.75)
High influence (H)	(0.5, 0.75, 1)
Very high influence (VH)	(0.75, 1, 1)

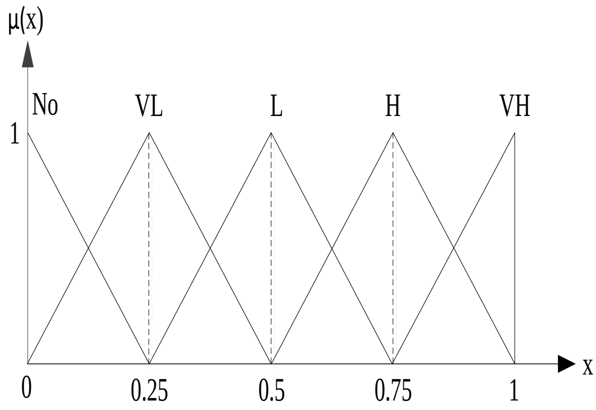

Figure 2. Fuzzy ratings and their membership function

For any two triangular fuzzy numbers $\tilde{A}_1 = (l_1, m_1, u_1)$ and $\tilde{A}_2 = (l_2, m_2, u_2)$, the mathematical calculation of the two triangular fuzzy numbers can be defined as follows:

The inset process among the triangular fuzzy numbers;

$$\tilde{A}_1 + \tilde{A}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (2)$$

The removal operation among the triangular fuzzy numbers;

$$\tilde{A}_1 - \tilde{A}_2 = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \quad (3)$$

The multiplication operation among the triangular fuzzy numbers;

$$\tilde{A}_1 \, x \, \tilde{A}_2 = (l_1 x l_2, m_1 x m_2, u_1 x u_2) \quad (4)$$

The arithmetical operation for the triangular fuzzy numbers;

$$k x \tilde{A}_1 = (k x l_1, k x m_1, k x u_1), (k > 0) \quad (5)$$

$$\frac{\tilde{A}_1}{k} = \left(\frac{l_1}{k}, \frac{m_1}{k}, \frac{u_1}{k}\right), (k > 0) \quad (6)$$

The normalized direct-relation matrix can be obtained through with equation 7. It should be noted that all diagonal elements are equal to zero. Also, total relation matrix (T) is calculated by using equation 8. Finally, r_i and c_j are determined with the help of equations 9 and 10 respectively.

$$D = \frac{1}{\max\limits_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}} \quad (7)$$

$$T = D(1 - D)^{-1} \quad (8)$$

$$r_i = \sum_{1 \le j \le n} t_{ij} \quad (9)$$

$$c_j = \sum_{1 \le i \le n} t_{ij} \quad (10)$$

2.2. Integration of Methods

In this part, fuzzy sets and DEMATEL methods are combined to perform sensitive evaluation. A flow diagram of the fuzzy DEMATEL approach is illustrated in Figure 3. The base steps of the method is described as below [17], [25], [27].

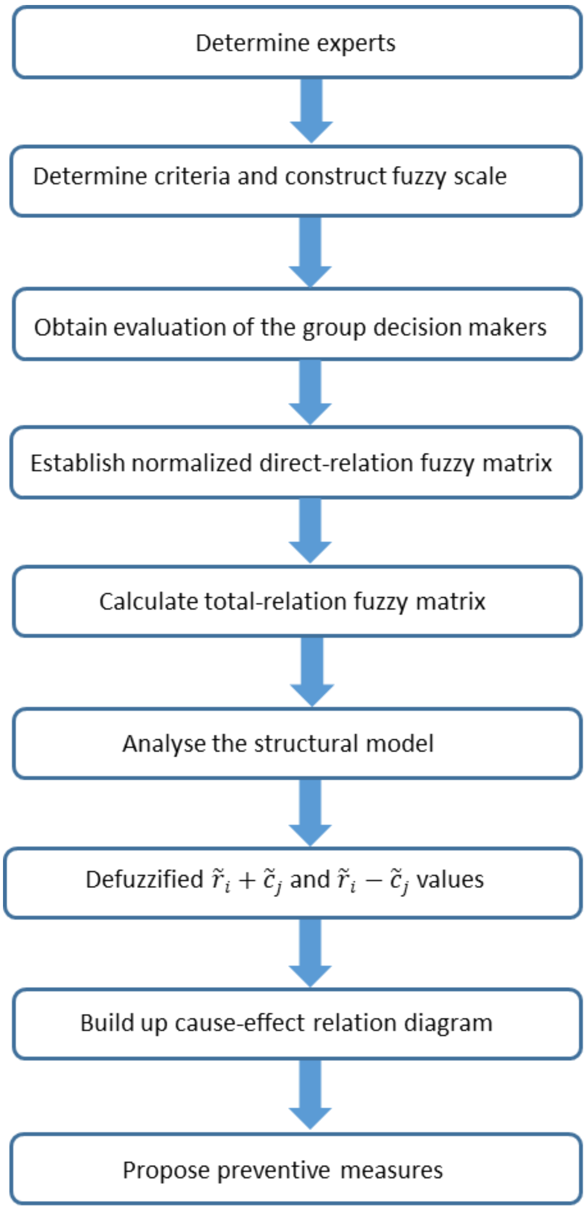

Figure 3. Flow order of the Fuzzy DEMATEL method [28]

Step 1- Determine experts: In this step, it is consulted to the experts who have profound knowledge and experience about the problem in order to obtain coherent assessments.

Step 2-Determine factors and construct fuzzy scale: In this part, important factors are determined in order to be analyzed and assessed appropriately. Later on, linguistic variable is utilized with five scales (no influence, very low influence, low influence, high influence, and very high influence) due to the linguistic terms and fuzzy numbers. Thenceforth, corresponding triangular fuzzy members are shared.

Step 3: Acquire assessment of the group decision makers: The comparison is acquired in terms of verbal variables. Moreover, the fuzzy evaluations are converted into defuzzified and aggregated as a crisp value. As a consequence, initial direct-relation fuzzy matrix ($\tilde{E}$) of group decision makers is builded.

$$\tilde{E} = \begin{bmatrix} 0 & \cdots & \tilde{E}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{E}_{n1} & \cdots & 0 \end{bmatrix} \tag{11}$$

$$\tilde{e}_{ij} = \left(l_{ij}, m_{ij}, u_{ij}\right) \tag{12}$$

Step 4-Demonstrate normalized direct-relation fuzzy matrix: In the presence of the initial direct-relation matrix, normalized direct-relation fuzzy matrix is created. For achieving that, first of all it is considered $\tilde{\beta}_i$and γ as triangular fuzzy numbers. The below calculation is carried out respectively.

$$\tilde{\beta}_i = \sum \tilde{e}_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij}\right) \tag{13}$$

$$\gamma = max\left(\sum_{j=1}^{n} u_{ij}\right) \tag{14}$$

Furthermore, the linear scale transformation is implemented to convert the factors into corresponding scales. The normalized direct-relation fuzzy matrix ($\tilde{F}$) of group decision makers can be shown as below.

$$\tilde{F} = \begin{bmatrix} \tilde{F}_{11} & \cdots & \tilde{F}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{F}_{n1} & \cdots & \tilde{F}_{nn} \end{bmatrix} \tag{15}$$

where $\tilde{f}_{ij} = \frac{\tilde{e}_{ij}}{\gamma} = \left(\frac{\tilde{e}_{ij}}{\gamma}, \frac{\tilde{e}_{ij}}{\gamma}, \frac{\tilde{e}_{ij}}{\gamma}\right)$

Step 5-Calculate total-relation fuzzy matrix: After having established normalized direct-relation fuzzy matrix, a total-relation fuzzy matrix is calculated by making sure that $\lim_{\omega\to\infty} F^{\omega} = 0$. After, the crisp case of the total-relation fuzzy matrix is identified as follows.

$$\tilde{T} = \lim_{\omega\to\infty}\left(\tilde{F} + \tilde{F}^2 + \cdots + \tilde{F}^{\omega}\right) \tag{16}$$

$$\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \cdots & \tilde{t}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{t}_{n1} & \cdots & \tilde{t}_{nn} \end{bmatrix} \tag{17}$$

where $\tilde{t}_{ij=} = (l''_{ij}, m''_{ij}, u''_{ij})$

$$Matrix\left[l''_{ij}\right] = F_l \; x \; (I - F_l)^{-1} \tag{18}$$

$$Matrix\left[m''_{ij}\right] = F_m \; x \; (I - F_m)^{-1} \tag{19}$$

$$Matrix\left[u''_{ij}\right] = F_u \; x \; (I - F_u)^{-1} \tag{20}$$

Step 6-Analyse the structural model: After calculating matrix $\tilde{T}$, $\tilde{r}_i + \tilde{c}_j$and $\tilde{r}_i - \tilde{c}_j$are calculated. In the formula, $\tilde{r}_i$and $\tilde{c}_j$denote the sum of the rows and columns of matrix $\tilde{T}$. While $\tilde{r}_i + \tilde{c}_j$ shows the importance of factor i, $\tilde{r}_i - \tilde{c}_j$ shows the net effect of factor i.

Step 7- Defuzzify $\tilde{r}_i + \tilde{c}_j$ and $\tilde{r}_i - \tilde{c}_j$: Thenceforth, $\tilde{r}_i + \tilde{c}_j$+ and $\tilde{r}_i - \tilde{c}_j$are defuzzified by using COA (centre of area) defuzzification technique which is introduced by Ross [29] in order to determine BNP (best non-fuzzy performance) value. For a convex fuzzy number $\tilde{\delta}$, a real number z^* corresponding to its centre of area can be expressed as below: [30].

$$z^* = \frac{\int \mu_{\tilde{\delta}}(z) z dz}{\int \mu_{\tilde{\delta}}(z) dz} \tag{21}$$

The BNP value of a fuzzy number $\tilde{G} = (l_{ij}, m_{ij}, u_{ij})$can be determined with following formula.

$$BNP_{ij} = \frac{u_{ij}-l_{ij}+m_{ij}-l_{ij}}{3} + l_{ij} \quad (22)$$

Step 8-Build up cause-effect relation diagram: Lastly, the cause and effect relation diagram is illustrated by representing the dataset of $r_i + c_j$ and $r_i - c_j$. The calculation can be done with the step 6 approach.

3. APPLICATION

This section includes fuzzy DEMATEL method which is applied to assess most common critical operational faults of marine boilers. The 15 critical problems identified by an overall assessment and the reports of several boiler manufacturers are addressed.

3.1. Problem Description

Operational faults in boilers operating at high temperatures and pressures can have serious damages to people working in the ship machinery room, as well as to auxiliary equipment and systems that the boiler feeds. The boiler, which is directly and indirectly connected to many systems, is at the forefront of the most important auxiliary machinery on the ship. If the heating cannot be done, many systems, especially the fuel system, will be negatively affected and the ship operation will suffer a great deal of problems. Therefore, both physical and operational failures must be identified, hazards that may potentially be known, and necessary maintenance repairs made accordingly. In this context, Table 2 shows most common critical operational and physical problems of marine steam boilers.

Table 2. Critical operational faults of marine composite boiler

C1	High or low water level alarm
C2	Hotwell tank low level alarm
C3	Leakage from pipes or valves
C4	Turbolator fan doesn't work properly
C5	Atomizer doesn't work properly
C6	Ignition electrodes are dirty
C7	Safety valve doesn't work properly
C8	Feed water pump doesn't work properly
C9	PH, Alkalinity or Chloride problem
C10	General corrosion problems
C11	Boiler fuel supply pump doesn't work properly
C12	Air ratio setting is not proper
C13	Fluctuation problem on steam pressure
C14	Very high furnace pressure and temperature
C15	Boiler takes excessive time to reach pressure

3.2. Determining of Experts

The views of experienced engineers who have profound knowledge and also working in the sector are very important because of the lack of academic studies and books about the systems on the ships. Thus, evaluations from experts' verbal experiences are very practical and useful. Marine engineers usually make a 6 month long distance marine internship as engine cadet. After an oceangoing marine training, they become an oceangoing watch keeping engineer (third engineer). After working for 30 months at sea, they become second engineers by going into exams in Turkey. After being a second engineer, they become chief engineers when they work at sea for 30 months and pass exams. One, have to work at sea for almost 5 years to become chief engineer. Thus, in this study, the knowledge of two oceangoing chief engineers who have at least 10 years' experience and have been closely interested in boiler repair & maintenance and also the information of a naval architecture and marine engineer who has done oceangoing second engineering at ships have been referred. The marine engineers were asked to evaluate the relationship between faults on boiler according to the verbal scale. It seems that the consensus of experts is achieved to get meaningful result.

3.3. Application of Proposed Method

Critical operational problems related to boiler operation are given in Table 2 and marine egineers were asked to understand the relationship between faults. Then, marine engineers assess the relationship between the faults through the use of fuzzy verbal scale. Accordingly, Table 3 illustrates the initial direct-fuzzy matrix. After determining established initial direct-fuzzy matrix, normalized direct-relation fuzzy matrix is determined by using equations 13-15 respectively. Table 4 demonstrates the normalized initial direct-relation fuzzy matrix. Moreover, total relation fuzzy matrix can be determined with the help of equations 16-20. So, Table 5 shows the total-relation fuzzy matrix. Later on, table 6 Illustrates defuzzified threshold values of T-matrix, table 7 demonstrates fuzzy values of $\tilde{r}_i, \tilde{c}_j,$ $\tilde{r}_i + \tilde{c}_j$, $\tilde{r}_i - \tilde{c}_j$ and lastly in the light of above, with the help of equations 21 and 22 the crisp results.

Table 3. The initial direct-relation fuzzy matrix

	C1	C2	C3	C4	…	C12	C13	C14	C15
C1	(0, 0, 0.25)	(0.50, 0.75, 1)	(0.33, 0.50, 0.67)	(0, 0, 0.25)	…	(0, 0, 0.25)	(0, 0.17, 0.42)	(0, 0, 0.25)	(0.08, 0.25, 0.50)
C2	(0, 0.17, 0.42)	(0, 0, 0.25)	(0.75, 1, 1)	(0, 0, 0.25)	…	(0, 0, 0.25)	(0.25, 0.42, 0.67)	(0, 0, 0.25)	(0.08, 0.25, 0.50)
C3	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	…	(0, 0, 0.25)	(0.17, 0.42, 0.67)	(0, 0.17, 0.42)	(0.08, 0.25, 0.50)
C4	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	…	(0.25, 0.50, 0.75)	(0.08, 0.25, 0.50)	(0.25, 0.42, 0.67)	(0.17, 0.33, 0.58)
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
C12	(0, 0, 0.25)	(0, 0, 0.25)	(0.33, 0.50, 0.67)	(0.75, 1, 1)	…	(0, 0, 0.25)	(0.17, 0.33, 0.58)	(0, 0.08, 0.33)	(0.33, 0.50, 0.75)
C13	(0.5, 0.75, 0.92)	(0.58, 0.83, 0.92)	(0.50, 0.75, 1)	(0.42, 0.67, 0.92)	…	(0.25, 0.42, 0.67)	(0, 0, 0.25)	(0.25, 0.42, 0.67)	(0.17, 0.33, 0.58)
C14	(0.33, 0.50, 0.67)	(0, 0.17, 0.42)	(0.17, 0.42, 0.67)	(0.08, 0.25, 0.50)	…	(0.17, 0.33, 0.58)	(0.17, 0.33, 0.58)	(0, 0, 0.25)	(0.08, 0.25, 0.50)
C15	(0, 0.17, 0.42)	(0.08, 0.25, 0.50)	(0.75, 1,1)	(0.50, 0.75, 0.92)	…	(0.75, 1, 1)	(0.25, 0.42, 0.67)	(0, 0, 0.25)	(0, 0, 0.25)

Table 4. Normalized initial direct-relation fuzzy matrix

	C1	C2	C3	C4	…	C12	C13	C14	C15
C1	(0, 0, 0.03)	(0.05, 0.08, 0.11)	(0.04, 0.05, 0.07)	(0, 0, 0.03)	…	(0, 0, 0.03)	(0, 0.02, 0.04)	(0, 0, 0.03)	(0.01, 0.03, 0.05)
C2	(0, 0.02, 0.04)	(0, 0, 0.03)	(0.08, 0.11, 0.11)	(0, 0, 0.03)	…	(0, 0, 0.03)	(0.03, 0.04, 0.07)	(0, 0, 0.03)	(0.01, 0.03, 0.05)
C3	(0, 0, 0.03)	(0, 0, 0.03)	(0, 0, 0.03)	(0, 0, 0.03)	…	(0, 0, 0.03)	(0.02, 0.04, 0.07)	(0, 0.02, 0.04)	(0.01, 0.03, 0.05)
C4	(0, 0, 0.03)	(0, 0, 0.03)	(0, 0, 0.03)	(0, 0, 0.03)	…	(0.03, 0.05, 0.08)	(0.01, 0.03, 0.05)	(0.03, 0.04, 0.07)	(0.02, 0.04, 0.06)
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
C12	(0, 0, 0.03)	(0, 0, 0.03)	(0.04, 0.05, 0.07)	(0.08, 0.11, 0.11)	…	(0, 0, 0.03)	(0.02, 0.04, 0.06)	(0, 0.1, 0.4)	(0.04, 0.05, 0.08)
C13	(0.05, 0.08, 0.10)	(0.06, 0.09, 0.10)	(0.05, 0.08, 0.11)	(0.04, 0.07, 0.10)	…	(0.03, 0.04, 0.07)	(0, 0, 0.03)	(0.03, 0.04, 0.07)	(0.02, 0.04, 0.06)
C14	(0.04, 0.05, 0.07)	(0, 0.02, 0.04)	(0.02, 0.04, 0.07)	(0.01, 0.03, 0.05)	…	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0, 0, 0.03)	(0.01, 0.03, 0.05)
C15	(0, 0.02, 0.04)	(0.01, 0.03, 0.05)	(0.08, 0.11, 0.11)	(0.05, 0.08, 0.10)	…	(0.08, 0.11, 0.11)	(0.03, 0.04, 0.07)	(0, 0, 0.03)	(0, 0, 0.03)

Table 5. Total–relation fuzzy matrix

	C1	**C2**	**C3**	**C4**	**…**	**C12**	**C13**	**C14**	**C15**
C1	(0, 0.01, 0.18)	(0.06, 0.10, 0.27)	(0.05, 0.09, 0.32)	(0, 0.01, 0.19)	**…**	(0, 0.01, 0.18)	(0.01, 0.04, 0.26)	(0, 0.01, 0.17)	(0, 0.04, 0.20)
C2	(0, 0.03, 0.20)	(0.01, 0.02, 0.20)	(0.09, 0.14, 0.36)	(0, 0.01, 0.19)	**…**	(0, 0.01, 0.18)	(0.03, 0.07, 0.29)	(0, 0.01, 0.17)	(0, 0.05, 0.20)
C3	(0, 0.01, 0.17)	(0, 0.02, 0.19)	(0.01, 0.03, 0.27)	(0, 0.01, 0.18)	**…**	(0, 0.01, 0.17)	(0.02, 0.06, 0.27)	(0, 0.02, 0.18)	(0, 0.04, 0.20)
C4	(0, 0.01, 0.15)	(0, 0.01, 0.16)	(0, 0.02, 0.24)	(0, 0.02, 0.17)	**…**	(0.03, 0.07, 0.21)	(0.01, 0.04, 0.23)	(0.03, 0.05, 0.20)	(0, 0.05, 0.20)
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
C12	(0, 0.01, 0.18)	(0, 0.01, 0.19)	(0.04, 0.08, 0.32)	(0.08, 0.12, 0.28)	**…**	(0.01, 0.02, 0.19)	(0.02, 0.06, 0.28)	(0, 0.03, 0.20)	(0, 0.07, 0.3)
C13	(0.06, 0.10, 0.32)	(0.07, 0.12, 0.35)	(0.07, 0.15, 0.48)	(0.05, 0.10, 0.35)	**…**	(0.03, 0.07, 0.30)	(0.01, 0.05, 0.36)	(0.03, 0.06, 0.30)	(0, 0.08, 0.4)
C14	(0.04, 0.07, 0.23)	(0.01, 0.04, 0.23)	(0.03, 0.08, 0.34)	(0.01, 0.04, 0.23)	**…**	(0.02, 0.05, 0.23)	(0.02, 0.06, 0.29)	(0, 0.01, 0.19)	(0, 0.05, 0.3)
C15	(0, 0.04, 0.25)	(0.01, 0.05, 0.28)	(0.10, 0.17, 0.46)	(0.06, 0.11, 0.34)	**…**	(0.09, 0.13, 0.32)	(0.04, 0.09, 0.38)	(0.01, 0.03, 0.25)	(0, 0.04, 0.3)

Table 6. Defuzzified threshold values of T-matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	0.06	0.14	0.15	0.07	0.07	0.06	0.11	0.15	0.14	0.14	0.07	0.06	0.10	0.06	0.06
C2	0.08	0.07	0.20	0.07	0.07	0.06	0.14	0.15	0.11	0.14	0.07	0.06	0.13	0.06	0.07
C3	0.06	0.07	0.10	0.06	0.07	0.06	0.13	0.12	0.14	0.15	0.07	0.06	0.12	0.07	0.07
C4	0.05	0.06	0.09	0.07	0.09	0.08	0.07	0.07	0.07	0.10	0.07	0.10	0.09	0.09	0.09
C5	0.05	0.06	0.09	0.07	0.06	0.07	0.07	0.07	0.07	0.12	0.12	0.06	0.10	0.08	0.08
C6	0.06	0.07	0.11	0.12	0.13	0.07	0.08	0.08	0.10	0.13	0.14	0.12	0.11	0.10	0.11
C7	0.07	0.08	0.15	0.07	0.07	0.06	0.08	0.08	0.15	0.16	0.07	0.06	0.14	0.06	0.07
C8	0.12	0.15	0.16	0.07	0.08	0.06	0.09	0.09	0.11	0.15	0.07	0.07	0.14	0.06	0.07
C9	0.05	0.05	0.14	0.05	0.05	0.05	0.08	0.08	0.08	0.16	0.05	0.05	0.08	0.05	0.05
C10	0.05	0.05	0.12	0.05	0.05	0.05	0.06	0.08	0.15	0.08	0.05	0.05	0.09	0.05	0.05
C11	0.05	0.06	0.13	0.06	0.09	0.10	0.07	0.07	0.08	0.16	0.06	0.06	0.10	0.09	0.08
C12	0.06	0.07	0.15	0.16	0.16	0.08	0.08	0.08	0.09	0.15	0.12	0.07	0.12	0.08	0.09
C13	0.16	0.18	0.23	0.16	0.18	0.13	0.19	0.19	0.17	0.20	0.15	0.13	0.14	0.13	0.13
C14	0.11	0.09	0.15	0.10	0.10	0.09	0.11	0.13	0.10	0.15	0.10	0.10	0.13	0.07	0.07
C15	0.10	0.12	0.24	0.17	0.19	0.13	0.20	0.16	0.15	0.20	0.19	0.18	0.17	0.09	0.09

Table 7. Fuzzy values of $\tilde{r}_i, \tilde{c}_{j,}\ \tilde{r}_i + \tilde{c}_j, \tilde{r}_i - \tilde{c}_j$

	$\tilde{r}_i$	$\tilde{c}_j$	$\tilde{r}_i + \tilde{c}_j$	$\tilde{r}_i - \tilde{c}_j$
C1	(0.28, 0.67, 3.53)	(0.17, 0.42, 2.87)	(0.45, 1.09, 6.40)	(-2.59, 0.24, 3.36)
C2	(0.28, 0.69, 3.55)	(0.24, 0.54, 3.18)	(0.52, 1.23, 6.73)	(-2.89, 0.15, 3.32)
C3	(0.22, 0.58, 3.36)	(0.59, 1.23, 4.80)	(0.81, 1.81, 8.16)	(-4.58, -0.66, 2.77)
C4	(0.14, 0.43, 2.99)	(0.27, 0.56, 3.22)	(0.40, 0.99, 6.21)	(-3.08, -0.12, 2.73)
C5	(0.13, 0.42, 2.98)	(0.29, 0.63, 3.44)	(0.42, 1.05, 6.42)	(-3.31, -0.21, 2.69)
C6	(0.30, 0.71, 3.65)	(0.16, 0.41, 2.84)	(0.46, 1.12, 6.49)	(-2.54, 0.30, 3.50)
C7	(0.23, 0.57, 3.38)	(0.33, 0.72, 3.63)	(0.55, 1.30, 7.01)	(-3.40, -0.15, 3.05)
C8	(0.32, 0.71, 3.61)	(0.33, 0.78, 3.75)	(0.65, 1.49, 7.37)	(-3.43, -0.07, 3.28)
C9	(0.15, 0.36, 2.76)	(0.32, 0.86, 3.95)	(0.47, 1.22, 6.71)	(-3.80, -0.49, 2.44)
C10	(0.14, 0.34, 2.67)	(0.49, 1.18, 4.89)	(0.63, 1.52, 7.57)	(-4.75, -0.84, 2.18)
C11	(0.20, 0.49, 3.06)	(0.29, 0.60, 3.33)	(0.49, 1.09, 6.39)	(-3.13, -0.11, 2.77)
C12	(0.37, 0.77, 3.70)	(0.23, 0.47, 2.98)	(0.60, 1.24, 6.68)	(-2.61, 0.29, 3.47)
C13	(0.68, 1.42, 5.42)	(0.29, 0.85, 4.12)	(0.97, 2.26, 9.54)	(-3.44, 0.57, 5.12)
C14	(0.26, 0.76, 3.85)	(0.14, 0.39, 2.90)	(0.39, 1.15, 6.75)	(-2.64, 0.37, 3.72)
C15	(0.71, 1.42, 5.09)	(0.27, 0.71, 3.72)	(0.98, 2.13, 8.81)	(-3.00, 0.71, 4.82)

Table 8. Crisp values of $\tilde{r}_i, \tilde{c}_j, \tilde{r}_i + \tilde{c}_j, \tilde{r}_i - \tilde{c}_j$

	$\tilde{r}_i$	$\tilde{c}_j$	$\tilde{r}_i + \tilde{c}_j$,	$\tilde{r}_i - \tilde{c}_j$
C1	1.49	1.16	2.65	0.34
C2	1.51	1.32	2.83	0.19
C3	1.38	2.21	3.59	-0.82
C4	1.19	1.35	2.53	-0.16
C5	1.18	1.45	2.63	-0.28
C6	1.56	1.14	2.69	0.42
C7	1.39	1.56	2.96	-0.17
C8	1.55	1.62	3.17	-0.07
C9	1.09	1.71	2.80	-0.62
C10	1.05	2.19	3.24	-1.14
C11	1.25	1.40	2.66	-0.15
C12	1.61	1.23	2.84	0.38
C13	2.50	1.75	4.26	0.75
C14	1.62	1.14	2.76	0.48
C15	2.41	1.56	3.97	0.84

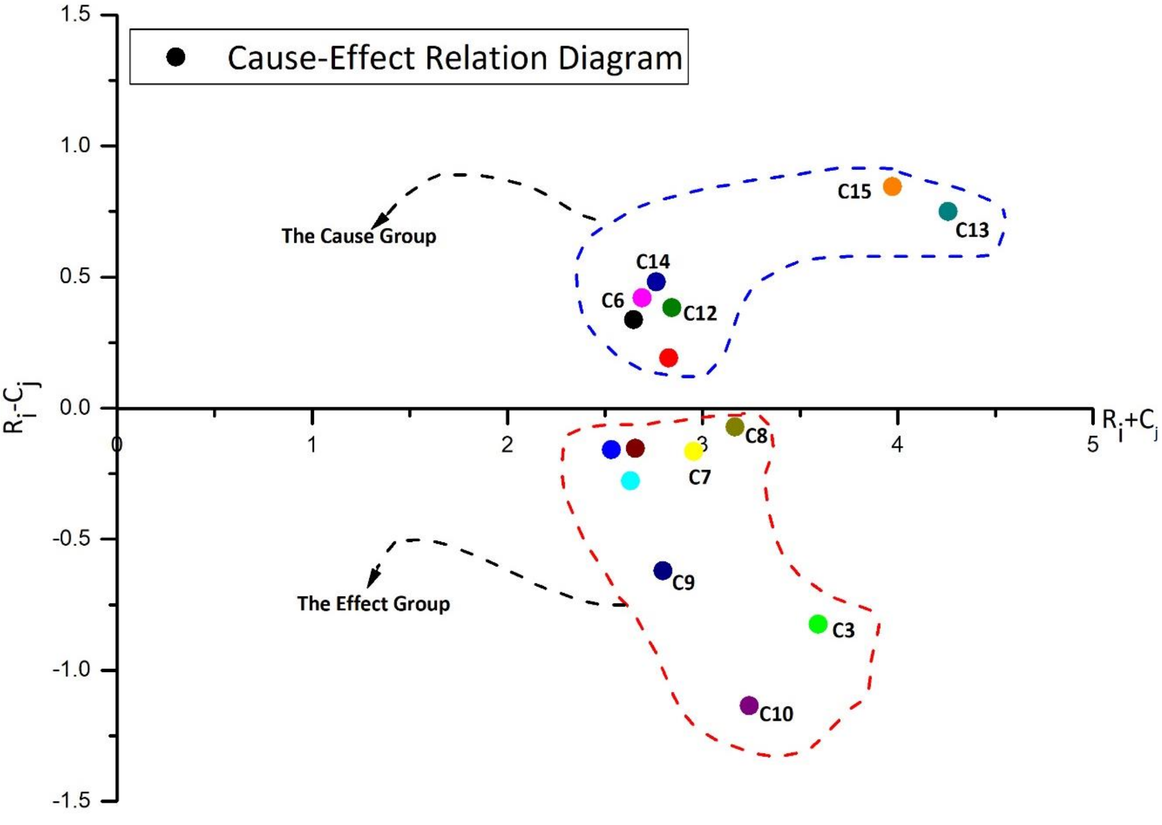

Figure 4. Cause-effect relation diagram

3.4. Findings and Comments

With the help of the above calculations results, figure 4 illustrates the cause effect relation diagram which is divided into two different groups; the cause and the effect group.

3.4.1. Cause Factors

In order to clearly assess the most common critical marine boiler operational faults it is really important to focus on the cause factors which require great caution. While investigating figure 4 C15 (Boiler takes excessive time to reach pressure) has the highest r_i-c_j value (0.84) between the all factors in cause group. This tells that C15 has more impact on the whole process. Thereafter, C13 (Fluctuation problem on steam pressure) is the second most important causal factor since it is at second place between entire process. Also C13 has third highest r_i value (1.75) which means that it has substantial influence on entire process. The third most critical factor between all factors is C14 (Very high furnace pressure and temperature) since its r_i-c_j value is (0.48). This sequence continues with C6 (Ignition electrodes are dirty) and C12 (Air ratio setting is not proper). And it seems from hereafter other cause factors have relatively moderate impact on the whole boiler system.

3.4.2. Effect Factors

As it is known, influential effect factors can easily be affected by other factors. It may still be necessary to analyze the effect factors (faults) that could lead to serious consequences in the operations of the marine boiler. According to the cause effect relation diagram in figure 4, there is every appearance that C3 (Leakage from pipes or valves) has the highest r_i+c_j value (3.59) between effect factor group. Furthermore, its influenced impact index (c_j) has the biggest value (2.21) among entire process. r_i-c_j value of C3 is also appears to be in the middle when the whole process is taken into consideration. The system will continue to operate at its maximum capacity so that the operating pressure of the system can be provided in case of a leakage from pipes or valves. The boiler fuel pumps will run continuously and the water will be pumped consistently from the hotwell tank to the boiler. If the leakages can not be remedied urgently, there is a possibility of encountering more problems in a short time. Moreover, C10 (General corrosion problems) and C8 (Feed water pump doesn't work properly) have great influence on the whole process as effect factors. But, C8 r_i-c_j value is (-0.07) which means that it should be excepted from critical cause faults list. Because feed water pump can easily be repaired if a problem is encountered or a spare pump can be replaced quite easily.

3.5. Recommendations for Preventing Failures

Planned maintenance and repairs must be carried out either at the ship's main engine or at the ship auxiliary engine(s). Both the intermediate surveys and the main machinery surveys, which is held every 5 years, have the vital importance of eliminating any kind of glitches. When examining 15 common problems with the boiler, for preventing any malfunction some important inspections should be done. Careless handling of the burner unit can seriously lead up to causing accidents such as explosion and fires which may lead to loss of life. For example, if there is burner ignition failure, electrodes should be checked and dirt on electrode and insulator should be removed. Likewise, in case of the oil temperature is improper the setting of the thermostat for temperature control should be done. Furthermore, in case of safety valve(s) fault the reason is generally; operating and limit switch set higher that safety valve, incorrect wired gas valve or somehow pressure of boiler exceeds pressure setting of safety valve. Finally it can be say that instruction manuals must be read before operation of boiler.

4. CONCLUSION

Both on land and onboard, security and safety are the most important issues. Safety of life at sea is the most important issue as there is little chance of medical intervention at sea. For this reason, the operation of ship machinery which usually operates at high temperatures and pressures needs to be done with great care and attention. A malfunction at the machinery can cause serious damage either to crew or to machinery. There is almost no study in the marine boiler problems in literature related to this subject. In order to close this gap in the literature, in this study, 15 critical problems of marine boilers were investigated by using fuzzy DEMATEL approach for betterment of safety as well as prevention loss of crew life and machinery hazards. While DEMATEL gives chances to an intelligent decision-making approach for evaluation by dividing potential failures into a cause-effect group, fuzzy sets make it possible to interpret uncertain and ambiguous judgments in group decision. Thus, most common and critical operational faults in the course of marine boiler process are determined and evaluates associated with visual cause - effect relation diagram. When all these results are examined, it is clear that scheduled maintenance is vital to the ship. It should be remembered that all the systems on the ship are somehow connected to each other and it should not be forgotten that an error will trigger other failures. For this reason, it is very important to carry out all maintenance and repair operations on time. As a result, contribution of the research findings to seafarers and indirectly to the ship owners can be considerably admirable. Also, the result of research contributes an important way to sustainably enrich safety of shipboard machinery operations in an extensive way. Moreover, if boiler takes excessive time to reach pressure the reasons are mostly: burners can be out of adjustment, improper gas pressure, insufficient quantity of gas supply, dirty boiler flue passages.

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