

A Multi-Criteria Decision-Making Method Based upon Type-2 Interval Fuzzy Sets for Auxiliary Systems of a Ship's Main Diesel Engine

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Abstract: A well-qualified ship engine conductor having an effective error detection system is required to find failure as a result of which action is immediately to be taken to prevent any possible engine impairments. Otherwise failures cumulatively can end up with crippling and irreversible profit loss. This paper proposes a fuzzy MADM methodology, which can help determine the most effective system for main diesel engine of a ship. A novel interval type-2 fuzzy MADM method is chosen for the study, resting on VIKOR, to assess and employ the failure detection of auxiliary systems of a marine diesel engine. The evaluation is conducted by various groups of experts. It has been presumed that this study will also work out as a useful future maintenance process reference for marine engineering operators. However, the importance of the using time effectively to determine and respond to such failures is also underlined within the study. The results reveal that a fuel system is categorized as the most effective alternative subsequently followed by a governor system, an air supply system, and lastly, a cooling system. The results are grounded on the opinions expressed by three decision-making groups who put the MDEAS alternatives according to twenty ably selected criteria.

Keywords: Interval type-2 fuzzy sets, VIKOR, troubleshooting, ship main diesel engine

1. Introduction

Marine diesel engines require fuel, governor and other systems to work in a proper way to get the desired power and rotation ranges set by engine manufacturers. Operating engines out of this range can cause severe failures in the long run. In order to foresee failures, early warning tools and measures like temperature, pressure and flow sensors are advised to be available. Reading and assessing the values of these indicators, measures to prevent such failures can then be taken. The early identification of power transfer failures can eliminate the disruption of a ship's diesel engine completely. Thus, by dint of such expert analytical systems, a clear correlation relationship of these failures with other systems is to be revealed and efficiency values are examined.

Adequate number of aggregation methods, which are based on fuzzy sets theory, has been put forward to acquire the resulting evaluation from the experts' individual opinions. Yeh and Chang [1] suggested a hierarchical weighting method. Development of a decision support system based on a model by Ma et al. [2] increased the level of overall satisfaction in the MCDM. Fan and Liu [3] introduced a method for group decision-making based on multi-granularity uncertain linguistic information. Cebi et al. [4] introduced, thanks to PROLOG programming language, an expert failure detection system to detect and handle failures, which often take place in ship cooling system. Considering the types of failures that priorly happened, they shaped action tables to display what to do in case of emergency. Calder [5] advanced a detection failure instrument to check the fuel, oil, exhaust, combustion air and cooling water systems. Taking into consideration the utilization of warning indicators and alarms, it appears rather toilsome to find possible machine failures beforehand due to the relationships

between the systems. To deal with this difficulty, a fuzzy MCDM was proposed for the selection of marine diesel engine failures. Fuzzy analytic hierarchy process and the fuzzy technique were enjoyed in FAHP-TOPSIS methods.

Various techniques have been compared in the literature for failure analysis. In the study conducted by Liu et al. [6], linguistic variables, which were defined in trapezoidal or triangular fuzzy numbers, were the necessary instruments to evaluate the ratings and weights for the risk factors. While selecting the most severe failure modes, the expanded Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method was used to recognize the risk priorities of the failure modes that were defined. Consequently, a fuzzy FMEA based on a fuzzy set theory and the VIKOR method to prioritize failure modes, specifically were meant to some restrictions of the classical FMEA. Vinodh et al. [7] launched into a research method in which the concept selection in a proper environment was improved as MCDM. For problem and solutions, utilization of a fuzzy based compromise solution method VIKOR was offered. Martinez-Martin et al. [8] introduced a general framework to solve the representation magnitude and the basic step of inference process of qualitative models based on intervals. Type-2 fuzzy sets qualified with primary and secondary membership came out as an extension of type-1 fuzzy sets [9]. In the literature, some articles appertaining to type-2 fuzzy sets were possible to encounter. A type-2 fuzzy technique for the priority sequence close to an ideal solution (TOPSIS) by Chen and Lee [10] aimed to overcome group decision-making problems based upon TOPSIS.) Chen et al. [11] introduced a method to discuss multi-quality group decision-making problems which depend upon the sequence of type-2 interval fuzzy sets. Chen [12] put forward a new method in order to surmount multi-criteria group decision making problems depending upon type-2 interval fuzzy sets and to

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set the targeted importance of criteria.

From the survey and data using statistical analysis are the attributes determined. Interval type-2 fuzzy sets, more suitable, flexible and intelligent than type-1 fuzzy sets, represented uncertainties for handling fuzzy group decision-making problems [10], [13]-[16]. We then start combining VIKOR with interval type-2 fuzzy sets to acquire the rankings of the auxiliary systems. The major advantages of the VIKOR method arise from its trading off the maximum “group utility” of the “majority” and the minimum of the individual regret of the “opponent”, and it is simple and straight forward to calculate. Combination of VIKOR method and interval type-2 fuzzy sets can be considered as an interesting and important research topic. Briefly, integration of all these methods brings a valid and reliable evaluation of auxiliary systems rank.

In this paper interval type 2 fuzzy set was used because of their easiness and reduced computational effort in comparison with general fuzzy sets. It is also emphasized that type-2 fuzzy sets handle more uncertainty and hence, produces more accurate and robust results. Also this method was first used in ship industry. The framework of this paper falls into four sections: in Section I, the research methodologies. In Section II, setting and illustration of the model VIKOR based interval type-2 fuzzy set. In Section III, use of data collection on the study introduction and the application of the hierarchical structure adopted for trouble shooting the operational problems of the ship’s diesel engine, finally, in Section IV, the discussion and conclusion of the paper.

2. Decision Making Methods

If you are using Word, use either the Microsoft Equation Editor or the MathType add-on (<http://www.mathtype.com>) for equations in your paper (Insert | Object | Create New | Microsoft Equation or MathType Equation). “Float over text” should not be selected.

2.1. Type-2 Fuzzy Sets

Over the decision-making process, due to the increase in complexity of the socio-economic environment and the uncertainty of the immanent subjective nature of human thought, the information in relation with quality values has been uncertain and fuzzy in general. This reality has led numerous researchers to act for the fuzzy set theory so as to model uncertainty and ambiguity along the decision-making processes [17].

Depending upon the type-1 fuzzy sets, certain MADM methods have been put forward. Type-2 fuzzy sets entail a higher degree of uncertainty rather than the type-1 fuzzy sets. These provide us more room for representing the uncertainty and fuzziness of the real world. Type-2 fuzzy sets can be regarded as an extensive version of type-1 fuzzy sets. For type-2 interval fuzzy sets can replace traditional type-1 fuzzy sets to point to the weights of the qualities and evaluation values, type-2 fuzzy sets help us with a more beneficial method to solve the fuzzy multi-criteria decision-making problems more flexibly and intelligently [10], [17].

2.2. VIKOR Based Interval Type-2 Fuzzy Set Methodology

The VIKOR method is defined as a (Multi-Attribute Decision Making) MADM technique rooted in compromise solution [18-20]. It gives a maximum group utility for the majority and a minimum of an individual regret for the opponent. Interval-valued fuzzy sets [21], interval-valued fuzzy with gray relational analysis [22], triangular intuitionistic fuzzy numbers [23], and 2-tuple fuzzy numbers [24] are combined with VIKOR. Therefore, type-2 fuzzy sets are subject to more uncertainty than type-1 fuzzy sets with additional degrees of freedom [10]. A comprehensive review paper

on interval based type-2 fuzzy sets literature has been recently studied by Celik et al. [25]. Interested readers are advised to read this useful review paper.

In this paper, the extended VIKOR method with interval type-2 fuzzy sets is set forth to get the best Affected System (AS) level of marine diesel engines auxiliary systems (MDEAS) established on average and the worst group scores among the set of alternatives. In the AS evaluation process of MDEAS, it is well in advance accepted that m alternatives (auxiliary systems), where (R_1, R_2, \dots, R_m) , n attributes (A_1, A_2, \dots, A_n) and L decision makers (C_1, C_2, \dots, C_L) are present.

The steps of the VIKOR, based on interval type-2 fuzzy sets, are displayed as the following [26]:

Step 1. The importance weights of the attributes are estimated using Equation 1

$$A_n = (\tilde{a}_j^k)_{n \times 1} = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_n \end{matrix} \begin{bmatrix} \tilde{a}_1^k \\ \tilde{a}_2^k \\ \dots \\ \tilde{a}_n^k \end{bmatrix} \quad (1)$$

where $\tilde{a}_j = (\frac{\tilde{a}_j^1 \oplus \tilde{a}_j^2 \oplus \dots \oplus \tilde{a}_j^L}{L})$ \tilde{a}_j is an interval type-2 fuzzy set

$1 \leq i \leq m, 1 \leq j \leq n, 1 \leq k \leq L$ and L signifies the number of decision makers.

Step 2. The average fuzzy performance values of MDEAS are also calculated by use of Equation 2

$$E_c = (\tilde{e}_{ij}^k)_{n \times m} = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_n \end{matrix} \begin{matrix} R_1, R_2, \dots, R_m \\ \begin{bmatrix} \tilde{e}_{11}^k & \tilde{e}_{12}^k & \dots & \tilde{e}_{1m}^k \\ \tilde{e}_{21}^k & \tilde{e}_{22}^k & \dots & \tilde{e}_{2m}^k \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{e}_{n1}^k & \tilde{e}_{n2}^k & \dots & \tilde{e}_{nm}^k \end{bmatrix} \end{matrix} \quad (2)$$

Where $\tilde{e}_{ij} = (\frac{\tilde{e}_{ij}^1 \oplus \tilde{e}_{ij}^2 \oplus \dots \oplus \tilde{e}_{ij}^L}{L})$, \tilde{e}_{ij} is an interval type-2

fuzzy set $1 \leq i \leq m, 1 \leq j \leq n, 1 \leq k \leq L$ and L means the number of customers.

Step 3. The weighted type-2 fuzzy decision matrix is calculated as the following:

$$\tilde{V} = \left[\tilde{v}_{ij} \right]_{m \times n} \quad (3)$$

Where

$$\tilde{v}_{ij} = \tilde{a}_j \otimes \tilde{e}_{ij} = \left(\left(f_{i1}^U, f_{i2}^U, f_{i3}^U, f_{i4}^U; H_1(\tilde{F}_i^U), H_2(\tilde{F}_i^U) \right), \left(f_{i1}^L, f_{i2}^L, f_{i3}^L, f_{i4}^L; H_1(\tilde{F}_i^L), H_2(\tilde{F}_i^L) \right) \right)$$

Step 4. The positive ideal solution (p^{**}, p^{**}) and negative ideal solution (N^{*-}) for upper and lower reference points of the interval type-2 fuzzy numbers are evaluated [27].

$$\begin{aligned}
P^{s*} &= \{\tilde{e}_{ij}^s, \tilde{e}_{ij}^s, \dots, \tilde{e}_{ij}^s\} = \{\max_j \tilde{e}_{ij}^s | j \in \text{Benefit}\} \\
P^{e*} &= \left(\left(e_{i1}^{s*}, e_{i2}^{s*}, e_{i3}^{s*}, e_{i4}^{s*}; \max H_1(\tilde{E}_i^s), \max H_2(\tilde{E}_i^s) \right), \right. \\
&\quad \left. \left(e_{i1}^{e*}, e_{i2}^{e*}, e_{i3}^{e*}, e_{i4}^{e*}; \max H_1(\tilde{E}_i^e), \max H_2(\tilde{E}_i^e) \right) \right) \\
P^{v*} &= \{\tilde{v}_{ij}^s, \tilde{v}_{ij}^s, \dots, \tilde{v}_{ij}^s\} = \{\max_j \tilde{v}_{ij}^s | j \in \text{Benefit}\} \\
P^{v*} &= \left(\left(f_{i1}^{v*}, f_{i2}^{v*}, f_{i3}^{v*}, f_{i4}^{v*}; \max H_1(\tilde{F}_i^v), \max H_2(\tilde{F}_i^v) \right), \right. \\
&\quad \left. \left(f_{i1}^{e*}, f_{i2}^{e*}, f_{i3}^{e*}, f_{i4}^{e*}; \max H_1(\tilde{F}_i^e), \max H_2(\tilde{F}_i^e) \right) \right) \\
N^{s*} &= \{\tilde{e}_{ij}^s, \tilde{e}_{ij}^s, \dots, \tilde{e}_{ij}^s\} = \{\min_j \tilde{e}_{ij}^s | j \in \text{Benefit}\} \\
N^{e*} &= \left(\left(e_{i1}^{s*}, e_{i2}^{s*}, e_{i3}^{s*}, e_{i4}^{s*}; \min H_1(\tilde{E}_i^s), \min H_2(\tilde{E}_i^s) \right), \right. \\
&\quad \left. \left(e_{i1}^{e*}, e_{i2}^{e*}, e_{i3}^{e*}, e_{i4}^{e*}; \min H_1(\tilde{E}_i^e), \min H_2(\tilde{E}_i^e) \right) \right)
\end{aligned} \tag{4}$$

Next, the average (S_i) and the worst (R_i) group scores of the CS for each RTN is calculated

$$\begin{aligned}
S_i &= \sum_{j=1}^n \frac{1}{2} (S_{ij}^U + S_{ij}^L), \forall i=1, \dots, m \\
R_i &= \max_j \frac{1}{2} (S_{ij}^U + S_{ij}^L), \forall i=1, \dots, m
\end{aligned} \tag{5}$$

Where,

$$\begin{aligned}
S_{ij}^U &= \sum_j \sqrt{\frac{\frac{1}{4} \sum_{k=1}^4 \left[\left(f_{i1}^{u*} - f_{i4}^{u*} \right)^2 + \left(f_{i2}^{u*} - f_{i3}^{u*} \right)^2 + \right.}{\frac{1}{4} \sum_{k=1}^4 \left[\left(f_{i3}^{u*} - f_{i2}^{u*} \right)^2 + \left(f_{i4}^{u*} - f_{i1}^{u*} \right)^2 + \right.}} \\
&\quad \left. \left(e_{i1}^{u*} - e_{i4}^{u*} \right)^2 + \left(e_{i2}^{u*} - e_{i3}^{u*} \right)^2 + \right.}{\left. \left(e_{i3}^{u*} - e_{i2}^{u*} \right)^2 + \left(e_{i4}^{u*} - e_{i1}^{u*} \right)^2 \right]} \quad \forall i=1, \dots, m \\
S_{ij}^L &= \sum_j \sqrt{\frac{\frac{1}{4} \sum_{k=1}^4 \left[\left(f_{i1}^{l*} - f_{i4}^{l*} \right)^2 + \left(f_{i2}^{l*} - f_{i3}^{l*} \right)^2 + \right.}{\frac{1}{4} \sum_{k=1}^4 \left[\left(f_{i3}^{l*} - f_{i2}^{l*} \right)^2 + \left(f_{i4}^{l*} - f_{i1}^{l*} \right)^2 + \right.}} \\
&\quad \left. \left(e_{i1}^{l*} - e_{i4}^{l*} \right)^2 + \left(e_{i2}^{l*} - e_{i3}^{l*} \right)^2 + \right.}{\left. \left(e_{i3}^{l*} - e_{i2}^{l*} \right)^2 + \left(e_{i4}^{l*} - e_{i1}^{l*} \right)^2 \right]} \quad \forall i=1, \dots, m
\end{aligned}$$

Step 5. The Q_i is calculated according to the S_i and R_i by use of Equation 6

$$Q_i = v \frac{(S_i - S^*)}{(S^- - S^*)} + (1-v) \frac{(R_i - R^*)}{(R^- - R^*)} \tag{6}$$

($v = 0.5$)

where $S^* = \min_i S_i$, $S^- = \max_i S_i$, $R^* = \min_i R_i$, $R^- = \max_i R_i$, $v \in [0,1]$ is the weight of the decision making strategy of the “majority of attributes” (or “maximum group utility”). Then the smallest Q_i is set as a compromise solution if two conditions are acceptable.

Condition 1. The acceptable advantage $Q_{R2} - Q_{R1} \geq DQ$, where $DQ = 1/(m-1)$

Condition 2. Acceptable stability in decision-making: Q_{R1} alternative is worth being the best ranked S and/or R.

If Condition 1 and Condition 2 are unacceptable, then the compromise solution remains the same.

This article developed fuzzy VIKOR depending upon MADM methodology developed according to type-2 fuzzy sets. The steps of the given methodology are shown in Figure 1. In the first stage, attribute is set as a result of the literature review. Weights of the attribute and the most effected alternative for MDEAS are certain.

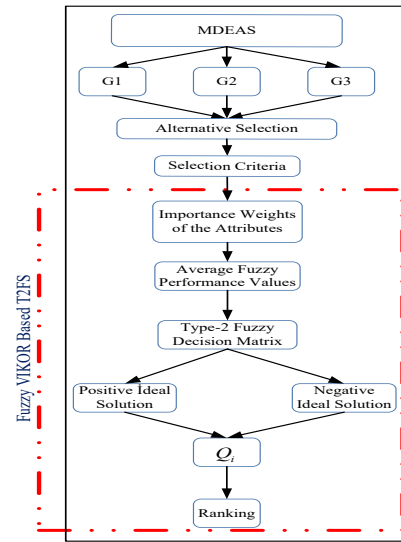


Fig. 1. Suggested type-2 fuzzy VIKOR methodology

In Figure 1 above, this method is used for determining main engine failures. To the best our knowledge, this method has been exerted for the first time in order to find main engine failures and the most effective type of failure in the system. It is also able to instruct the operator about which system to analyze first in case of an error faced during system operation. Depending on this result, a certain minimization of the time is need for the reactivation of the system.

3. An Application for Auxiliary Systems of A Ship’s Main Diesel Engine

When the causes and symptoms of the failures in the marine diesel engines are checked, they are observed to mostly underlie the problems originating a former breakdown. In each case of failure, there is a reason, which may emerge during the operating conditions. As far as factors for failures are concerned, auxiliary systems in connection with the failures may be grouped as follows: Fuel System (FS), Cooling System (CS), Governor System (GS), and Air Supply System (ASS). The hierarchical structure adopted in this study to deal with the problems of operation of the machine assessment for ship is shown in Figure 2.

The key dimensions of the attribute to evaluate and select machine operation systems for ship alternatives are received through comprehensive investigation and consultation with three groups, first group including three professor in the department of Naval Architecture and Marine Engineering, second group working in the private sector engineers and senior managers working in the private sector. They have been tasked to rate the accuracy, adequacy and relevance of the attribute and dimensions and to confirm their “content validity” with respect to the operation of the machine assessment. Reasons for failures in the main engine systems are drawn from previous records and maintenance logbooks, and the data are then combined with the personnel’s experiences. Six types of failure of high priority have come to be apparent when these failures are studied. Failures have been coded as C_{ij} where i is the number of attribute and j is the number of sub attribute of the relevant failure (Table 1)

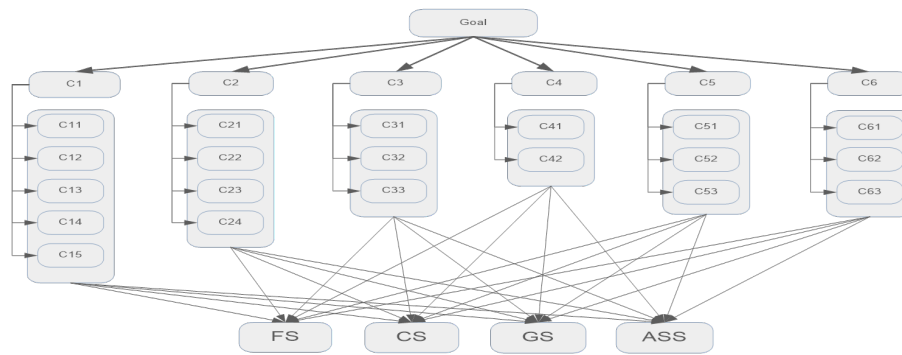


Fig. 2. The hierarchical structure for MDEAS

Table 1. Dimensions and attributes of MDEAS evaluation for failure

C1. High heat level in all exhaust cylinders of the engine

- C11. Fuel injector problems
- C12. Exhaust valve failure
- C13. Blower not working fully
- C14. Wrong adjustment of governor
- C15. Insufficient intake air

Wrong adjustment of governor determines the amount of fuel supplied to the combustion chamber. The lack of an optimal mixture ratio in the combustion chamber reduces the combustion quality and this situation causes an increase of the exhaust temperature.

C2. Unstable engine speed

- C21. Dirty fuel oil filter
- C22. Booster pump pressure
- C23. Fouling in the turbocharger
- C24. Wrong adjustment of governor

Dirty fuel oil filter and low booster pump pressure reduce the inlet pressure of the fuel supplied to the engine and this situation makes it difficult to provide sufficient fuel and unstable engine speed occurs.

C3. Shut down of the engine during normal operation

- C31. Low-level day tank
- C32. Low- low Oil pressure
- C33. High Pressure Fuel pump failures

Low-level day tank give rise discontinuation of fuel supplied to the engine and engine stops. In any pump failure, oil pressure decreases and if oil pressure is not enough, engine will not work so switch gives the instruction and engine is stopped.

C4. Increase of the oil level during engine operation

- C41. Cooling water leakage
- C42. Fuel oil leakage

Cooling water leakage cause water leakage into the crankcase and this situation increases oil level in crankcase. Fuel oil leakage cause spread of fuel into the crankcase.

C5. Fire in the Scavenging area

- C51. Dirty scavenging manifold inlet
- C52. Scuffing of the piston oil ring and piston
- C53. Air cooler problem

Dirty inlet manifold means that the presence of combustible materials at the location and combustion takes place here in the formation of the necessary conditions for combustion.

C6. Surge in the turbocharger

- C61. Exhaust valve burns
- C62. Mechanical failure in the turbocharger
- C63. Scavenging pressure high

Burns that occur in the exhaust valve cause gas leakage into the exhaust manifold except egzost time. This situation cause temperature fluctuations in the turbine inlet and occur the turbine speed fluctuations.

By use of Eq. (2) in Step 2, the averages of type-2 fuzzy performance values for MDEAS are calculated. The linguistic terms are converted into type-2 fuzzy numbers using nine different scales as shown in Table 2 by using Eq. (2). For example, type-2 fuzzy performance value of FS with respect to C11 is calculated considering frequencies for each linguistic

scale, i.e., Absolutely strong (AS), Very strong (VS), Fairly strong (FS), Semi-strong (SS), Equal (E), Semi-weak (SW), Fairly weak (FW), Very weak (VW), Absolutely weak (AW). Table 5 provides the results of paired comparison of oral expressions related to the evaluation attribute performed by the decision-making groups.

Table 2. Fuzzy values used for the paired comparison of the attribute

Oral Terms	Type-2 fuzzy sets
Absolutely strong (AS)	((4.00, 5.00, 5.00, 6.00; 1.00 1.00), (4.50, 5.00, 5.00, 5.50; 1.00 1.00))
Very strong (VS)	((3.00, 4.00, 4.00, 5.00; 1.00 1.00), (3.50, 4.00, 4.00 4.50; 1.00 1.00))
Fairly strong (FS)	((2.00, 3.00, 3.00, 4.00; 1.00 1.00), (2.50, 3.00, 3.00, 4.50; 1.00 1.00))
Semi-strong (SS)	((1.00, 2.00, 2.00, 3.00; 1.00 1.00), (1.50, 2.00, 2.00, 3.50; 1.00 1.00))
Equal (E)	((1.00, 1.00, 1.00, 1.00; 1.00 1.00), (1.00, 1.00, 1.00, 1.00; 1.00 1.00))
Semi-weak (SW)	((0.33, 0.50, 0.50, 1.00; 1.00 1.00), (0.29, 0.50, 0.50, 0.67; 1.00 1.00))
Fairly weak (FW)	((0.25, 0.33, 0.33, 0.50; 1.00 1.00), (0.22, 0.33, 0.33, 0.40; 1.00 1.00))
Very weak (VW)	((0.20, 0.25, 0.25, 0.33; 1.00 1.00), (0.22, 0.25, 0.25, 0.29; 1.00 1.00))
Absolutely weak (AW)	((0.17, 0.20, 0.20, 0.25; 1.00 1.00), (0.18, 0.20, 0.20, 0.22; 1.00 1.00))

Seven-item scale given in Table 3 shows the oral expressions used by the decision-making groups for creating an alternative-attribute matrix.

Table 3. Fuzzy values used for the paired comparison of the alternatives

Oral terms	Type-2 fuzzy sets
Very Low: (VL)	((0.00, 0.00, 0.00, 0.10; 1.00, 1.00), (0.00, 0.00, 0.00, 0.05; 0.90 0.90))
Low : (L)	((0.00, 0.10, 0.10, 0.30; 1.00, 1.00), (0.05, 0.10, 0.10, 0.20; 0.90 0.90))
Mid-Low: (ML)	((0.10, 0.30, 0.30, 0.50; 1.00, 1.00), (0.20, 0.30, 0.30, 0.40; 0.90 0.90))
Medium: (M)	((0.30, 0.50, 0.50, 0.70; 1.00, 1.00), (0.40, 0.50, 0.50, 0.60; 0.90 0.90))
Mid-High: (MH)	((0.50, 0.70, 0.70, 0.90; 1.00, 1.00), (0.60, 0.70, 0.70, 0.80; 0.90 0.90))
High: (H)	((0.70, 0.90, 0.90, 1.00; 1.00, 1.00), (0.80, 0.90, 0.90, 0.95; 0.90 0.90))
Very High:(VH)	((0.90, 1.00, 1.00, 1.00; 1.00, 1.00), (0.95, 1.00, 1.00, 1.00; 0.90 0.90))

In a similar way, the type-2 fuzzy performance values for each attribute with respect to each MDEAS are acquired.

Table 1 presents MDEAS attributes and related dimension classifications. Based on four questions (“what is the first, the second, the third, and the fourth important attribute for you, to detect more effected auxiliary system?”), which are asked to three decision-making groups, the weight of each attribute is set. The averages of the importance level of the weights, in linguistic terms, are converted into type-2 fuzzy numbers using nine different scales in Table 2 via Eq. (1) in Step 1. As a consequence, based on type-2 fuzzy numbers, the weights of twenty attributes are ordered. Table 4 displays the averages of the weights regarding all attributes.

Then, as shown in Step 3, the weighted type-2 fuzzy performance

values of the MDEAS are calculated by multiplying the importance weights of attributes (in Table 4). The positive (P^{e+}), negative (N^{e-}) and weighted (P^{v*}) type-2 fuzzy ideal solutions for upper and lower reference points are set using formulations in Step 4. Then, upper (S_{ij}^u), lower (S_{ij}^l) and average (S_{ij}) group scores are determined using Eq. (4) in Step 4, and the scores are shown in Table 5.

Step 5 puts that final rankings based on averages and the worst group scores are calculated by use of Eq. (6). Maximum group utility (v) is regarded as 0.5. Final rankings, and related regret and average scores are demonstrated in Table 6. The smaller Q values stand for higher level comparing other MDEAS.

Table 4. The importance weights of the attributes.

Attributes	Weight
C11	((0.49 ; 0.673 ; 0.673 ; 0.984 ; 1 ; 1),(0.505 ; 0.673 ; 0.673 ; 0.859 ; 0.9 ; 0.9))
C12	((0.592 ; 0.806 ; 0.806 ; 1.166 ; 1 ; 1),(0.616 ; 0.806 ; 0.806 ; 1.043 ; 0.9 ; 0.9))
C13	((1.144 ; 1.571 ; 1.571 ; 2.114 ; 1 ; 1),(1.278 ; 1.571 ; 1.571 ; 2.03 ; 0.9 ; 0.9))
C14	((1.779 ; 2.538 ; 2.538 ; 3.229 ; 1 ; 1),(2.172 ; 2.538 ; 2.538 ; 3.335 ; 0.9 ; 0.9))
C15	((0.814 ; 1.134 ; 1.134 ; 1.607 ; 1 ; 1),(0.887 ; 1.134 ; 1.134 ; 1.492 ; 0.9 ; 0.9))
C21	((1.779 ; 2.538 ; 2.538 ; 3.229 ; 1 ; 1),(2.172 ; 2.538 ; 2.538 ; 3.335 ; 0.9 ; 0.9))
C22	((0.99 ; 1.342 ; 1.342 ; 1.843 ; 1 ; 1),(1.077 ; 1.342 ; 1.342 ; 1.735 ; 0.9 ; 0.9))
C23	((1.144 ; 1.571 ; 1.571 ; 2.114 ; 1 ; 1),(1.278 ; 1.571 ; 1.571 ; 2.03 ; 0.9 ; 0.9))
C24	((1.567 ; 2.212 ; 2.212 ; 2.86 ; 1 ; 1),(1.882 ; 2.212 ; 2.212 ; 2.912 ; 0.9 ; 0.9))
C31	((1.144 ; 1.571 ; 1.571 ; 2.114 ; 1 ; 1),(1.278 ; 1.571 ; 1.571 ; 2.03 ; 0.9 ; 0.9))
C32	((1.779 ; 2.538 ; 2.538 ; 3.229 ; 1 ; 1),(2.172 ; 2.538 ; 2.538 ; 3.335 ; 0.9 ; 0.9))
C33	((1.144 ; 1.571 ; 1.571 ; 2.114 ; 1 ; 1),(1.278 ; 1.571 ; 1.571 ; 2.03 ; 0.9 ; 0.9))
C41	((0.421 ; 0.575 ; 0.575 ; 0.829 ; 1 ; 1),(0.44 ; 0.575 ; 0.575 ; 0.724 ; 0.9 ; 0.9))
C42	((0.297 ; 0.369 ; 0.369 ; 0.507 ; 1 ; 1),(0.297 ; 0.369 ; 0.369 ; 0.424 ; 0.9 ; 0.9))
C51	((0.297 ; 0.369 ; 0.369 ; 0.507 ; 1 ; 1),(0.297 ; 0.369 ; 0.369 ; 0.424 ; 0.9 ; 0.9))
C52	((0.592 ; 0.806 ; 0.806 ; 1.166 ; 1 ; 1),(0.616 ; 0.806 ; 0.806 ; 1.043 ; 0.9 ; 0.9))
C53	((0.814 ; 1.134 ; 1.134 ; 1.607 ; 1 ; 1),(0.887 ; 1.134 ; 1.134 ; 1.492 ; 0.9 ; 0.9))
C61	((0.49 ; 0.673 ; 0.673 ; 0.984 ; 1 ; 1),(0.505 ; 0.673 ; 0.673 ; 0.859 ; 0.9 ; 0.9))
C62	((0.297 ; 0.369 ; 0.369 ; 0.507 ; 1 ; 1),(0.297 ; 0.369 ; 0.369 ; 0.424 ; 0.9 ; 0.9))
C63	((0.327 ; 0.425 ; 0.425 ; 0.612 ; 1 ; 1),(0.327 ; 0.425 ; 0.425 ; 0.515 ; 0.9 ; 0.9))

Table 5. Upper, lower and average group scores

	$[S_{ij}^U, S_{ij}^L]$	$[S_{ij}]$	$[S_{ij}^U, S_{ij}^L]$	$[S_{ij}]$	$[S_{ij}^U, S_{ij}^L]$	$[S_{ij}]$	$[S_{ij}^U, S_{ij}^L]$	$[S_{ij}]$
C11	[0.58 ; 0.37]	0.48	[0.73 ; 0.63]	0.68	[0.6 ; 0.41]	0.51	[0.8 ; 0.72]	0.76
C12	[0.94 ; 0.66]	0.80	[1.11 ; 0.96]	1.03	[0.98 ; 0.73]	0.85	[1.06 ; 0.89]	0.97
C13	[2.62 ; 2.44]	2.53	[2.19 ; 1.67]	1.93	[2.9 ; 2.85]	2.88	[2.07 ; 1.53]	1.80
C14	[1.27 ; 0.89]	1.08	[1.81 ; 1.72]	1.76	[1.27 ; 0.89]	1.08	[1.73 ; 1.6]	1.67
C15	[1.19 ; 1]	1.09	[1.03 ; 0.75]	0.89	[1.34 ; 1.24]	1.29	[1.01 ; 0.68]	0.84
C21	[1.8 ; 1.29]	1.54	[2.64 ; 2.58]	2.61	[1.93 ; 1.49]	1.71	[2.77 ; 2.77]	2.77
C22	[1.12 ; 0.77]	0.94	[1.57 ; 1.46]	1.52	[1.18 ; 0.87]	1.03	[1.64 ; 1.57]	1.60
C23	[1.58 ; 1.07]	1.32	[1.72 ; 1.47]	1.60	[1.55 ; 1.05]	1.30	[1.72 ; 1.47]	1.60
C24	[1.72 ; 1.22]	1.47	[2.47 ; 2.43]	2.45	[1.81 ; 1.39]	1.60	[2.47 ; 2.43]	2.45
C31	[1.97 ; 1.45]	1.71	[2.06 ; 1.78]	1.92	[2.06 ; 1.78]	1.92	[2.44 ; 2.49]	2.46
C32	[2.6 ; 2.06]	2.33	[3.03 ; 2.94]	2.98	[2.61 ; 1.91]	2.26	[2.75 ; 2.43]	2.59
C33	[1.19 ; 0.82]	1.00	[1.77 ; 1.69]	1.73	[1.26 ; 0.93]	1.10	[1.61 ; 1.48]	1.54
C41	[0.69 ; 0.62]	0.66	[0.52 ; 0.33]	0.42	[0.69 ; 0.62]	0.66	[0.69 ; 0.62]	0.66
C42	[0.27 ; 0.15]	0.21	[0.42 ; 0.38]	0.40	[0.29 ; 0.19]	0.24	[0.38 ; 0.32]	0.35
C51	[0.38 ; 0.21]	0.29	[0.39 ; 0.26]	0.32	[0.39 ; 0.26]	0.32	[0.38 ; 0.24]	0.31
C52	[1.18 ; 0.87]	1.02	[1.29 ; 1.08]	1.19	[1.25 ; 1.01]	1.13	[1.58 ; 1.56]	1.57
C53	[1.35 ; 1.25]	1.30	[1.01 ; 0.69]	0.85	[1.35 ; 1.25]	1.30	[1.07 ; 0.81]	0.94
C61	[0.62 ; 0.4]	0.51	[0.65 ; 0.45]	0.55	[0.66 ; 0.47]	0.57	[0.73 ; 0.59]	0.66
C62	[0.38 ; 0.21]	0.30	[0.41 ; 0.29]	0.35	[0.38 ; 0.21]	0.30	[0.47 ; 0.39]	0.43
C63	[0.98 ; 1.19]	1.09	[1 ; 1.28]	1.14	[0.98 ; 1.19]	1.09	[0.93 ; 1.03]	0.98

Table 6. The final rankings for five rail transit lines

	FS	CS	GS	ASS
S_i	21.69	26.33	23.13	26.95
R_i	2.53	2.98	2.88	2.77
$Q_i (v = 0.5)$	0.00	0.95	0.57	0.72

Eventually, acceptable advantage, the Condition (1) in Step 5, between line FS, ($Q_{FS} = 0.00$) and GS ($Q_{GS} = 0.57$), is reassured. Therefore, FS has, respectively, the best and GS the second best scores. MDEAS can be ranged as FS, GS, ASS, and CS from the best to the worst score, based on the survey. The alternative evaluation results in Table 6 display that, the Fuel System is the most influenced alternative of errors taking into consideration the weights of all the decision-making groups. The results in Table 4 explain the common perception that any change in criteria weights may manipulate the evaluation outcome to a certain degree. Additionally, the Cooling System is apparently the least affected alternative by errors in comparison with the other alternatives.

3.1. Sensitivity Analysis

This subsection of the study demonstrates that the concept of sensitivity analysis studies the impact of attributes with the proposed interval type-2 fuzzy VIKOR approach for validation of the results of AS level to be steadier. The maximum group utility (v) is allocated to study the ranking of MDEAS. This study also presumes that the v value corresponds to 1 while the Q values of each alternative FS, CS, GS and ASS are 0.00, 0.88, 0.27 and 1.00, respectively. The ranking order of the four MDEAS is FS > GS > CS > ASS. When v value corresponds to 0.5, then the Q values of each MDEAS, FS, CS, GS and ASS, are 0.00, 0.94, 0.52, and 0.76, respectively. The ranking order of the four MDEAS is FS > GS > ASS > CS. If v value corresponds to 0, then the ranking order is FS > ASS > GS > CS. The Q values of

each MDEAS, FS, CS, GS and ASS are 0.00, 0.88, 0.27 and 1.00, respectively. According to the sample previously mentioned, this study makes use of each maximum group utility value, v , from 0.00 to 1.00 enhancing by 0.1 to study the proposed approach, and then the results obtained are considered satisfactory, as Table 7 and graphically in Figure 3 show.

Table 7. The Q_i values for different maximum group utilities.

	FS	CS	GS	ASS
V=0.0	0.00	1.00	0.76	0.53
V=0.1	0.00	0.99	0.71	0.57
V=0.2	0.00	0.98	0.67	0.62
V=0.3	0.00	0.96	0.62	0.67
V=0.4	0.00	0.95	0.57	0.72
V=0.5	0.00	0.94	0.52	0.76
V=0.6	0.00	0.93	0.47	0.81
V=0.7	0.00	0.92	0.42	0.86
V=0.8	0.00	0.91	0.37	0.91
V=0.9	0.00	0.89	0.32	0.95
V=1.0	0.00	0.88	0.27	1.00

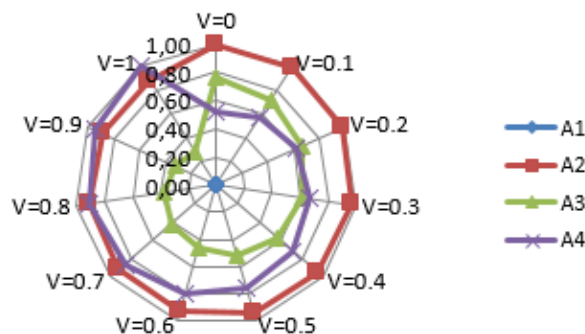


Fig. 3. Sensitivity analyses of Q_i values for each MDEAS

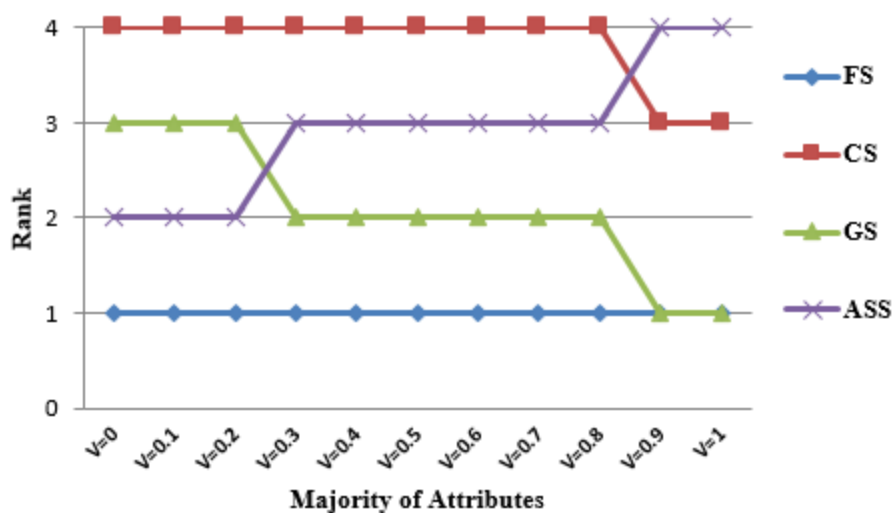


Fig. 4. The rankings of MDEA

The results point out that, the variations of the v values for each MDEAS change rankings of the MDEAS as shown in Figure 4. The auxiliary systems FS has the best rankings, in all cases GS has the second best ranking when $v = 1.0$, but gets the poorest score when v declines to 0.0. Furthermore ASS ranking increases while the v decreases. CS has the least ranking at almost all cases.

This study proves that the results of the ranking orders of all four MDEAS, acquired as a result of using the proposed approach, are coherent. Furthermore, the proposed approach detects the gap between the Q values of various MDEAS. Q values get smaller when the maximum group utility value raises from 0.1 to 1.0. Resting on the analysis above, this paper confirms that the proposed approach brings about satisfactory outputs and provides suitable information to consolidate managers in decision-making.

4. Conclusion

A fault possible to place in any system can quickly influence the engine and cause a breakdown or a failure in the engine. By dint of expert application, the cause of the fault must be immediately detected and fixed. With the aim of helping the chief engineers, assessment analysis attribute should readily present to show why the marine engine system failure happened and methods, which reduce such failures, must be developed. This method was intended to determine which part of the main engine system is the most open to be the subject of failure. It was also used to determine more common types of main engine failures within the system. Examination of the results drawn from this study makes it possible to guide the operator about which system to analyze first in case of an error encountered during the systems operation. Achieving this crucial profit-saving, time can be saved in reactivating the system. This study helps the hierarchical structure adapt to the troubleshooting of main engine auxiliary systems, which Fuel System, Cooling System, Governor System and Air Supply System by using the Fuzzy VIKOR method, evaluation of failures can be more efficiently assessed and decided upon. All these results observed in Table 7, by the Fuzzy VIKOR approach, the fuel system is the most affected system according to all the decision-making groups. For further research, the other multi-attribute evaluation methods such as TOPSIS, ELECTRE, and DEA (data envelopment analysis) can be employed and compared with the results provided by this paper.

References

- [1] C.H.Yeh and Y.H.Chang, "Modelling subjective evaluation for fuzzy group multi-criteria decision making", *European Journal of Operational Research*, Vol. 194, 464–473, 2009.
- [2] J.Ma, J.Lu, and G.Q.Zhang, "Decider: a fuzzy multi-criteria group decision support system", *Knowledge-Based Systems*, Vol. 23, 23–31, 2010.
- [3] Z.P.Fan, and Y.Liu, "A method for group decision-making based on multi-granularity uncertain linguistic information", *Expert Systems with Applications*, Vol. 37(5), 4000–4008, 2010.
- [4] S.Cebi, M.Celik, C.Kahraman, and I. D.Er, "An expert system auxiliary machinery troubleshooting: Shipamtsolver", *Expert Systems with Applications*, Vol. 36, 7219-7227, 2009.
- [5] N. Calder.1992. Marine diesel engines, maintenance troubleshooting and repair, 2nd ed., International Marine, Camden, Maine.
- [6] H.C.Liu, L.Liu, N.Liu, and L.X.Mao, "Risk evaluation in failure mode and effects analysis with extended VIKOR method under fuzzy environment", *Expert Systems with Applications*, Vol.39.17 pp. 12926-12934, 2012.
- [7] S.Vinodh, S.Sarangan and S. Chandra Vinoth, "Application of fuzzy compromise solution method for fit concept selection", *Applied Mathematical Modelling*. 2013.
- [8] E.Martinez-Martin, M. T. Escrig, and A. P.Pobil, "Naming Qualitative Models Based on Intervals: A General Framework", *International Journal of Artificial Intelligence*, Vol. 11. A13 pp. 74-92, 2013.
- [9] Lee, L. W., and Chen, S. M. 2008. "Fuzzy multiple attributes hierarchical group decision-making based on the ranking values of interval type-2 fuzzy sets". In *Machine Learning and Cybernetics, 2008 International Conference on IEEE*: 3266-3271,
- [10] S. M.Chen, and L. W. Lee, "Fuzzy multiple attributes group decision-making based on the interval type-2 TOPSIS method". *Expert Systems with Applications*, 37(4): 2790-2798, 2010.
- [11] S. M. Chen, M. W. Yang, L. W.Lee, and S. W. Yang, "Fuzzy multiple attributes group decision-making based on ranking interval type-2 fuzzy sets". *Expert Systems with Applications*, 39(5): 5295-5308, 2012.
- [12] T. Y. Chen, "Multiple criteria group decision-making with generalized interval-valued fuzzy numbers based on signed distances and incomplete weights". *Applied Mathematical Modelling*, 36(7): 3029-

3052, 2012.

- [13] J. M. Mendel, R. I. John, and F. Liu, "Interval type-2 fuzzy logic systems made simple". *Fuzzy Systems, IEEE Transactions on*, 14(6): 808-821, 2006.
- [14] Lee, L. W., and Chen, S. M. 2008. "A new method for fuzzy multiple attributes group decision-making based on the arithmetic operations of interval type-2 fuzzy sets". In *Machine Learning and Cybernetics, 2008 International Conference on IEEE*: 3084-3089.
- [15] E. Celik, O. N. Bilisik, M. Erdogan, A. T. Gumus, & H. Baraclı, "An integrated novel interval type-2 fuzzy MCDM method to improve customer satisfaction in public transportation for Istanbul", *Transportation Research Part E: Logistics and Transportation Review*, 58, 28-51, 2013.
- [16] E. Celik, A. T. Gumus & M. A. Alegoz, "Trapezoidal type-2 fuzzy MCDM method to identify and evaluate critical success factors for humanitarian relief logistics management", *Journal of Intelligent & Fuzzy Systems: Applications in Engineering and Technology*, 27(6), 2847-2855, 2014.
- [17] Y. M. Wang, and T. Elhag, "Fuzzy TOPSIS method based on alpha level sets with an application to bridge risk assessment", *Expert Systems with Applications*, 31(2): 309-319, 2006.
- [18] S. Opricovic, Multicriteria optimization of civil engineering systems. Faculty of Civil Engineering, Belgrade, 2(1), 5-21, 1998.
- [19] S. Opricovic, & G. H. Tzeng, "Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS", *European Journal of Operational Research*, 156(2), 445-455, 2004.
- [20] G. H. Tzeng, C. W. Lin, & S. Opricovic, "Multi-criteria analysis of alternative-fuel buses for public transportation", *Energy Policy*, 33(11), 1373-1383, 2005.
- [21] B. Vahdani, H. Hadipour, J. S. Sadaghiani, & M. Amiri, "Extension of VIKOR method based on interval-valued fuzzy sets", *The International Journal of Advanced Manufacturing Technology*, 47(9-12), 1231-1239, 2010.
- [22] M. S. Kuo, "A novel interval-valued fuzzy MCDM method for improving airlines' service quality in Chinese cross-strait airlines", *Transportation Research Part E: Logistics and Transportation Review*, 47(6), 1177-1193, 2011.
- [23] S. P. Wan, Q. Y. Wang, & J. Y. Dong, "The extended VIKOR method for multi-attribute group decision making with triangular intuitionistic fuzzy numbers", *Knowledge-Based Systems*, 52, 65-77, 2013.
- [24] Y. Ju, & A. Wang, "Extension of VIKOR method for multi-criteria group decision making problem with linguistic information", *Applied Mathematical Modelling*, 37(5), 3112-3125, 2013.
- [25] E. Celik, M. Gul, N. Aydin, A. T. Gumus, & A. F. Guneri, "A comprehensive review of multi criteria decision making approaches based on interval type-2 fuzzy sets", *Knowledge-Based Systems*, 2015.
- [26] E. Celik, N. Aydin, & A. T. Gumus, "A multiattribute customer satisfaction evaluation approach for rail transit network: A real case study for Istanbul, Turkey", *Transport Policy*, 36, 283-293, 2014.
- [27] M. S. Kuo, G. S. Liang, "A soft computing method of performance evaluation with MCDM based on interval-valued fuzzy numbers", *Applied Soft Computing*, 12(1), 476-485, 2012.