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ISSN 0007-215X
eISSN 1845-5859

A HIERARCHICAL STRUCTURE FOR SHIP DIESEL ENGINE TROUBLE-SHOOTING PROBLEM USING FUZZY AHP AND FUZZY VIKOR HYBRID METHODS

UDC 629.5.026:621.436
Professional paper

Summary

Although considerable technical preventive measures have been taken in marine diesel engine and auxiliary systems, it is possible to observe unexpected faults in the course of the operating conditions. These faults can become so severe that they can cause losses which can be irreversible. This study aims to present Fuzzy Analytic Hierarchy Process (AHP) and VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje) methods applied for the expert failure detection of marine diesel engine and auxiliary systems. In this study, the failures of marine diesel engine have been revealed and prioritized. Accordingly, the section of the machine from which the failures primarily arise has been determined. At the same time, the importance of the effective use of time in determining and responding to the failures has been indicated. By means of the evaluation of decision-making groups, the system most severely affected by failures has been decided.

Key words: *Fuzzy AHP, Fuzzy VIKOR, MCDM, Failure detection, Auxiliary systems.*

1. Introduction

When considering marine diesel engines, it is required that fuel, governor and the other systems work correctly to acquire desired power and ranges of rotation determined by the engine producers. Operating the engine out of this range and for a long time leads to serious failures.

Early warning instruments and measures such as heat, pressure, and flow sensors are available to detect failures. Precautions can be taken according to the values of these indicators that reflect failures. In case of the disruption of the operation of ship diesel engines, the engines should be removed entirely and the failures in power transfer are needed to be identified. Explicit connection of these failures with other systems should be revealed and efficiency values should be analyzed through expert systems.

Calder introduced a failure detection tool to control the fuel, oil, exhaust, combustion air and cooling water systems [1].

Even if the utilization of warning indicators and alarms are taken into account, early detection of possible machine failures is still quite difficult because of the dependency of these systems on each other.

In order to handle this problem, fuzzy multi-criteria decision-making method is suggested. Fuzzy analytic hierarchy process and the fuzzy technique are adopted in FAHP-VIKOR methods in order to detect marine diesel engine failures.

There have been several techniques discussed in the literature about failure analysis. Sharma et al. introduced a multi-factor decision-making approach for prioritizing Failure Mode Analysis using Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [2].

Çebi et al. developed an expert failure detection system to anticipate and overcome failures which take place in ship cooling system by the use of PROLOG programming language [3]. Taking into consideration the failure types that are already encountered; they created action tables to demonstrate what to do in the event of an emergency.

In the study carried out by Liu et al., linguistic variables, which are described in trapezoidal or triangular fuzzy numbers, are used to evaluate the ratings and weights for the risk factors [4]. When selecting the most severe failure modes, the expanded VIKOR method is utilized in order to determine the risk priorities of the failure modes that have been defined. Consequently, a fuzzy FMEA based on fuzzy set theory and VIKOR method is presented to prioritize failure modes which are specifically aimed to refer to some restrictions of the classical FMEA.

Ju and Aihua introduced a new method that makes it possible to overcome multi-criteria group decision-making problems in which both the criteria values and criteria weights take the form of linguistic information on the basis of the traditional idea of VIKOR method [5].

Anojkumar et al. depicted the implementation of four Multi Criteria Decision Making methods in order to solve the material selection problem of piping in sugar industry [6]. The four methods utilized to choose the best alternative among several different materials are FAHP-TOPSIS, FAHP-VIKOR, FAHP-ELECTRE (Elimination et choix traduisant la realite) and FAHP-PROMETHEE (Preference Ranking Organisation Method for Enrichment Evaluation).

Vinodh et al. introduced a research in which the concept selection in fit environment was developed as Multi Criteria Decision Making (MCDM) problem, and solutions were offered by utilising fuzzy based compromise solution method VIKOR [7]. Alarcin et al. examined failure detection in auxiliary systems and marine diesel engine determined by group of experts and determined the system most affected by failures [8].

Perovic et al. revealed guidelines on how to formalize fuzzy relational database queries [9]. The stability analysis of fuzzy logic control systems was done according to Lyapunov's direct method by Precup et al [10]. Fodor and Baets examined uninorms of which both the underlying t-norm and underlying t-conorm are strict [11]. Martinez-Martin et al. presented a general framework to solve the representation magnitude and the basic step of inference process of qualitative models based on intervals [12].

In this study, it is aimed to present Fuzzy Analytic Hierarchy Process (AHP) and VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje) hybrid methods applied for the expert failure detection of marine diesel engine and auxiliary systems. In this respect, the failures of marine diesel engine have been revealed and prioritized. Accordingly, the section of the machine from which the failures primarily arise has been determined. At the same time, the importance of the effective use of time in determining and responding to the failures has been indicated. By means of the evaluation of decision-making groups, the system most severely affected by failures has been decided.

In this present paper, Fuzzy AHP and Fuzzy VIKOR hybrid methods are used for the failure detection of marine diesel engine and auxiliary systems. The framework of this study is organized into five sections: In Section 1, the research methodologies are introduced. The model based on the Fuzzy AHP and Fuzzy VIKOR method is presented in Section 2 and Section 3. In Section 4, a discussion on the hierarchical structure employed for the problems of the operation of the ship diesel engine trouble-shooting using Fuzzy AHP and Fuzzy VIKOR methods is provided. Finally, the last section offers some concluding remarks.

2. Fuzzy AHP Approach

The research on Fuzzy AHP approach found in the literature can be summarized as follows. A method for group decision-making based on the multi-granularity uncertain linguistic information was proposed by Fan and Liu [13]. Ma et al. established a decision support system based on a model for enhancing the level of overall satisfaction in the multi-criteria group decision-making [14]. Yeh and Chang proposed a hierarchical weighting method for assessing weights; furthermore, they suggested an algorithm for classifying MDCM to combine criteria weights including decision makers' subjective judgments [15]. Jiang and Fan examined the probability degree for triangular fuzzy number and introduced a new method on the basis of judgment matrix [16]. Xu and Da described the probability degree of interval number, and some desired properties were verified [17]. Lee presented a repetitive approximation procedure for aggregating individual opinions into the optimal consensus [18]. Mohammad et al. suggested a new method to overcome parametric form of fuzzy numbers problem and applied it to a case study of diversion of water [19]. Kacprzyk et al. put forward the assignation of fuzzy relations made by each expert [20]. They obtained a resulting preference relation from individual fuzzy preference relations to determine the best alternative. Dubois and Koning examined numerous fuzzy set aggregation connectors to assess their significance as social choice functions [21]. Cholewa propounded a collection of axioms for the aggregation of fuzzy weighted opinions and pointed out that the weighted mean satisfied those axioms [22].

Linguistic variable: A linguistic variable can be defined as a variable of which values consist of words or sentences in language naturally and artificially. Here, we employ this sort of expression to make a comparison among auxiliary system selection evaluation criteria by using several basic linguistic terms; ''absolutely important,'' ''very strongly important,'' ''essentially important'', ''weakly important'' and ''equally important'' as to a fuzzy five level scale [23].
This study grounds the computational technique on the ensuing fuzzy numbers given in Table 1.

Table 1. Membership function of linguistic scale [24]

Fuzzy number	*Linguistic scales*	*Scale of fuzzy number*
$\tilde{1}$	*Equally important (EQ)*	*(1,1,3)*
$\tilde{3}$	*Weakly important (WK)*	*(1,3,5)*
$\tilde{5}$	*Essentially important (ES)*	*(3,5,7)*
$\tilde{7}$	*Very strongly important (VS)*	*(5,7,9)*
$\tilde{9}$	*Absolutely important (AB)*	*(7,9,9)*

The linguistic variables shown in Table 1 are enjoyed to indicate the superior or weak dimensions of AHP method by the five appointed groups in the criteria-criteria comparison.

Alternatives measurement: if the measurement of linguistic variables to show the criteria performance (effect-values) by expressions such as ‘‘very good,’’ ‘‘good,’’, ‘‘medium good,’’, ‘‘fair,’’ “medium poor”, ‘‘poor,’’, ‘‘very poor,’’ is used, the evaluators are required to carry out their subjective judgements, and all variables can be demonstrated by a Triangular Fuzzy Number (TFN) within the scale range 0–10, as shown in Table. 2

Table 2. Fuzzy evaluation scores for the alternatives [25]

Linguistic terms	*Fuzzy score*
Very poor (VP)	*(0, 0, 1)*
Poor (P)	*(0, 1, 3)*
Medium poor (MP)	*(1, 3, 5)*
Fair (F)	*(3, 5, 7)*
Medium good(MG)	*(5, 7, 9)*
Good (G)	*(7, 9, 10)*
Very good (VG)	*(9,10,10)*

The linguistic variables presented in Table 2 are used to demonstrate the superiority or weakness status of VIKOR method by the five designated groups in the alternative-criteria comparison.

Besides, personal range of the linguistic variable that are possible indicators for the membership functions of the expression values of each evaluator can be assigned in a subjective way by evaluators. If E_{ij}^{k} is taken to indicate the fuzzy performance value of evaluator k towards alternative “i” under the criterion j, and all of the criteria to evaluate are due to be illustrated by $E_{ij}^{k} = (LE_{ij}^{k}, ME_{ij}^{k}, UE_{ij}^{k})$ For the perception of all evaluators differs according to the evaluator s experience and knowledge, and the descriptions of the linguistic variables diverge as well, this study rests on the concept of average value to join the fuzzy judgment values of m evaluators, that is,

$$\hat{E}_{ij}^{k} = 1/m(LE_{ij}^{k}, ME_{ij}^{k}, UE_{ij}^{k}) \quad (1)$$

$\hat{E}_{ij}^{k}$ points out the average fuzzy number of the judgment of the decision-makers, which a triangular fuzzy number can display as $LE_{ij}^{k}, ME_{ij}^{k} and\, UE_{ij}^{k}$. The end-point values LE_{ij}, ME_{ij} *and* UE_{ij} can be worked out by the method, as Buckley put it Buckley [26], that is,

$$LE_{ij}^{k} = \frac{\sum_{k=1}^{m} LE_{ij}^{k}}{m}; ME_{ij}^{k} = \frac{\sum_{k=1}^{m} ME_{ij}^{k}}{m}; UE_{ij}^{k} = \frac{\sum_{k=1}^{m} UE_{ij}^{k}}{m} \quad (2)$$

Fuzzy synthetic decision: The weights of the all criteria of auxiliary system selection evaluation in addition to the fuzzy performance values need be unified by the calculation of fuzzy numbers, with a view to being located at the fuzzy performance value (effect-value) of the integral evaluation. According to the each criterion weight obtained by F-AHP, the criteria weight vector $\widehat{W} = (\widehat{W}_1 \ldots\ldots \ldots \widehat{W}_j \ldots\ldots \widehat{W}_n)^t$ j can be acquired, but on the other hand the fuzzy performance matrix $\hat{E}$ of each of the alternatives are highly likely to be derived from the fuzzy performance value of each alternative under n criteria, that is, $\hat{E} = \hat{E}_{ij}$ From the criteria weight vector $\widehat{W}$ and fuzzy performance matrix $\hat{E}$, the final fuzzy synthetic decision can be carried out, and the fuzzy synthetic decision matrix $\hat{R}$ will provide the derived result, that is,

$$\hat{R} = \hat{E} o \hat{w} \tag{3}$$

The sign ''o'' points out computing the fuzzy numbers as well as fuzzy addition and fuzzy multiplication. For the calculation of fuzzy multiplication can be taken quite complex, it is usually signified by the approximate multiplied result of the fuzzy multiplication and the approximate fuzzy number $\hat{R}$ i, of the fuzzy synthetic decision of each alternative can be described as $\hat{R} = (L\hat{R}_i, M\hat{R}_i, U\hat{R}_i)$, in which, $L\hat{R}_i, M\hat{R}_i \, and \, U\hat{R}_i$ are the lower, middle and upper synthetic performance values of the alternative i, that is:

$$LR_i = \sum_{j=1}^{n} LE_{ij} x Lw_j ; MR_i = \sum_{j=1}^{n} ME_{ij} x Mw_j ; \; UR_i = \sum_{j=1}^{n} UE_{ij} x Uw_j ; \tag{4}$$

Ranking the fuzzy number: The result of the fuzzy synthetic decision acquired by each alternative is a fuzzy number. Hence, it is essential that a nonfuzzy ranking method for fuzzy numbers be utilized to compare each building P&D alternative. To put in a different way, the procedure of defuzzification is to find the Best Nonfuzzy Performance value (BNP). Methods of such defuzzified fuzzy ranking generally involve mean of maximal (MOM), center of area (COA), and a-cut. To use the COA method to find out the BNP is a simple and practical method, and it is not needed to bring in the preferences of any evaluators, so it is benefited in this study. The BNP value of the fuzzy number $\hat{R}_i$ can be found by the following equation:

$$BNP_i = [(UR_i - LR_i) + (MR_i - MR_i)]/3 + LR_i \quad \forall i \tag{5}$$

According to the value of the derived BNP for each of the alternatives, the ranking of the building P&D of each of the alternatives can then proceed.

3. Fuzzy VIKOR Approach

VIKOR is a method developed on the basis of the compromise programming of MCDM. The implementation of the steps of VIKOR can be maintained by acquiring the weight vector through the extensive analyses. Yu and Zeleny first presented the concepts of compromise solutions [27-28]. The methodology, merely works on the principle that each alternative can be evaluated by each criterion function, which enables the compromise ranking to be obtained by comparing the degrees of proximity to the ideal alternative. In fuzzy VIKOR, it is proposed that decision makers utilise linguistic variables to evaluate the ratings of alternatives according to the criteria. The linguistic scale for the evaluation of alternatives is presented in Table 2. Supposing that a decision-making group has K people, the ratings of alternatives with reference to each criterion can be computed as herein below [29];

$$x_{ij} = \frac{1}{K}\left[\overset{1}{x_{ij}} (+) \overset{2}{x_{ij}} (+) .... (+) \overset{K}{x_{ij}} \right] \tag{6}$$

where $\overset{K}{x_{ij}}$ is the rating of the Kth expert for ith alternative with regard to jth criterion.
After acquiring the weights of criteria and fuzzy ratings of alternatives corresponding to each criterion, the fuzzy multi-criteria decision-making problem in matrix format can be explained as,

$$D = \begin{pmatrix} x_{11} & \dots & x_{1n} \\ \vdots & \cdots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix} \tag{7}$$

$$W = [w_1, w_1, ..., w_n] \quad j = 1, 2, ..., \text{n}$$

where x_{ij} is the rating of Alternative Ai with reference to Criterion j (i.e. C_j) and w_j indicates the importance weight of C_j.

The next step will be the determination of the Fuzzy Best Value (FBV, $\tilde{f}_j^*$) and the Fuzzy Worst Value (FWV, $\tilde{f}_j^-$) of each criterion function.

$$\tilde{f}_j^* = \max_i x_{ij}, \quad j \in B; \quad \tilde{f}_j^- = \min_i x_{ij}, \quad j \in C \tag{8}$$

Then, the values $w_j(\tilde{f}_j^* - x_{ij})/(\tilde{f}_j^* - \tilde{f}_j^-)$, $\tilde{S}_i$ and R_i are calculated as follow,

$$\tilde{S}_i = \sum_{j=1}^{n} w_j(\tilde{f}_j^* - x_{ij})/(\tilde{f}_j^* - \tilde{f}_j^-) \tag{9}$$

$$R_i = \max_j \left[w_j(\tilde{f}_j^* - x_{ij})/(\tilde{f}_j^* - \tilde{f}_j^-) \right] \tag{10}$$

where $\tilde{S}_i$ signifies the separation measure of A_i from the fuzzy best value, and R_i the separation measure of A_i from the fuzzy worst value.

$$\tilde{S}^* = \min_i \tilde{S}_i, \quad \tilde{S}^- = \max_i \tilde{S}_i$$
$$R^* = \min_i R_i, \quad R^- = \max_i R_i \tag{11}$$

In the next step, $\tilde{S}^*$, $\tilde{S}^-$, R^*, R^-, and Q_i values are calculated as

$$Q_i = v(\tilde{S}_i - \tilde{S}^*)/(\tilde{S}^- - \tilde{S}^*) + (1-v)(R_i - R^*)/(R^- - R^*) \tag{12}$$

The indices $\min_i \tilde{S}_i$ and $\min_i R_i$ are relevant to a maximum majority rule and a minimum individual regret of an opponent strategy, respectively. In addition, v is presented as the weight of the strategy of the maximum group utility. "v" is usually assumed to be 0.5.

The next task is the defuzzification of the triangular fuzzy number Q_i and ranking the alternatives by the index Q_i. Different defuzzification strategies have been suggested in the literature. In this present study, the graded mean integration approach is adapted [30]. According to the graded mean integration approach, for triangular fuzzy numbers, a fuzzy number $C = (c_1, c_2, c_3)$ can be changed into a crisp number by utilising the equation below:

$$P(C) = C = \frac{c_1 + 4c_2 + c_3}{6} \tag{13}$$

Finally, the best alternative with the minimum of Q_i is determined.

Methodology steps of application for Fuzzy AHP-VIKOR hybrid method is summarized as follows in Figure. 1.

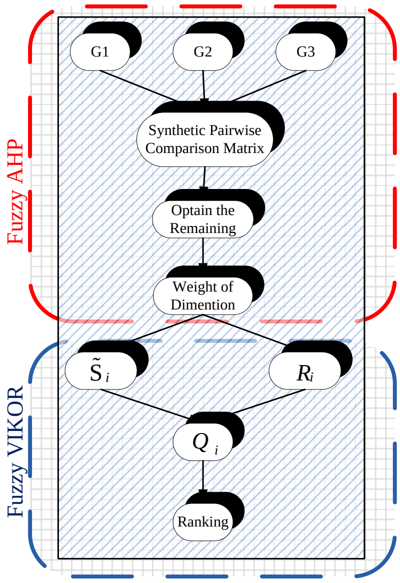

Figure 1. Fuzzy AHP-VIKOR hybrid method

Step 1: Constructing pairwise comparison matrices among all the criteria in the dimensions of the system hierarchy.
Step 2: Calculating the elements of synthetic pairwise comparison matrix by utilising the geometric mean method proposed by Buckley:
Step 3: Likewise, we can obtain the remaining $\hat{r}_i$,
Step 4: For the weight of each dimension, below mentioned processes can be followed
Step 5: Fuzzy best value (FBV, $\tilde{f}_j^*$) and fuzzy worst value (FWV, $\tilde{f}_j^-$) of each criterion function are determined.
Step 6: Separation measures ($\tilde{S}_i$ and R_i) are computed.
Step 7: Q_i values are calculated.
Step 8: Q_i values are defuzzified and the alternatives are ranked by the index Q_i
Step 9: The best alternative with the minimum of Q_i is determined.

4. Trouble Shooting Application In Marine Diesel Auxiliary Engines Via FAHP-VIKOR Approach

In most cases, it is seen that faults cause serious damage and considerable loss of capital investment. In this paper, five auxiliary systems, resulting in various realistic events are taken into consideration. The failures listed herein below are explained further.
The severity levels of these faults are different. Some of these failures are so severe that a fast fault detection and adjustment is needed to avoid serious accidents in case of a component failure during the operating conditions.

Causes and symptoms of failures in marine diesel engines examined mostly turn out to be precursors of a further breakdown. In every failure, any reason is not found instantly but during the operating conditions. The hierarchical structure suited in this work to cope well with the problems of operation of the machine assessment for ship is shown in Fig. 2.

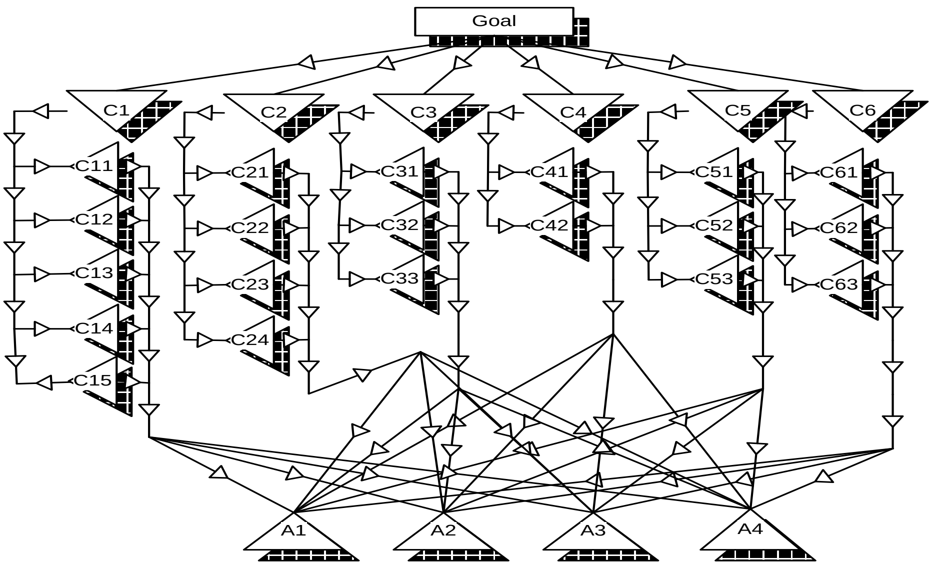

Figure 2. The hierarchical structure designed for ship machine systems

Any probable main engine breakdown can be identified by using the efficient main engine failure detection. In addition to the recognized symptoms and the detected faults, the frequency of faults related to auxiliary systems should also be taken into account in order to find out the possible causes of failure which increases the productivity of the managing systems.

The key aspects of the criteria to evaluate and select machine operation systems for ship alternatives were obtained from extended investigation and consultation in three groups, with a professor in department of Naval Architecture and Marine Engineering.

They were requested to rate the accuracy, adequacy and relevance of the criteria and dimensions and to confirm ‘‘content validity’’ with regard to operation of the machine assessment. Reasons for failures in the main engine systems were drawn from former records, maintenance log-books and is consolidated with the experience of personnel. Six kinds of failures of high priority show up when aforementioned failures are monitored. Failures are identified as C_i in which “i” is the number of pertinent failure.

Table 3. Auxiliary systems for main engine failures criteria

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*
C2. Unstable engine speed
C21. Dirty fuel oil filter *C22. Booster pump pressure* *C23. Fouling in the turbocharger* *C24. Wrong adjustment of governor*
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*
C4. Increase of the oil level during engine operation
C41. Cooling water leakage *C42. Fuel oil leakage*
C5. Fire in the Scavenging area
C51. Dirty scavenging manifold inlet *C52. Scuffing of the piston oil ring and piston* *C53. Air cooler problem*
C6. Surge in the turbocharger
C61. Exhaust valve burns *C62. Mechanical failure in the turbocharger* *C63. Scavenging pressure high*

Criteria were explained how the individual subsystems affect the engine operation as follows [1-31];

High heat level in all exhaust cylinders of the engine: Wrong adjustment of governor determine 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.
The ventilation does not work properly can cause insufficient amount of oxygen incoming from the combustion chamber. Exhaust temperature increases due to the lack of non-uniform combustion. Exhaust valve failure reduces the combustion quality because of the decrease in compression pressure. Problems in the fuel injector cause taking the unburnt fuel inside the combustion chamber, combustion continues after ignition and this situation cause increasing the exhaust temperature.
Unstable engine speed: 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 occur. Fouling in the turbocharger cause failure in the the balance of the turbocharger and turbocharger speed changes, this situation cause fluctuations in compressed air pressure and counter- pressure on the exhaust side. Wrong adjustment of governor gives rise to errors in the fuel feed rate and leads to imbalance in engine speed.
Shut down of the engine during normal operation: 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. High Pressure Fuel pump failures cause absence fuel into combustion chamber because of insufficient pressure so engine stops or engine speed changes.
Increase of the oil level during engine operation: 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.
Fire in the Scavenging area: 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. Scuffing of the piston oil ring and piston cause to move scavenging area from the combustion chamber of combustion and combustion occur in here. Due to air cooler problem, compression air come to the scavenging area without cooling, high temperature air cause combustion in here.
Surge in the turbocharger: 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. Mechanical failure in the turbocharger disrupt the turbocharger balance and this situation cause speed fluctuations in addition it gives rise to noisy operation.

When above mentioned engine faults, which vary from one another in terms of basic characteristics are technically analyzed with the aim of classifying, it is recognized that each has a relationship with a different system. The fact that failures in particular groups which build a relationship along with the ones in other groups is also known. Considering the causes for failures, auxiliary systems in connection with the failures can be categorized as follows:

A1. Fuel System
A2. Cooling System
A3. Governor System
A4. Air supply System

Table 4. Weights of dimensions and criteria for decision-making groups

Criteria	*Weights*	***BNP***
C1. High heat level in all exhaust cylinders of the engine	(0.076 0.166 0.436)	**0.226**
C11. Fuel injector problems	(0.186 0.407 0.962)	**0.518**
C12. Exhaust valve failure	(0.116 0.292 0.667)	**0.358**
C13. Blower not working fully	(0.038 0.070 0.203)	**0.104**
C14. Wrong adjustment of governor	(0.058 0.153 0.343)	**0.185**
C15. Insufficient intake air	(0.030 0.078 0.163)	**0.09**
C2. Unstable engine speed	(0.021 0.037 0.101)	**0.053**
C21. Dirty fuel oil filter	(0.091 0.257 0.671)	**0.34**
C22. Booster pump pressure	(0.064 0.145 0.492)	**0.234**
C23. Fouling in the turbocharger	(0.112 0.268 0.762)	**0.381**
C24. Wrong adjustment of governor	(0.107 0.329 0.757)	**0.397**
C3. Shut down of the engine during normal operation	(0.143 0.318 0.724)	**0.395**
C31. Low-level day tank	(0.059 0.110 0.317)	**0.162**
C32. Low- low Oil pressure	(0.128 0.285 0.733)	**0.382**
C33. High Pressure Fuel pump failures	(0.257 0.605 1.206)	**0.689**
C4. İncrease of the oil level during engine operation	(0.040 0.095 0.255)	**0.13**
C41. Cooling water leakage	(0.376 0.781 1.457)	**0.871**
C42. Fuel oil leakage	(0.132 0.219 0.513)	**0.288**
C5. Fire in the Scavenging area	(0.132 0.328 0.650)	**0.37**
C51. Dirty scavenging manifold inlet	(0.128 0.285 0.733)	**0.382**
C52. Scuffing of the piston oil ring and piston	(0.257 0.605 1.206)	**0.689**
C53. Air cooler problem	(0.059 0.110 0.317)	**0.162**
C6. Surge in the turbocharger	(0.024 0.056 0.130)	**0.07**
C61. Exhaust valve burns	(0.128 0.285 0.733)	**0.382**
C62. Mechanical failure in the turbocharger	(0.257 0.605 1.206)	**0.689**
C63. Scavenging pressure high	(0.059 0.110 0.317)	**0.162**

Depending on the Fuzzy AHP results, for the decision-making groups, we conclude that the first two most important aspects are the Shutdown of the engine during normal operation (0.395) and the Fire in the Scavenging area (0.370) whereas the least important aspect is the unstable engine speed (0.053). When considered the decision-making groups, the first two important sub-criteria in Shut down of the engine during normal operation are the High Pressure Fuel pump failures (0.689) and the Low- low Oil pressure (0.382), whereas the least important aspect is the Low-level day tank (0.162). Additionally, for the groups of experts, the most important sub-criteria in the Fire in the Scavenging area are presented respectively; as the Scuffing of the piston oil ring and piston (0.689), the dirty scavenging manifold inlet (0.382) and the Air cooler problem (0.162). Nevertheless, the first two important dimensions in the least important criteria are the Wrong adjustment of governor (0.397) and the Fouling in the turbocharger (0.381), and the least is the Booster pump pressure (0.234).

These results denote that the decision-making groups' concern is the safety of managing the Shutdown of the engine during normal operation. They also pay attention to the Fire in the Scavenging area, which will be considered the suitability of freighter operating. The decision-making groups focus on the associated professional issues for the Shutdown of the engine during normal operation, but they consider that the High Pressure Fuel pump failures and Low-low Oil pressure are stable to be secured under professional calculations, so they rate it attaching great importance.

We can acquire the fuzzy evaluation and "Q_i" values of other alternatives for comparison; finally, details of the results are shown in Table 5.

Table 5. The evaluation results

Alternatives	*Fuzzy Evaluation*			Q_i	*Ranking*
A1: Fuel System	*0.500*	*0.500*	*0.500*	*0.500*	***2***
A2: Cooling System	*0.345*	*0.350*	*0.367*	*0.352*	***1***
A3: Governor System	*0.715*	*0.693*	*0.658*	*0.691*	***3***
A4: Air supply System	*1.000*	*1.000*	*1.000*	*1.000*	***4***

As can be seen from the results of alternative evaluation in Table 5, the *Cooling System* is considered as the most affected alternative by errors regarding the weights of all decision-making groups. The results shown in Table 4 demonstrate the common perception that the changes in criteria weights may have an impact on the evaluation outcome to a certain extent. Moreover, it can obviously be seen that the air supply system is the least affected alternative by errors in comparison to the other alternatives, which is the most common consensus among the groups.

5. Conclusions

The engine can quickly be affected by a failure that occurs in any system and this failure can cause a breakdown or a malfunction in the engine. The reason of the failure should be immediately found out and repaired by expert applications. To help the chief engineers, the conditions in which those failures occurred in marine engine system should be figured out and methods must be developed to decrease the rates of failures.

In this paper, the hierarchical structure is adapted to the troubleshooting of main engine auxiliary systems, including cooling, governor, air supply and fuel systems. By means of FAHP and VIKOR hybrid methods, a more efficient decision for engine failure evaluation can be made. Taking into account all the results in Table 5, in FAHP-VIKOR approach, it can be concluded that all decision making groups agree that the most severely influenced system is the *Cooling System*.

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Submitted: 20.10.2014.
Accepted: 20.12.2104.

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