AN EVALUATION APPROACH FOR ELIMINATING THE FAILURE EFFECT IN GAS TURBINE USING FUZZY MULTIPLE CRITERIA

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This paper demonstrated the fuzzy AHP combined with fuzzy VIKOR technique integrated with essentials of weight in order to overcome the risk evaluation process of the uncertainty in subjective perception and experience of human. Gas turbine has considerably expanded its role in several areas subsequent to the improvement in high efficiency and clean energy such as aviation and marine propulsion systems, electric power stations, and natural gas and petroleum transportation. However, the cost of various industrial plants and their relevant maintenance appear to be extremely expensive to be operated by these gas turbines. This paper aimed to cope with the essential elements of gas turbine including hydraulic-pneumatic equipment, electronic control equipment, and bearing equipment. The results have proved the bearing equipment to have been the most effected alternative, as being ensued by hydraulic-pneumatic equipment and electronic control equipment.

1. INTRODUCTION

Gas turbines turn out to be one kind of the most important devices in power engineering where the air is compressed, mixed with fuel, and burnt in a combustor, with the generated hot gas expanded through a turbine to generate power, which is wielded for driving the compressor and for supplying the means to overcome external loads (Wang et al. 2014 [54]). An important function is mostly carried out by gas turbines in the domains of mechanical drives in the oil and gas departments, electricity generation in the power department, and propulsion systems in the aerospace and marine departments.

A product material is mass produced as much as it functions successfully till it expires. Designing, detecting/fixing are as important as extending a product`s life as well as making the sensible decisions about the production stage. Considering that, product design and maintenance are precisely related to the consumer demands. For that reason, the consumers and producers are mostly affected from reducing maintenance and repairing costs. In today's technology, the prediction of probable time of the fault is slowly becoming quite important before determining the location of the fault takes place. Extending the running time and decreasing the downtime is the way to the target.

It is quite unusual for service`s downfall as much as high efficiency of the modern aviation gas turbine engines. Actually, being a misconception, freedom from service failures results from stringent standards imposed during frequent inspections. Thus, suitable proceeding takes place in the early stage in order to elude service downfall as the whole failures almost are discovered here. Many investigators have become aware of the field of diagnosis in terms of the technical area and medical area through the last ten years. It is so noticeable that the various techniques were developed for an automatic diagnosis of errors due to an increasing requirement for safety in industry (Wang et al. (2014) [54] and Nozari et al. (2012) [28]). Regarding the procedure of gas turbine in the literature, various analysis have been emerged. Some studies were mentioned below.

Some multi-criteria decision making (MCDM) methods were used by Peng, Wang and Wang (2012) [36] in order to grade categorization algorithms established with the software defect detection datasets. Thirty-eight classification algorithms and 13 assessment criteria were studied through 10 public-domain software error datasets, and the most suitable algorithms were calculated for software error data sets. The technology of semantic failure detection was studied by Weihua, Zhensheng, and Xiaojin, (2002) [55], in which a strategy integrated with statistical and rules procedures were proposed, the gradation relationship with instances and rules were used to check errors. In the study carried out by Youren and Ullah (2012) [57], a novel TOPSIS-based method was suggested to form the closed-pack of analog test vector out of test signals managed via detailed search method, and the test costs were reduced with the compacted test vector`s assistant when the test designer were allowed for the compaction methodology formed via objectively obtained deterministic data. In the study of Wang et al. (2014) [54], a remote system was created to monitor online condition and error diagnosis of gas turbine as the oil well drilling platform was increased through the core information entropy model. Turbine vibration error diagnosis was studied by Shaaban and Nabwey (2013) [44]. Decision-making rules of error diagnosis data was applied accepting redundant and inconsistent information. A study upon the latest failure of the gas turbines of a cogeneration plant was studied by Yoon et al. (2012) [56] to mainly describe the crack initiation mechanism of blade fracture. A model-based robust error detection and isolation method that came with a hybrid structure including the system uses time-delay multilayer perceptron models, local linear neuro fuzzy models, and linear model tree was created by Nozari et al. (2012) [28]. Error analysis of gas turbine compressor and the whole blades were preserved by Farrahi et al. (2011) [6]. Different analysis method was utilized to elude failure. The major aims of error diagnosis such as detection, isolation and errors analysis for marine diesel engine turbocharger system were expressed by Golub, Anonic and Cibilic (2010) [10]. A prognostic method was expressed by Li and Nilkitsaranont (2009) [20] for the remaining useful life of gas turbine engines as being evaluated prior to their next main overhaul grounded over a combined regression technique with linear models as well as quadratic models in 2009. Fatigue under operating conditions were researched by Shlyannikov, Iltchenko and Stepanov (2001) [46] to rotate disks of aircraft gas turbine engines. The model-based robust error detection (RFD) method of soft computing techniques was developed by Nozari et al. (2012) [28]. Therefore, the tests were carried out and assessed on a single-shaft industrial gas turbine prototype because of non-linear simulations resting on the gas turbine data to show the efficiency of RFD method. Fuzzy decision tree or Soft Decision Tree (SDT) were established by Sahu, Jha and Qureshi (2014) [42] as the data mining for steam turbine error analysis of a power system rotatory machine component classified with the help of interval type-2 fuzzy logic rule.

2. FUZZY MULTIPLE CRITERIA METHODOLOGY

In literature, it was generally applied on fuzzy multiple criteria methods. The major subjects were particularly the importance of criteria and sub-criteria. It could be studied in this direction as described below. As the techniques were grasped by MCDM, the complicated criteria involved higher interest for their capabilities of solving spatial decision problems and supported analysts in addressing conflicted problems Kordi and Brandt (2012) [18]. It was still quite difficult to tackle the problems appertaining to natural hazards considering permanent unknown thanks to the multiple method nature of natural hazard model (e.g. LSM) (Nefeslioglu et al., 2013 [27]). The outcomes were considerably affected by such uncertainty, as the wrong findings and disagreeable result might every now and again be influenced from it (Feizizadeh and Blaschke, 2013 [8]). In order to obtain the last assessment out of expert's personal ideas, some methods were presented concerning the fuzzy sets theory.

A decision support system was created by Ma, Lu and Zhang (2010) [26] in order to improve the level of total satisfaction on the basis of the multi-criteria group decision making on a model. A method for group decision-making was improved by Fan and Liu (2010) [5] on the basis of the multi-granularity indefinite linguistic information.

2.1 FUZZY AHP METHODOLOGY

The contemporary form of the method owes much to Fechner (1966) [7], Thurstone (1994) [48], and Saaty (1977) [41]. In the early 1970s, T.L. Saaty created the hierarchical analysis that consisted of a decision-making process which was called analytical hierarchy process AHP. Decision makers have provided benefits with this method for prioritizing various alternatives systematically as the various properties and measurement criteria of decision-making factors are involved with a multi standard decision-making process through the effective application. A multi-criteria decision making method was established for comparing conceptions (alternatives) in pairs. AHP has been utilized for decision theory, economics, and other fields.

Phased and hierarchical analysis processes have been used by the human brain while making decisions after the intelligent conception AHP was created. The weighted values are utilized by this method as the ratio scale. As the previous studies proved, three principals were focused by human when solving problems, as the major AHP theoretical bases were followed as Saaty (1980) [40], Triantaphyllou and Mann (1995) [49], Vaidya and Kumar (2006) [51], Gumus et al (2013) [11], Aydin et al (2015) [1] and Hyun et al. (2015) [13].

(1) Setting a hierarchical structure: The AHP hierarchy has the simple structure as the target on the top, after the criteria, and the alternatives on the bottom. Criteria factors can be classified into multi-steps, a sub-criterion, and/or a further sub-sub criterion, if necessary.

(2) Setting the relative importance/priority: The relations between observed objects can be identified, similar objects can be compared with each other in the group for specific criteria, and a preference among element factors can be recognized for the group with ability by the human beings. With a simple pairwise comparison, the weighted values or the relative importance of numerous decision-making factors can be assessed through directly reflecting human distinctive.

(3) Maintaining logical consistency: The inspection can be made on the decision maker`s logical consistency via derived consistency index (CI). The rationality and logicality of decision making can be extended by this process. The consistency ratio (CR) is used for calculating the discerning how consistent the judgments have been relative to large samples of purely random judgments. It is highly believed that the decision maker's judgments are logically unreliable and unpredictable, if the consistency ratio (CR), that the CI divided by the random index (RI), exceeds 0. If more information is required on the computation of CI, CR and RI, then please look up Saaty (1980) [40].

Various values are such words or sentences in a natural or artificial language that can be known as Linguistic variables. This expression is used here to make comparison of energy technology selection evaluation criteria regarding to a fuzzy five level scale divided into five basic linguistic terms such as ''absolutely important,'' ''very strongly important,'' ‘‘essentially important’’, ‘‘weakly important’’ and ‘‘equally important’’ (Chiou and Tzeng, 2001 [4]). The following fuzzy numbers under the computational technique can be seen on the Table 1.

Table 1. Membership function of linguistic scale

Linguistic scales	Scale of fuzzy number
Absolutely Strongly (AS)	(7.00, 9.00, 9.00)
Very Strongly (VS)	(5.00, 7.00, 9.00)
Fairly Strong (FS)	(3.00, 5.00, 7.00)
Strongly (SS)	(1.00, 3.00, 5.00)
Equal (E)	(1.00, 1.00, 1.00)
Strongly Weak (SW)	(0.20, 0.33, 1.00)
Fairly Weak (FW)	(0.14, 0.20, 0.33)
Very Weak (VW)	(0.11, 0.14, 0.20)
Absolutely Weak (AW)	(0.11, 0.11, 0.14)

As could be seen clearly in the data in Table 1, the superiority or weakness status of AHP method were shown by five designated groups in the criteria-criteria comparison.

Substitutes measurement: The criteria performance (effect-values) was presented with the measurement of linguistic variables by phrases such as ‘‘very good,’’ ‘‘good,’’ ‘‘medium good,’’ ‘‘fair,’’ “medium poor,” ‘‘poor,’’ ‘‘very poor,’’ as their subjective judgments were created by assessors by the help of these phrases. The results received from the preliminary analysis of indication of every linguistic variable were shown on the table below by the help of a TFN between the scale ranges of 0–10.

Table 2. Fuzzy assessment grades for the alternatives

Linguistic terms	Fuzzy score
Very poor (VP)	(0.00, 0.00, 1.00)
Poor (P)	(0.00, 1.00, 3.00)
Medium poor (MP)	(1.00, 3.00, 5.00)
Fair (F)	(3.00, 5.00, 7.00)
Medium good (MG)	(5.00, 7.00, 9.00)
Good (G)	(7.00, 9.00, 10.00)
Very good (VG)	(9.00, 10.00, 10.00)

It was obvious that five designated groups in the criteria-criteria comparison showed the superiority or weakness status of AHP method, as written above, exactly same as the data shown in Table 2 (Fechner, 1966) [7]. Moreover, the evaluators could reserve the personal range of the linguistic variable for showing the membership functions of the wording values of each assessor. E_{ij}^k indicated the hazy performance value of assessor k towards alternative i under criterion j, as a demonstration, and $E_{ij}^k = (LE_{ij}^k, ME_{ij}^k, UE_{ij}^k)$ indicated the whole assessment criteria. This study proposed the calculation of the notion of average value combining the fuzzy finding values of m evaluators’ experience and knowledge.

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

$\hat{E}_{ij}^k$ indicated a triangular hazy number as $LE_{ij}^k, ME_{ij}^k and UE_{ij}^k$ indicated the average fuzzy number of the judgment of the decision-makers. Buckley [2] utilized from the end-point value of LE_{ij}, ME_{ij} and UE_{ij}, as shown below,

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

Fuzzy synthetic verdict: The calculation of fuzzy numbers must be combined with the weights of the each criterion of energy technology selection evaluation and the fuzzy production values for identifying the fuzzy performance value (effect-value) of the integral assessment. F-AHP developed the each criterion weight correspondently, the criteria weight vector $\widehat{W} = (\widehat{W}_1 \ldots\ldots \ldots \widehat{W}_j \ldots\ldots \widehat{W}_n)^t$ j could be integrated with the fuzzy performance matrix; on the other hand, $\widehat{E}$ of each alternative could also be combined out of the fuzzy performance value of each alternative under n criteria; that is, $\widehat{E} = \widehat{E}_{ij}$ out of the criteria weight vector $\widehat{W}$ and fuzzy performance matrix $\widehat{E}$, the final fuzzy synthetic decision could be administered, and the obtained result will be the fuzzy synthetic decision matrix $\widehat{R}$, which is,

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

The calculation of the fuzzy numbers were indicated with ‘‘o’’ sign including fuzzy addition and fuzzy multiplication. The approximate multiplied result of the fuzzy multiplication usually make expression due to the complicated calculation of fuzzy multiplication and, the approximate fuzzy number $\widehat{R}$ i of the fuzzy synthetic decision of each alternative could be indicated as $\widehat{R} = (L\widehat{R}_i, M\widehat{R}_i, U\widehat{R}_i)$, where, $L\widehat{R}_i, M\widehat{R}_i and U\widehat{R}_i$ were the lower, middle and upper synthetic performance values of the alternative i as follows:

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

Rating the fuzzy number: A fuzzy number is one of the every alternative in which a decision made through the result of the fuzzy synthetic. For that reason a non-fuzzy ranking method was especially used for fuzzy numbers to compare each alternative. In other words, the Best Non-fuzzy Performance value (BNP) was detected with the procedure of de-fuzzificiation. De-fuzzified fuzzy ranking is such a method that usually consists of mean of maximal (MoM), center of area (CoA), and a-cut. It is easy and practical method to use the COA methods for discovering BNP and any evaluators does not have to be conveyed through the preferences as it is demonstrated in this study. The fuzzy number $\hat{R}_i$ BNP value is possible to be created with the next equation presented below:

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

The ranking of each of the alternatives could be carried out as the value of the derived BNP for each of the alternatives indicated.

2.2. FUZZY VIKOR METHOD

Opricovic presented, multi-attribute optimization of complex system in 1998 producing a new well known MCDM technique which was called VIKOR method (VlseKriterijumska Optimizacijia I Kompromisno Resenje, multi-criteria optimization and compromise solution) contributing upon the ''classical'' MCDM decision models. The ranking and selecting options from a set of alternatives and determining the compromise solution were emphasized by VIKOR approach for MCDM problems to be handled by the decision maker through a certain problem through conflicting attributes that a maximum ''group utility'' for the ''majority'' and a minimum ''individual regret'' for the ''opponent'' are identifying. The VIKOR method was subsequently expanded by some investigators on various uncertain environmental situations. The decision makers aimed to have maximum profit without worrying to have too much decision risk in order to deal with the circumstances, so they expanded the VIKOR method to the intuitionistic fuzzy context for solving the problems (Buckley, 1985 [2]; Opricovic, 1998 [29]; Opricovic and Tzeng, 2002 [30]; Opricovic and Tzeng, 2004 [31]; Opricovic and Tzeng, 2007 [32]; Vahdani et al., 2010 [50]; and Park and Cho, 2013 [34]; Celik et al., 2014 [3]). Recently, the application of VIKOR approach was extended due to its characteristics and capabilities.

Some uncertain fuzzy measures such as distance measure, group application measure and individual remorse measure were presented by Liao, Xu and Zeng (2015) [21], and subsequently a VIKOR-based method was expanded for uncertain fuzzy MCDM issues. The concept design selection was managed by Vinodh, Sarangan and Vinoth (2014) [52] in order to fit environment using fuzzy VIKOR method, so that the customers' dynamic needs were managed to be fulfilled. VIKOR-fuzzy AHP method was used by Pourebrahim et al. (2014) [37] as being combined with making a choice among criteria and substitutes for conservation growth in seaside areas. A developed VIKOR method was used by Liu et al. (2014) [22] to have a site choice in municipal solid unwanted management under a fuzzy environment. A hybrid MCDM model was utilized by Liu et al. (2014) [23] integrating DEMATEL-based analytic network method (DANP), and VIKOR was transformed for solving the material choice problems of multiple dimensions and interconnecting the criteria. An integrated hazy AHP and VIKOR method were administered by Rezaie et al. (2014) [38] in order to assess the performance of the cement firms in Iran. A novel hybrid MCDM model was extended by Tadi´c, Zeˇcevi´c and Krsti´c (2014) [47], and they combined the method with the hazy DEMATEL, fuzzy ANP and fuzzy VIKOR for city logistics idea selection. A MCDM model was used by Hu, Lu and Tzeng (2014) [12] for integrating DEMATEL with ANP and VIKOR methods in order to cope with the complex interrelated relationships among dimensions and criteria and figuring out the best way to search smart phone developments. The VIKOR method was expanded by Park, Cho and Kwun, (2011) [34] in order to solve MCDM issues with interval-value intuitionistic hazy information. An extended fuzzy VIKOR method was expanded by Sanayei and Farid Mousavi, (2010) [43] in order to fix MCDM problems, and employed to the proposed method for supplier selection issues. AHP and VIKOR approach is proposed for renewable energy planning (Kaya and Kahraman, 2010 [16]) and forestry decision (Kaya and Kahraman, 2011 [17])

VIKOR in supplier selection, material choice, water resource planning, risk assessment , insurance firm selection, service quality, entrepreneurial assessment and customer satisfaction were all included in the studies of Kang and Park (2014) [14], Rostamzadeh, Ismail and Nobar (2014) [37], Liu, Wu and Li (2013) [25], Kim and Chung (2013) [17], Liu et al. (2012) [24], Yücenur and Demirel (2012) [59], Girubha and Vinodh (2012) [9], Kuo and Liang (2011) [19], Opricovic (2011) [33], Shemshadi et al. (2011) [45] and Sanayei, Mousavi and Yazdankhah (2010) [43]. The compromise programming of MCDM was supported with an approach that was created by VIKOR. Acquiring the weight vector through the vast analyses can preserve the appliance of the VIKOR's steps. The concepts of compromise solutions were firstly introduced by Yu (1973) [58] and Zeleny (1982) [60]. Each criterion function makes assessment on each alternative as the methodology was hardly effective through the principles providing opportunity to compare the degrees of proximity for gaining the compromise ranking to the ideal alternative. According to the criteria, in hazy VIKOR, the linguistic variables were used by decision makers for assessing the ratings of alternatives as suggested. The linguistic scale was presented in Table 2 below for the assessment of alternatives. The ratings of alternatives with reference to each criterion could be measured as indicated below according to the study of Wang, Liang and Ho (2006) [53] that was made an assumption for decision-making group have K people;

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

in which $\overset{K}{x_{ij}}$ was the figure of the Kth qualified for ith substitute regarding to jth criterion.

After the weights of criteria and fuzzy ratings of substitute were obtained in reference to each criterion, the fuzzy multi-criteria decision-making problem in matrix format could be indicated as below,

$$D = \begin{pmatrix} x_{11} & \dots & x_{1n} \\ \vdots & \cdots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix}$$
$$W = [w_1, w_1, ..., w_n] \quad j = 1, 2, ..., n \tag{7}$$

in which x_{ij} was the rating of Alternative Ai corresponding to Criterion j (i.e. C_j) and w_j indicated the importance weight of C_j.

The next step would 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 were measured 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 $\tilde{S}_i$ signified 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 were estimated 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 $\min_i R_i$ were relevant to a maximum majority rule and a minimum individual regret of an opponent strategy, respectively. V was additionally presented as the weight of the strategy of the maximum group tool. "v" was usually considered to be 0.5.

The de-fuzzification of the triangular fuzzy number of Q_i was the next assignment, and ranking the substitutes by the index Q_i was the following. There were suggestions including to have different defuzzification strategies in the literature. In this recent study, the graded mean integration approach was accustomed [29]. According to the graded mean integration approach for triangular fuzzy numbers, a fuzzy number $C = (c_1, c_2, c_3)$ could be transformed into a crisp number using the equation as:

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

Finally, the best substitute with the minimum of Q_i was agreed. The sum up of methodology steps of application for Fuzzy AHP-VIKOR hybrid method was presented in Figure 1.

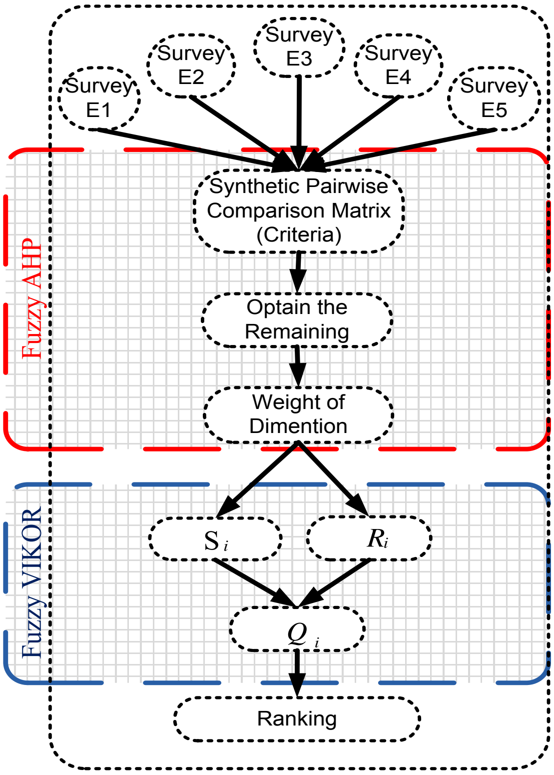

Figure 1. Fuzzy AHP-VIKOR hybrid method

Step 1: Setting up into the pair contrast matrices through all the criteria in the dimensions of the system hierarchy.

Step 2: Estimating the features of synthetic pairwise contrast matrix as Buckley suggested using the geometric mean method:

Step 3: Same way, we can have the remaining $\tilde{r}_i$,

Step 4: The weight of every measurement was stated below as the processes could be observed

Step 5: The best value of Fuzzy (FBV, $\tilde{f}_j^*$) and the worst value of Fuzzy (FWV, $\tilde{f}_j^-$) were agreed for each criterion function.

Step 6: Division measures ($\tilde{S}_i$ and R_i) were calculated.

Step 7: Q_i values were estimated.

Step 8: Q_i defuzzified values and the index Q_i ranked the alternatives

Step 9: The best alternative was agreed on the minimum of Q_i .

3. A CASE STUDY IN FAILURE MANAGEMENT USING FUZZY MULTIPLE CRITERIA METHOD

In most cases, it is definitely accurate that some serious damage and considerable loss of capital investment increases due to the fault. The tree gas turbine component following various realistic events needs to be taken into account as presented in this study. If there is any element breakdown during the operation conditions takes place, then the extreme levels of these errors present differences necessitating a quick error diagnosis and adjustment to avoid from serious accidents.

These are major driving aspects of another breakdown if an enquiry takes place in terms of the causes and signs of errors clashed with the gas turbine. Each of them has a reason for breakdown that stems from the course of operation. A clear hierarchical structure plan is used for managing the operational issues of gas turbine as presented in Figure 2.

A major hint demonstrates any probable failure while using the effective gas turbine element breakdown diagnosis. The discovered errors that continually breakdown related to gas turbine can be combined with the overall number of the well-known features together to figure out the possible causes of failure which strength the productivity of the managing turbine.

It is established during the assessment and selection of gas turbine elements that the main dimensions of the criteria are a result of an intensive research, and discussed with five experts involving a professor of Naval Architecture and Marine Engineering. Grading the criteria dimensions have been tried by the masters in terms of their accuracy, sufficiency and significance for validating the content of these criteria to the gas turbine failure assessment. The former reports, maintenance logbooks and acquired data fused with the personnel's experiences were originated for failures in gas turbine. The five types of high priority seem to be issuing as described on Table 3 showing the examination of the failures. "I" was the number of related failure that coded as failures.

Recognizing each of them formed a relationship with a different gas turbine element providing benefits from several engine errors from one to another in terms of basic technical features directing to analysis for classic categorization. There was a possibility that the failures in particular groups established a relationship along with the ones in other groups as possible to have awareness. Observing the causes for failures, gas turbine elements in coherence to the failures were divided into categorization as below:

A1. Hydraulic-Pneumatic Equipment
A2. Electronic Control Equipment
A3. Bearing Equipment

In conclusion, to the experts, related to the Fuzzy, the two foremost criteria included the facts that the starter motor coupling fell down (0.237), and the extraordinary of shafts (0233). On the other hand, the least two major criteria included the facts that the attaching shaft was destroyed between turbine and gear box (0.018), and sufficient pressure fuel did not reach to fuel pump (0.018).

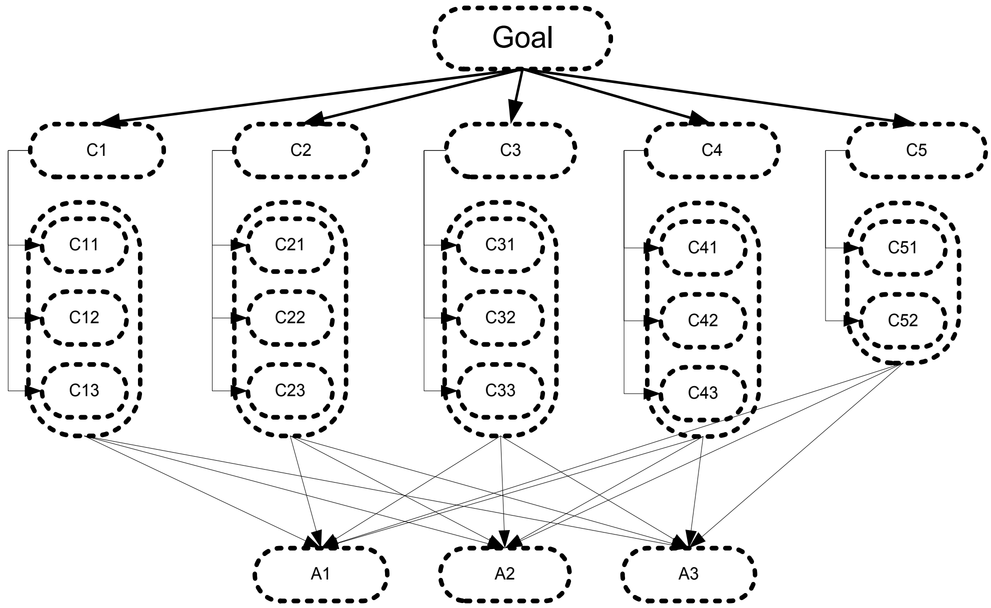

Figure 2. The hierarchical structure planned for gas turbine.

Table 3. The most common failure in gas turbines

Criteria and Sub-criteria
C1. Variations in rpm signal
C11. Electronic speed regulator failure
C12. Starter motor coupling failure
C13. Connecting shaft has been broken between turbine and gear box
C2. Falling and Fluctuations in Pressure Value
C21. Sufficient pressure fuel does not come for fuel pump
C22. The oil pressure switch failure
C23. The fuel solenoid valve failure
C3. Insufficient compressed air flow
C31. Blocked the outlet of air pressure regulator
C32. Load control valve failure
C33. Pressure regulator filter clogged
C.4 Excessive change in exhaust gas temperature
C41. Temperature control unit failure
C42. Problems in automatic control air supply lines
C43. Fuel atomizer filter clogged
C5. Turbine Vibrations
C51. Eccentricity of shafts
C52. Low oiling pressure

Table 4. Fuzzy AHP weights of dimensions and criteria for decision-making groups

Criteria	Weights			BNP
C11. Electronic speed regulator failure	(0.010	0.030	0.070)	0.038
C12. Starter motor coupling failure	(0.090	0.210	0.410)	0.237
C13. Connecting shaft has been broken between turbine and gear box.	(0.010	0.010	0.030)	0.018
C21. Sufficient pressure fuel does not come for fuel pump	(0.010	0.010	0.030)	0.018
C22. The oil pressure switch failure.	(0.010	0.020	0.050)	0.026
C23. The fuel solenoid valve failure.	(0.040	0.090	0.220)	0.117
C31. Blocked the outlet of air pressure regulator	(0.020	0.040	0.090)	0.049
C32. Load control valve failure	(0.020	0.060	0.140)	0.074
C33. Pressure regulator filter clogged	(0.040	0.090	0.200)	0.110
C41. Temperature control unit failure	(0.050	0.120	0.280)	0.154
C42. Problems in automatic control air supply lines	(0.030	0.070	0.160)	0.086
C43. Fuel atomizer filter clogged	(0.010	0.030	0.080)	0.041
C51. Eccentricity of shafts	(0.090	0.200	0.400)	0.233
C52. Low oiling pressure	(0.010	0.020	0.040)	0.023

Table 5. The fuzzy evaluation of "Q" results

Alternatives	Fuzzy Evaluation			Q	Ranking
A1. Hydraulic-Pneumatic Equipment	0.918	0.724	0.087	0.650	2
A2. Electronic Control Equipment	0.500	0.665	1.000	0.694	3
A3. Bearing Equipment	0.069	0.0000	0.467	0.089	1

The experts' concern were benefited for these outcomes about the safety of maintaining the variations in rpm signal to concentrate on the turbine vibrations that will be believed to be the suitability of freighter operating. At the same time, the associated professional issues were emphasized by the experts for the variations in rpm signal and turbine vibrations. The starter motor coupling still fell through and eccentricity of shafts was stable to be secured under professional estimations. They finally rated it achieving to the great importance.

The fuzzy assessment concluded, "Q" values of other alternatives for contrast; finally, Table 5 presented the detailed results.

As Table 5 indicated, it was concluded that the bearing equipment issued as the most efficient alternative for the failures regarding the weights of all experts. However, Table 4 illustrated the outcomes including the common perception related to the fact that the changes in criteria weights might have an effect on the assessment result to the some extent. These outcomes additionally offered major insights into the Electronic Control equipment as it was the least efficient alternative for the failures in contrast to the other alternatives as the most usual agreement between the experts.

In this paper, a sensitivity analysis is applied to evaluate of robustness and steadiness of the proposed approach. Hence, the weight of the strategy of the maximum group tool. “v” is used as changed between 0 and 1 as increasing by 0.1. The results of the sensitivity analysis are presented in Table 6 and Table 7 and graphically in Figure 3 and Figure 4. This study also presumes that the v value correspond to 0.5 while the Q values of each alternative A1, A2 and A3 are 0.650, 0.694 and 0.089, respectively. The ranking order of the three alternatives is A3 >A1 >A2.

Table 6. The Qi values for different maximum group utilities.

	A1	A2	A3
v=0.0	0.466	1.000	0.000
v=0.1	0.503	0.939	0.018
v=0.2	0.540	0.877	0.036
v=0.3	0.576	0.816	0.054
v=0.4	0.613	0.755	0.071
v=0.5	0.650	0.694	0.089
v=0.6	0.687	0.632	0.107
v=0.7	0.723	0.571	0.125
v=0.8	0.760	0.510	0.143
v=0.9	0.797	0.448	0.161
v=1.0	0.833	0.387	0.179

When v value corresponds to 0.0, then the Q values of each A1, A2 and A3 are 0.466, 1.000 and 0.00, respectively. The ranking order of the three alternatives is also A3 >A1 >A2. This study confirms that the results of the ranking orders of all three gas turbines components, by using the proposed approach, are consistent. Furthermore, the proposed approach finds the gap between the Q values of gas turbines components.

Table 7. The ranking of the alternatives for different maximum group utilities

	A1	A2	A3
v=0.0	2	3	1
v=0.1	2	3	1
v=0.2	2	3	1
v=0.3	2	3	1
v=0.4	2	3	1
v=0.5	2	3	1
v=0.6	3	2	1
v=0.7	3	1	1
v=0.8	3	1	1
v=0.9	3	1	1
v=1.0	3	1	1

4. CONCLUSION

In each process of production and marketing, a severe competition has been maintained by today’s industry. Manufacturing a product perfectly is as quite important as using it. The conditions of competition are directly affected by the customer satisfaction. Giving support to the economic life of a product is considered to be as much important as detecting and fixing the faults as well as the accurate decision making in the process of design and manufacturing the product. Customers are driven negatively from one of the factors including the frequent breakdown of a product, and this kind of a situation is hardly expected by anyone.

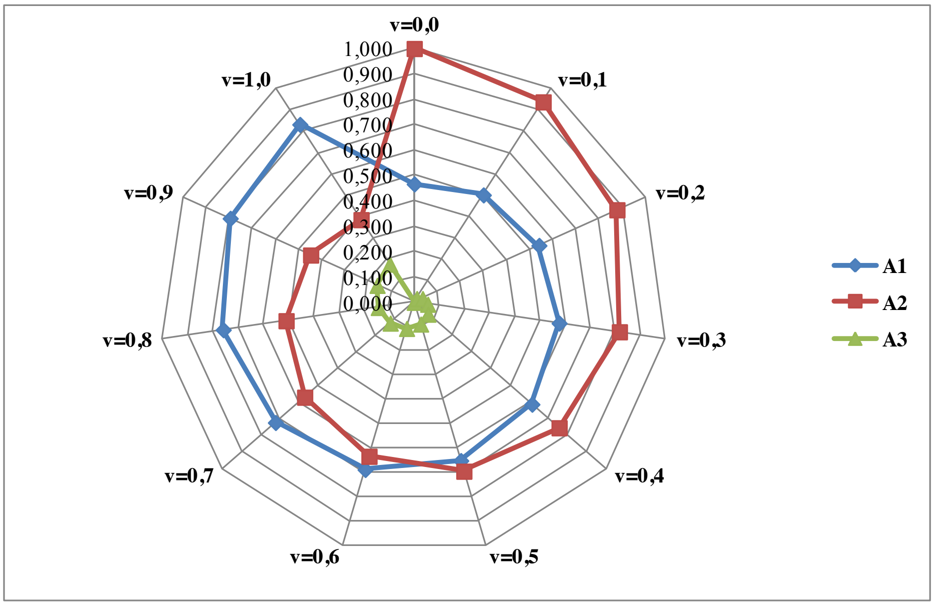

Figure 3. Sensitivity analyses of “Q” values.

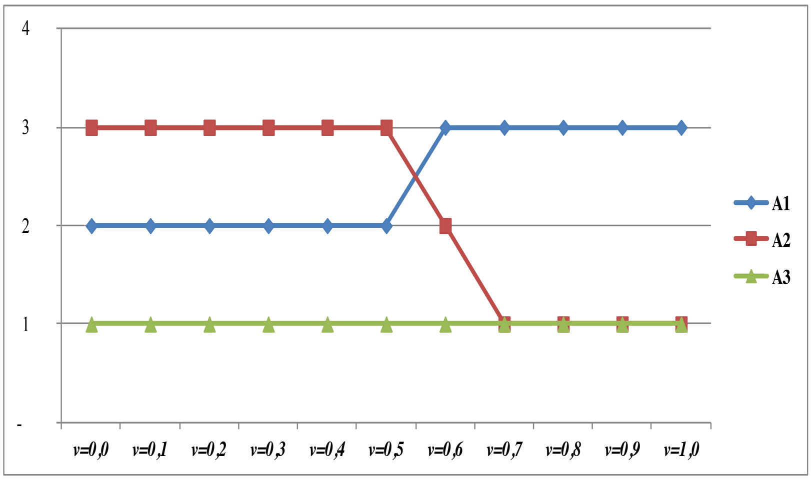

Figure 4. Sensitivity analyses of ranking.

It can be very hard to fix errors on board for the failure in rotating elements and seats, considering maintenance works. It is necessary to take turbines down and send it to the atelier for renovation due to that reason. The faulty non-rotating components and seats cost less than the rotating ones.

This study aimed to set and create a certain point of view for gas turbines in use. Thereby, this helped to re-design components exposed to breakdowns arisen in production phase and to yield to quick detection of faults and fix. The gas turbine can easily be influenced by a breakdown or a malfunction in the engine of a system due to failure. The reason of the failure needs to be noticed and fixed straightaway with an experienced application. It is important to find out the conditions in the failures in gas turbine in order to help the chief engineers, and methods should be improved for decreasing the rates of failures.

This paper presented the way the gas turbine components were arranged with the hierarchical structure consisting of Hydraulic-Pneumatic Equipment, Electronic Control Equipment and Bearing Equipment. The engine failure evaluation was selected to be performed effectively as being thankful to the fuzzy multiple criteria methodology.

All the consequences were under consideration as presented in Table 5 in fuzzy multiple criteria emphasizing the integrated AHP and VIKOR approach. The Bearing Equipment was agreed by all experts as the most influential element established.

There was a possibility of determining to what extent turbine elements could be damaged due to the evaluation of the calculated data. Therefore, all failures were almost prevented swiftly by the renewal or replacement of any component. Services and customer satisfaction were supported. Besides, this methodology was possible to be administered successfully to all systems in a very broad application area.

The high quality material, manufacturing sensitivity and experienced labor were required for internal combustion engines as the gas tribune systems which were used in shore, off shore, air and watercrafts, and power plants. Extending the duration of work, and therefore, reducing the engine's out-of-service duration were two major fundamental purposes. We aimed to build and develop a specific point of view for ship tribunes in-service in this study. Therefore, it would be at an earlier stage to comprehend and repair the malfunctions in faulty and faultless engines. Indirectly, the services would not have any failure. The customer services could be provided with full supports and great satisfaction.

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