Improving risk analysis capability of FMEA using evaluation based on distance from average solution (EDAS): a case study of turbocharger system

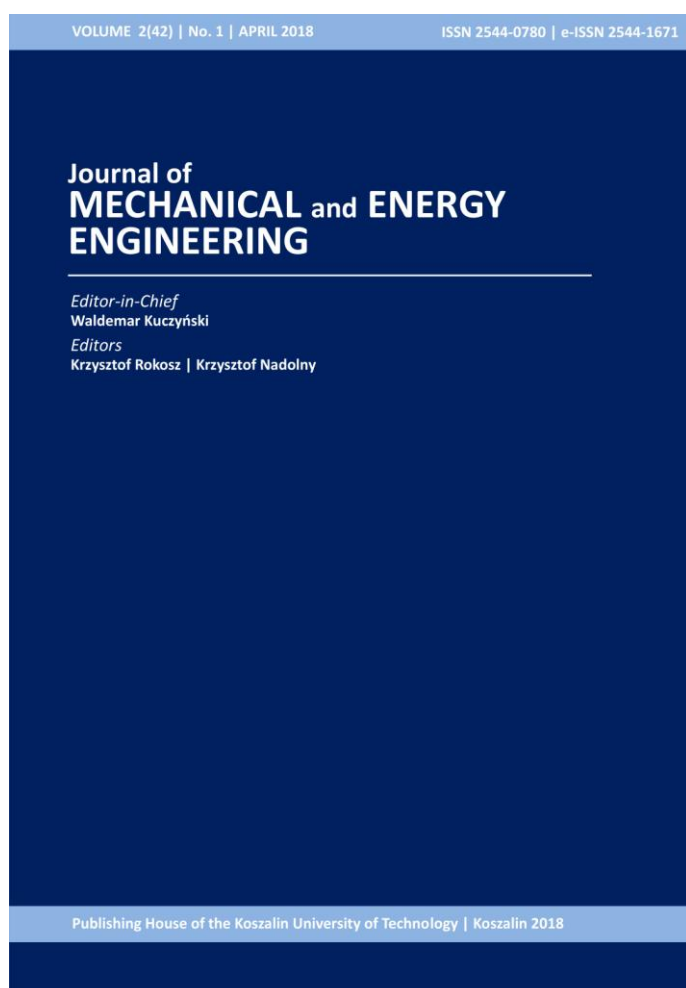Ikuobase EMOVON

IMPROVING RISK ANALYSIS CAPABILITY OF FMEA USING EVALUATION BASED ON DISTANCE FROM AVERAGE SOLUTION (EDAS): A CASE STUDY OF TURBOCHARGER SYSTEM

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Abstract: Failure Mode and Effect Analysis (FMEA) is a key risk management tool used in detecting and eradicating potential failure for the purpose of improving the reliability and safety of a system. However, the traditional FMEA in spite of its popularity has inadequacies that have hindered the effectiveness of the tool in analysing risk of failure modes. Due to the shortcomings of the technique, different improved versions have been suggested in the literature in order for risk to be analysed more effectively but majority of these versions are computationally challenging. In this paper, a simple approach is introduced for improving the risk analysis capability of the FMEA. The approach utilizes Evaluation based on Distance from Average Solution (EDAS) as an alternative to RPN of FMEA in analyzing risk of failure. A case study of the turbocharger system of a diesel engine is applied to demonstrate the usefulness of the method. The result obtained from the EDAS method were compared with approaches in the literature previously used to address risk analysis of a turbocharger. The result of the analysis indicated that the EDAS method is a feasible alternative technique for risk analysis.

Keywords: EDAS, decision criteria, FMEA, turbocharger, risk analysis, optimum alternative

1. INTRODUCTION

One of the key tools for management of risk of failure is the Failure Mode and Effect Analysis (FMEA), and it is generally applied for the identification and elimination of potential failures in order to improve system safety and reliability [1]. The major aim of the tool is to identify and assesses potential or known failure modes of system equipment and corresponding effects so as to establish optimum maintenance policy that will minimise or eliminate failure effects [2]. FMEA utilises RPN in assessing risk of failure mode and it is defined as a product of Occurrence (O), Severity (S) and Detectability (D) of failures. Values are generally assigned to O, S and D by a team of experts relying on a pre-determined scale. An example can be found in the work of [3-5].

The traditional FMEA, in spite of its popularity, has limitations that have hampered the effectiveness of the technique in analysing risk of failure modes. Some of the inadequacies of the methodology are (1) The tool incapability to apply more than three decision criteria in evaluating risk [6]; (2) The relative importance of O, S and D, are not taken into consideration in the course of risk analysis as the three decision criteria are assumed to be of the same significance [6, 7]; (3) Different combinations of O, S and D by RPN may yield the same risk values but the risk effect may not be the same [2, 8] and (4) The mathematical model for evaluating RPN remain debatable and questionable as the basis for finding the product of O, S and D is not rational [2, 8].

Therefore, due to the shortcomings of the FMEA, different improved versions have been suggested in the literature in order for the technique to analyse risk more effectively. Xu et al. [1] suggested the use of the fuzzy rule FMEA technique in resolving the interdependencies that exist among different failure modes in order to prioritize risk more efficiently.

However, the fuzzy rule approach is a computationally challenging and time consuming exercise [9]. Braglia [10] proposed an integration of the Analytical Hierarchy Process (AHP) with the FMEA in order to make it more viable for risk analysis. The authors used expected cost criteria in addition to the three traditional decision criteria; O, S and D as the basis for ranking of the failure causes of the Italian refrigerator industry. Seyed-Hosseini et al. [11] utilised DEMATEL method in enhancing FMEA in order to consider the relationship between the failure mode and to evaluate risk more effectively. Ayadi et al. [12] proposed the use of the PROMETHEE method for improving the FMEA risk analysis. Emovon [6] proposed a combination of the Dempster Shafer Theory and the ELECTRE Method in ranking the risk of failure of a ship system. The Multi-Criteria Decision Making (MCDM) tools that these authors applied in analyzing risk are rigorous in terms of computation especially as the number of alternatives and decision criteria increases.

In this paper, a less computationally intensive approach is introduced in improving the risk analysis capability of the FMEA. The approach utilizes Evaluation based on Distance from Average Solution (EDAS) as an alternative to RPN of FMEA in analyzing the risk of the failure of a plant system and with a focus on turbocharger system of a diesel engine.

2. METHODOLOGY – EDAS METHOD

The principle of the EDAS technique is a combination of the ideas of the TOPSIS and SAW methods [13]. In the TOPSIS approach, the optimum alternative is the one whose distance is closest to the ideal solution while in the EDAS method the optimum alternative is a function of the distance from the average solution [13, 14]. In determining the optimum alternative using EDAS approach, two measures are applied. The first is the positive distance from the average solution (PD) and the second measure is the negative distance from the average solution (ND). The alternatives with the higher PD and lower ND values are the better alternatives [13, 14].

The evaluation steps in the method are [13, 14]:

Step 1. Development of decision matrix, X, with n number of alternatives and m number of decision criteria, as follows:

$$X = \left[x_{ij}\right]_{nxm} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n1} & \cdots & x_{nm} \end{bmatrix}, \quad (1)$$

where x_{ij} characterize the rating of i_{th} alternative with regard to j_{th} criterion.

Step 2. Evaluation of the average solution (A) as follows:

$$A_j = \frac{\sum_{i=1}^{n} x_{ij}}{n}. \quad (2)$$

Step 3. PD and ND evaluation depend on the type of criteria. The PD and ND calculation for benefit criteria is performed as follows:

$$PD_{ij} = \frac{max\left(0, (x_{ij} - A_j)\right)}{A_j}, \quad (3)$$

$$ND_{ij} = \frac{max\left(0, (A_j - x_{ij})\right)}{A_j}. \quad (4)$$

For the non-benefit criteria, evaluation of PD and ND is carried out as follows:

$$PD_{ij} = \frac{max\left(0, (A_j - x_{ij})\right)}{A_j}, \quad (5)$$

$$ND_{ij} = \frac{max\left(0, (x_{ij} - A_j)\right)}{A_j}. \quad (6)$$

Step 4. PD and ND weighted sum evaluation is performed as follows:

$$EP_i = \sum_{j=1}^{m} w_j \, PD_{ij}, \quad (7)$$

$$EN_i = \sum_{j=1}^{m} w_j \, ND_{ij}, \quad (8)$$

where w_j denotes the j_{th} criterion weight.

Step 5. Normalisation of the EP and EN values for all the alternatives as follows:

$$NEP_i = \frac{EP_i}{\max_i EP_i}, \quad (9)$$

$$NEN_i = 1 - \frac{EN_i}{\max_i EN_i}. \quad (10)$$

Step 6. Performance score (PS) determination for each alternatives using Eq. 11:

$$PS_i = \frac{1}{2} (NEP_i + NEN_i). \quad (11)$$

The alternatives are ranked with regard to PS and the alternative having the highest value of PS is the best solution.

3. CASE STUDY

To illustrate how effective the EDAS method is, in evaluating the risk of failure modes, a case study of turbocharger system of the diesel engine is carried out. The example was taken from the work of Xu et al. [1]. The authors utilised the conventional RPN of FMEA and the Fuzzy rule FMEA to evaluate the risk of the turbocharger system. The decision problem was also resolved with the DEMATEL method by Seyed-Hosseini et al. [11] The turbocharger uses heat energy and the engine's exhaust gas pressure to produce a rotary motion of the turbine wheel which then result to the compression of the air-fuel mixture by the compressor wheel. The denser charge under pressure is sent to the engine combustion chamber and during the combustion cycle more power is generated.

However, the condition of operation of the turbocharger is very critical and this is due to the very high exhaust gas temperature and an extremely high rotational speed, which make an implementation of FMEA imperative, in order to maximise its reliability and life cycle. Eight failure modes have been identified and risk rating assigned by experts, and the results are shown in Table 1. The information on the turbine charger was provided from the work of Liu et al. [2] and Xu et al. [1] and details can found in these references.

From Figure 1, FM8 ranked 1 is the most critical failure mode of the turbocharger of the diesel engine. FM2 with PS value of 0 is ranked 8 and therefore, the least critical failure mode of the system.

In order to validate the EDAS method for application in the prioritisation of the risk of the failure modes of turbocharger, the approach is compared to the ranking order obtained from the RPN and Fuzzy methods [1] and the DEMATEL method [11]. A comparative analysis is indicated in Table 3.

From Table 3, FM8 is ranked 1 in all the methods. It is at this moment very obvious that the most critical failure mode of the turbocharger system is FM8. From the Table, both EDAS method and traditional RPN have same ranking for FM2, FM3, FM4, FM6, FM7 and FM8 representing 75% of the entire failure mode. Also, both EDAS and DEMATEL have the same rank for FM3, FM4, FM7 and FM8 indicating 50% of the whole failure mode, while other failure modes have a rank difference of one. However, Fuzzy based FMEA methods have same rank with that of EDAS method for only FM6, FM7 and FM8 largely due to the fact that the Fuzzy based method inability differentiates failure mode from each other. For example, the Fuzzy approach assigned same rank to FM3, FM4 and FM8. Nevertheless, by and large from the comparative analysis, the proposed EDAS method produces similar ranking of failure modes with that of RPN, Fuzzy method and DEMATEL technique, thereby validating

the proposed methodology for analysing the risk of the turbocharger system of diesel engine and other industrial system.

Tab. 1. Decision matrix

| FM#	Failure modes (FM)	Component	O	S	D
FM1	Blade heavy rubbing	Turbine wheel	2	5	3
FM2	Deposited carbon on the blade	Turbine wheel	2	4	2
FM3	Fracture	Locknut	2	8	8
FM4	Blocked oil inlet passage	Bearing housing	5	7	2
FM5	Blocked oil exit funnel	Bearing house	2	6	2
FM6	Fracture	Compressor sealing ring	2	7	4
FM7	Fracture	Turbine sealing ring	2	6	3
FM8`	Start and stop operational error	Operator	3	7	8
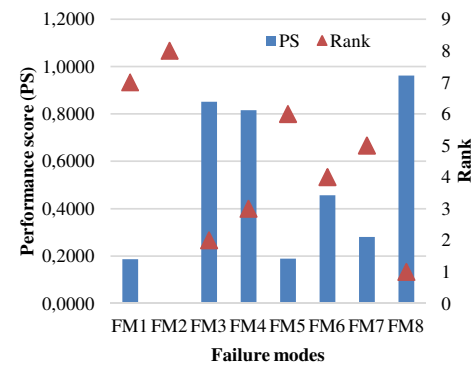
Fig. 1. Performance score (PS) and ranking of failure modes

Tab. 2. Results of analysis of EDAS method

Failure modes	PD			ND			EP	EN	NEP	NEN	PS
	O	S	D	O	S	D					
FM1	0.00	0.00	0.00	0.20	0.20	0.25	0.00	0.21	0.00	0.37	0.19
FM2	0.00	0.00	0.00	0.20	0.36	0.50	0.00	0.34	0.00	0.00	0.00
FM3	0.00	0.28	1.00	0.20	0.00	0.00	0.36	0.07	0.91	0.79	0.85
FM4	1.00	0.12	0.00	0.00	0.00	0.50	0.40	0.13	1.00	0.63	0.82
FM5	0.00	0.00	0.00	0.20	0.04	0.50	0.00	0.21	0.00	0.38	0.19
FM6	0.00	0.12	0.00	0.20	0.00	0.00	0.05	0.07	0.12	0.79	0.46
FM7	0.00	0.00	0.00	0.20	0.04	0.25	0.00	0.15	0.00	0.56	0.28
FM8	0.20	0.12	1.00	0.00	0.00	0.00	0.37	0.00	0.92	1.00	0.96

Tab. 3. Comparison of ranking of EDAS method with other MCDM methods

Failure modes	EDAS	RPN[+]	FUZZY[+]	DEMATEL[++]
FM1	7	6	5	8
FM2	8	8	7	6
FM3	2	2	1	2
FM4	3	3	1	3
FM5	6	7	7	4
FM6	4	4	4	7
FM7	5	5	5	5
FM8	1	1	1	1

[+]Proposed by Xu, et al. [1],
[++]Proposed by Seyed-Hosseini et al. [11]

4. CONCLUSIONS

In this paper, a new technique of Evaluation based on Distance from the Average Solution (EDAS) is suggested for enhancing the risk assessment capability of the traditional FMEA. The technique utilizes the positive and negative distances from the average solution in analyzing the risk of failure mode. The usefulness of the approach has been illustrated with a case of the turbocharger system of a diesel engine. The results of the analysis indicate that FM8 which denotes the start and stop operational error is the most critical failure mode of the system. The EDAS method suitability has been validated by comparing it with other tools such as the uzzy rule method and the DEMATEL method. The proportional analysis showed that the EDAS approach which is less computationally challenging, yielded similar results with that of DEMATEL method and rank failure modes better than that of the Fuzzy rule method. For future analysis, other MCDM tools such as the Grey Relational Analysis (GRA) may be compared with the EDAS technique. Additionally, since the EDAS method is capable of utilizing as many decision criteria as possible for risk analysis, other decision criteria such as maintainability might be included in the decision process.

Acknowledgement

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