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Application of FMEA Method Comparative with ELECTRE Method in Preventive Maintenance of CNC Lathe

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Abstract
Failure mode and effects analysis (FMEA) is one of the most popular reliability analysis tools for identifying, assessing and eliminating potential failure modes in a wide range of industries. In general, failure modes in FMEA are evaluated and ranked through the risk priority number (RPN), which is obtained by the multiplication of crisp values of the risk factors, such as the occurrence (O), severity (S), and detection (D) of each failure mode. However, the crisp RPN method has been criticized to have several deficiencies. In this paper, results obtained with the FMEA method are checked, using a method from decision theory, respectively the ELECTRE method, both applied for prioritizing the failures that could appear in the functioning of Turn 55 CNC lathe. Two case studies have been shown to demonstrate the methodology thus developed. It is illustrated a parallel between the results obtained by the traditional method FMA and ELECTRE method for determining the potential failures with the highest risk of occurrence in order to prevent them. The results show that the proposed approach somewhat modifies the obtained results and leads to the conclusion that other developments of the two methods are necessary, using fuzzy sets for the accuracy of the results.

Keywords
preventive maintenance, FMEA method, ELECTRE method, CNC lathe

1. Introduction

In any industrial system, preventive maintenance has a particular importance for the optimal and continuous operation of the equipment. In these conditions, the early identification of parameters with abnormal values, before the appearance of defects, the timely remediation of the conditions that may lead to the appearance of incorrect values of system parameters and thus preventing some failures are recommended and even necessary. The use of the FMEA method to anticipate possible failures of a CNC machine tool and, at the same time, to prioritize the risks of possible failures is useful for machine building companies. The method, in its classic form, only offers a subjective evaluation, being necessary, for greater accuracy and objectivity, to complete and compare the obtained results with other techniques developed by decision theory.

2. Description of the Classical FMEA

Failure Mode and Effects Analysis (FMEA) is one of the first structured, systematic and proactive techniques used for failure analysis. It is a widely used engineering technique for defining, identifying and eliminating known and/or potential failures, problems, errors and so on from system, design, process, and/or service before they reach the customer [1]. For analyzing a specific product or system, a cross-functional expert team should be set up to conduct FMEA first.

The first step in FMEA is to identify all possible failure modes of the product or system. Next, critical analysis is performed on the identified failure modes taking into consideration the risk factors: severity (S), occurrence (O), and detection (D). Conventionally, the ranking of failure modes for corrective actions is determined in terms of the risk priority number (RPN), which is the mathematical product of the S, O and D corresponding to the failure modes [2]. That is RPN = S × O × D, where O is the probability of the failure, S is the severity of the failure, and D is the probability of not detecting the failure. In order to obtain the RPN of a potential failure mode, the traditional FMEA uses an integer scale from 1 to 10 for evaluating the three risk factors.

Generally, failure modes with higher RPN values are considered to be more important and are given higher priorities than those with lower RPN values [3]. However, it suffers from several shortcomings. It has been pointed out that the same RPN can be obtained from different combinations of different sets of S, O and D. Although the same RPN is obtained, the risk can be different and the relative importance of three risk factors is not taken into account. In other words, the risk factors are given to have the equal importance, which may not be the case in many practical applications of FMEA. The three risk factors are mostly difficult to be precisely determined. Much information in FMEA is often uncertain or vague and can be expressed by using linguistic terms such as *likely, important* or *very high* and so on [4, 5]. In order to overcome the above shortcomings, a number of approaches have been suggested in the literature to enhance the FMEA methodology, such as grey theory [6], data envelopment analysis (DEA) [7], decision making trial and evaluation laboratory (DEMATEL) [8].

3. Description of the ELECTRE Method

The ELECTRE method (Elimination et Choix Traduisant la Realité) appeared in 1965, when a group of French researchers from SEMA (Société d'économie et de mathématiques appliquées) laid the foundations for a ranking and choice method in the presence of points of multiple vision [9 - 11]. The method is used in solving decision-making problems that include a number of options V_i (i = 1, n) possible to achieve an objective, but also decision criteria C_j (j = 1, m) that influence the decision-making consequences of each option. The application of the method involves going through the following stages:

- **Stage 1**: establishing the decision options and the related consequences;
- **Stage 2**: for each variant and criterion the utilities are established, and the results are presented in the form of a matrix (Table 1);

Table 1. Utility matrix

V_i/C_j	C_1	C_2	....	C_j	....	C_m
V_1	U_{11}	U_{12}	....	U_{1j}	....	U_{1m}
V_2	U_{21}	U_{22}	....	U_{2j}	....	U_{2m}
.	.	.		.		.
.	.	.		.		.
V_n	U_{n1}	U_{n2}	....	U_{nj}	....	U_{nm}

In table 1, the notations represent:

C_j = criteria for conditioning the decisional consequences;

V_i = decision variants;

U_{ij} = utility of variant i, conditioned by criterion j.

- **Stage 3**: establishing the concordance indicators $C(V_g, V_h)$ between two variants. The relationship is used:

$$C(V_g, V_h) = \frac{\sum K_j}{K_1 + K_2 + \cdots + K_m} \tag{1}$$

where:

K_j (j = 1...m) – the importance coefficients of the considered criteria;

ΣK_j – the sum of the importance coefficients of the criteria for which the condition is met $U(V_g) \geq U(V_h)$.

- **Stage 4**: establishing discordance indicators $D(Vg, Vh)$, using the relationship (2). For $U(V_g) < U(V_h)$, α is the maximum difference between the maximum and the minimum utility.

$$D(V_g, V_h) = \begin{cases} 0, & if\ U(V_g) \geq U(V_h) \\ \frac{1}{\alpha} \cdot max\{U(V_g) - U(V_h)\} & \end{cases} \tag{2}$$

- **Stage 5**: determining the optimal variant. It takes place through successive operations of super classing the variants with the help of super classing relations of the form:

$$\begin{cases} C(V_g, V_h) \geq p \\ D(V_g, V_h) \leq q \end{cases}, \quad (3)$$

where p and q are thresholds, values between 0 and 1 (p is as close as possible to 1, q is as close as possible to 0). From the super class relations, a series of graphs $G(p, q)$ result from which the optimal variant is deduced. As p decreases and q increases, one obtains that variant that outclasses all others.

4. Establishing the Critical Failure Variant. Case Study for CNC Lathe

4.1. Classical FMEA application

In the first part of the study a classical application of Design FMEA has been realized for CNC lathe Turn 55. The Concept Turn 55 is a desktop lathe driven by interchangeable CNC control software running on a commercially available PC (Figure 1). This dual purpose turning center is the ideal solution for training students in further education when large industrial machines are not suitable. Its role in education is defined by its interchangeable control systems.

Fig. 1. The lathe Turn 55 [12]

The evaluation of the failure modes is carried out by scoring the respective risk factors of occurrence, severity, and detection. For this purpose, usually 10-level scales are being used. The failure modes with higher RPNs are assumed to be more important and will be given higher priorities for correction. It is presented the failure with highest RPN values (54 and 72). Some of the data can be seen in Table 2 [13].

Table 2. Conventional FMEA for a CNC lathe

Failure mode	Failure effect(s)	Cause(s)	S	O	D	RPN
F1. Wear of the mechanical components of tool machine	Poor quality of the surface of piece	C1. Overcoming life of the mechanic component	6	4	3	**72**
F2. Difficult processing (high energy consumption)	Deposition of material on the surface of the face of cutting tool	C2. Improper cutting regime	4	2	5	40
		C3.Electrical component can be damaged	4	2	3	24
F3. Incomplete execution of the CNC program	Nonconforming parts	C4. Writing error on NC program	7	3	2	42
F4. CNC stopping	Cutting tool collision	C5. Errors on NC program	8	2	1	16
		C6. Incorrect installation of the blank on CNC	8	1	2	16
F5. Erosion of date cable	Data from computer are not transmitted to the tool machine	C7. Life cycle overflow	6	3	3	**54**
F6. Power LED no indication	Cannot determine whether the machine is on or off	C8. Faulty supply	2	2	1	4

4.2. Classical ELECTRE application

- **Stage 1**: The selection criteria considered are the risk factors C_1: severity (S); C_2: occurrence (O), and C_3: detection (D)

Decision variants V_i are the eight potential faults that can occur on the CNC lathe (the variants V_j are the eight causes C_j specified in Table 2).

The consequences of the variants depending on the established criteria are presented in Table 3 and are the scores given by the specialists for calculating the RPN (Table 2). To determine the coefficients of importance K_j, a team of three specialists was formed: head of maintenance workshop, head of production section and CNC specialist. They awarded, for each consequence, a grade from 0-1 so: $K_1 = 0.5$; $K_2 = 0.3$, and $K_3 = 0.2$.

Table 3. The consequences of the variants for each criterion

	C_1 (S)	C_2 (O)	C_3 (D)
$V_1(C_1)$	6	4	3
$V_2(C_2)$	4	2	5
$V_3(C_3)$	4	2	3
$V_4(C_4)$	7	3	2
$V_5(C_5)$	8	2	1
$V_6(C_6)$	8	1	2
$V_7(C_7)$	6	3	3
$V_8(C_8)$	2	2	1

- **Stage 2**: Determination of the utility matrix

In this stage, the consequences of the variants for each criterion are expressed in the same unit of measure. According to utility theory, linear interpolation between extreme values is used, respectively the relationship

$$U_{ij} = \frac{a_{ij} - (a_j)_{u=0}}{(a_j)_{u=1} - (a_j)_{u=0}} \tag{4}$$

where:
- a_{ij} is the consequence of variant V_i depending on C_j;
- $(a_j)_{u=0}$ is the consequence of the unfavorable variant of criterion j;
- $(a_j)_{u=1}$ is the consequence of the favorable variant of criterion j.

The results are presented in the utility matrix, Table 4.

Table 4. Utilities matrix

	C_1	C_2	C_3
V_1	0.33	0	0.5
V_2	0.67	0.67	1
V_3	0.67	0.67	0.5
V_4	0.17	0.33	0.25
V_5	0	0.67	0
V_6	0	1	0.25
V_7	0.33	0.33	0.5
V_8	1	0.67	0

- **Stage 3:** Calculation of concordance indicators $C(V_g, V_h)$

The relation (1) is used for the calculation, and the results are listed in Table 5.

- ***Stage 4***: Calculation of discordance indicators $D(V_g, V_h)$.

The relation (2) is used for the calculation, and the results are presented in Table 6. It is taken into account that $\alpha = 1$.

Table 5. Matrix of concordance indicators $C(V_g, V_h)$

V_g \ V_h	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8
V_1		0	0.2	0.7	0.7	0.7	0.7	0.7
V_2	1		0.7	0.7	1	0.7	0.7	0.5
V_3	1	0.8		1	1	0.7	1	0.5
V_4	0.3	0.3	0.3		1	0.7	0.3	0.5
V_5	0.3	0.3	0	0		0.5	0	0.5
V_6	0.3	0.3	0.3	0.5	1		0.3	0.5
V_7	1	0.3	0.5	1	1	0.7		0.5
V_8	0.8	0.8	0.5	0.5	1	0.5	0.5	

Table 6. Matrix of discordance indicators $D(V_g, V_h)$

V_g \ V_h	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8
V_1		0.50	0.67	0.67	0.33	1	0.67	0.67
V_2	0		0.33	0.33	0	0.67	0.50	0.33
V_3	0	0.50		0	0	0.33	0	0.33
V_4	0.25	0.75	0.25		0	0.33	0.25	0.33
V_5	0.50	1	0.67	0.33		0.67	0.50	1
V_6	0.33	0.75	0.67	0.17	0		0.33	1
V_7	0	0.50	0.33	0	0	0.33		0.67
V_8	0.50	1	0.50	0.33	0	0.67	0.50	

- ***Stage 5:*** Choosing the best option

To choose the optimal variant, enter threshold values, $p{\sim}1$ and $q{\sim}0$ according to relation (3). For each pair of values (p, q), a graph $G(p, q)$ can be constructed that expresses the superclass relations introduced by the threshold values. Thus, for the pair $p = 0.8$ and $q = 0.2$, the graph in Figure 2 is obtained, which shows that variant V_3 is the one that outranks the others, followed by V_7, $C(V_g, V_h) \geq 0.8$ and $D(V_g, V_h) \leq 0.2$, so it is the optimal variants.

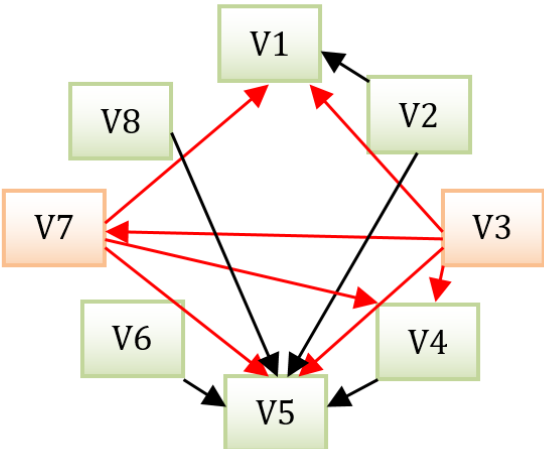

Fig.2 The graph of overranking

5. Conclusions

Although the FMEA method is easy to use, the calculated RPN coefficient does not indicate with great precision the potential risk that needs to be given maximum attention. Are taken into account the variants V_1 (RPN = 72) and V_7 (RPN = 54). After applying the ELECTRE method, it is found that there are two possible faults corresponding to variants V_3 and V_7 which must be given special importance. The ELECTRE method in the classical version has also a number of shortcomings, related to the subjectivity of the importance factor K, as well as the calculation method of the coefficients $C(V_g, V_h)$ and $D(V_g, V_h)$. A further development of research would be related to the use of fuzzy sets, both for the FMEA method and for ELECTRE. This approach will lead to an objective answer, but in practice the use of these concepts presents a high degree of difficulty and requires appropriate software.

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