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EVALUATING THE RISK OF FAILURE ON INJECTION PUMP USING FMEA METHOD COMPARATED WITH ELECTRE METHOD

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Abstract: *This research is aimed at utilizing failure mode and effect analysis (FMEA) which is a reliability analysis method applicable to Rotary Injection Pump design. In traditional FMEA, Risk Priority Number (RPN) ranking system is used to evaluate, the risk level of failures to rank failures and to prioritize actions. RPN is obtained by multiplying the scores of three risk factors like the Severity (S), Occurrence (O) and Detection (D) of each failure mode. RPN method can not emphasise the nature of the problem, which is multi-attributable and has a group of experts' opinions. Furthermore, attributes are subjective and have different importance levels.*
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 Rotary Injection Pump. 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: failure modes and effects, Rotary Injection Pump, risk evaluation, ELECTRE method.

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 R*otary Injection Pump* 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.

PRESENTATION OF THE METHODS USE

Description of the classical FMEA

Failure Mode and Effects Analysis (FMEA) is one of the most important quality methods used 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 is. FMEA stayed drawn up in sixties of the 20th century in the United States with the thought about the cosmic program Apollo. Next it was also used for the purposes of the automotive industry in requirements of the QS 9000 norm [1]. The major objective of application of FMEA is the identification of potential failure modes of the system components, evaluating their causes and their subsequent effects on the system behavior, and as a result determination of the ways to eliminate or reduce either the chances of occurrence or severity or increase the detectability of the particular failure mode [2]. The traditional FMEA determines the risk priority of each failure modes using the risk priority numbers (RPN), which can be obtained as a product of three risk factors namely Severity (S), Occurrence (O) and Detection (D). The RPN value for each failure mode is ranked to find out the failures with higher risks [3].

Several drawbacks of this crisp approach of calculating the RPN have been highlighted and it has been criticized by many authors. In [4, 5], the authors have criticized the fact that different combinations of the three risk parameters give rise to same RPN level which in reality may have very different risk implication altogether. Secondly, in [6, 7], the authors argued that it is very difficult for the experts to give precise numerical inputs for the three risk parameters as required in crisp model approach. Among the other drawbacks, another major drawback as pointed out by the authors in [5, 7] pointed out that the relative importance among the risk parameters are not taken into account while calculating the RPN value.

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 [8, 9, 10].

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_{n-1}	…….	C_m
V_1	U_{11}	U_{12}	………………	U_{1n-1}	…….	U_{1m}
V_2	U_{21}	U_{22}	………………	U_{2n-1}	…….	U_{2m}
.	.	.		.		.
.	.	.		.		.
V_n	U_{n1}	U_{n2}	………………	U_{nn-1}	…….	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:

$$C(\mathrm{V_g}, \mathrm{V_h}) = \frac{\sum \mathrm{k_j}}{\mathrm{k_1} + \mathrm{k_2} + \ldots + \mathrm{k_m}} \text{ , where:} \tag{1}$$

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.

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

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

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

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.

CASE STUDY FOR *ROTARY INJECTION PUMP (RIP)*. ESTABLISHING THE CRITICAL FAILURE VARIANT

Classical FMEA application

In the first part of the study a classical application of Design FMEA has been realized for *Rotary Injection Pump* product. An injection pump is the device that pumps fuel into the cylinders of a diesel engine. The injection pump with rotary distributor is characterized by a single pumping element that ensures the transmission of fuel under pressure to each individual injector.

Figure 1. The Rotary Injection Pump [11]

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 (63 and 140). Some of the data can be seen in Table 2 [12].

Table 2. Conventional FMEA for Rotary Injection Pump

Failure mode	Failure effect (s)	Cause (s)	S	O	D	RPN
F1. Underflow (< 48 mm^3/cycle)	The pump can not adjust in service (not provided nominal output)	C1. Overcoming life of the mechanic component	7	3	1	**21**
F2. Improper transfer pressure	**Engine interrupts, fumes (does not have advance)**	**C2. Discrepancy between the regulating valve bushing / spring**	**7**	**3**	**3**	**63**
F3. Improper injection pump feed	Engine running inadvertently	C3. Improper choice of advance device components (plug, cap, piston)	7	2	3	42

Failure mode	Failure effect (s)	Cause (s)	S	O	D	RPN
F4. Maximal idling speed smaller	Engine doesn't open up	C4. Improper choice of principal spring (spring too weak) or the number of weights	7	2	2	28
F5. Improper position of the driving sheave / pinion	The pump can not mount on the engine	C5. Improper position of the drive cone in relation to locating surface to the engine	8	3	2	48
F6. Transfer pressure below the lower threshold imposed	**Improper injection advance**	**C6. Uncontrolled delivering of the pump, as moment and quantity**	**7**	**5**	**4**	**140**
F7. Fuel not reaches into the combustion chamber	Engine is not running	C7. Improper tightness between injector and port injector	8	2	3	48

Classical ELECTRE application

- **Stage 1**:

The selection criteria considered are the risk factors:
C_1: severity (S);
C_2: occurrence (O);
C_3: detection (D).
Decision variants V_i are the eight ($C_1 \ldots C_7$) potential faults that can occur on the Rotary Injection Pump.
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 RIP specialist. They awarded, for each consequence, a grade from 0-1 so: K_1= 0,5; K_2= 0,3; 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)	7	3	1
V_2 (C_2)	7	3	3
V_3 (C_3)	7	2	3
V_4 (C_4)	7	2	2
V_5 (C_5)	8	3	2
V_6 (C_6)	7	5	4
V_7 (C_7)	8	2	3

- **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

$$U_{ij} = \frac{a_{ij} - (a_j)_{u=o}}{(a_j)_{u=1} - \left(a_j\right)_{u=0}}, \tag{5}$$

where:

- a_{ij} is the consequence of variant Vi depending on Cj;
- $(a_j)u=0$ 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	1	0,67	0
V_2	1	0,67	0,67
V_3	1	1	0,67
V_4	1	1	0,33
V_5	0	0,67	0,33
V_6	1	0	1
V_7	0	1	0,67

- **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.

Table 5. Matrix of concordance indicators C (Vg, Vh)

vh / vg	V_1	V_2	V_3	V_4	V_5	V_6	V_7
V_1		0,8	0,5	0,5	0,8	0,8	0,5
V_2	1		0,7	0,7	1	0,8	0,7
V_3	1	1		1	1	0,8	1
V_4	1	0,8	0,8		1	0,8	0,8
V_5	0,5	0,3	0	0.2		0,3	0,5
V_6	0,7	0,7	0,7	0,7	0,7		0,7
V_7	0.5	0,5	0,5	0,5	1	0,3	

- ***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 6. Matrix of discordance indicators D (V_g, V_h)

vh / vg	V_1	V_2	V_3	V_4	V_5	V_6	V_7
V_1		0,67	0,67	0,33	0,33	1	0,67
V_2	0		0,33	0,33	0	0,33	0,33
V_3	0	0		0	0	0,33	0
V_4	0	0,33	0,33		0	0,67	0,33
V_5	1	1	1	1		1	0,33
V_6	0,67	0,67	1	1	0,67		1
V_7	1	1	1	1	0	1	

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

To choose the optimal variant, enter threshold values, p~1 and q~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 = 0,9 and q = 0,1 the graph in Figure 2 is obtained, which shows that variant V_3 is the one that outranks the others, followed by V_2, $C(V_g, V_h) \geq$ 0,9 and $D\ (V_g, V_h) \leq$ 0,1 so it is the optimal variants.

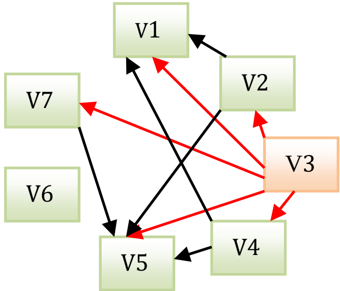

Figure 2. The graph of over ranking

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 V6 (RPN= 140) and V2 (RPN= 54). After applying the ELECTRE method, it is found that there are two possible faults corresponding to variants V3 and V2 which must be given special importance. And the ELECTRE method in the classical version has a number of shortcomings, related to the subjectivity of the K factor importance, 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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