Agricultural, Forest and Transport Machinery and Technologies (ISSN: 2367– 5888)
Volume VII – Issue 1, 2020

Variants of Solution and Evaluation of FMEA in Practice

Marian Bujna, Plamen Kangalov

Abstract: *Failure Mode and Effects Analysis (FMEA) is a model used to prioritize potential defects based on their severity, expected frequency, and likelihood of detection. An FMEA can be performed on a design or a process and is used to prompt actions to improve design or process. There is an uncertainty from manufacturers at present that the setting of criteria's of FMEA is subjective. There is another problem in determining the priority of resolving failure modes. The paper provides various options for prioritizing failure modes. At the same time, the individual methods specify the parameters for calculating the Risk priority number (RPN). We achieve objectification of criteria's for RPN calculation in FMEA. These are time-consuming and cost-effective designs. The proposed innovations are an extended RPN, including the creation of an extended FMEA and the use of the DEMATEL model.*

Keywords*: Risk management, FMEA, Objectivization of criteria, Extended FMEA, DEMATEL*

INTRODUCTION

Problems and defects are expensive. Customers understandably place high expectations on manufacturers and service providers to deliver quality and reliability (Polák et al., 2015; Prístavka et al., 2014, Korenko et al., 2015).

Often, faults in products and services are detected through extensive testing and predictive modeling in the later stages of development. However, finding a problem at this point in the cycle can add significant cost and delays to schedules. The challenge is to design in quality and reliability at the beginning of the process and ensure that defects never arise in the first place (Kotus et al., 2019; Girmanová et al., 2017; Žitňák et al., 2014).

Industries dealing with the production and maintenance of machines have to be reliable in order to meet the market demand and maintain integrity. To achieve reliability of the functional working machines, FMEA suggests a structured procedure for preventing failures or to reduce the effect of their consequences. FMEA is used in preventative activities for the most important maintenance planning. However, the high-risk components must be inspected and maintained frequently rather than components with a lower risk (Alrifaey M. et al. 2019).

The aim of the paper is to show different variations of the results of FMEA analyzes, the right prioritization before proposing actions. The second aim is to objectively determine the resulting RPN.

MATERIALS AND METHODS

1. To prepare the paper we used an example of a process with failures F1, F2, F3, F4 and F5.
2. Creation of a classical conventional FMEA.
   - Identification of causes, consequences and determining the method of control.
   - Determination of severity of consequences, occurrence of failures and detection - according to IATF 16 949: 2016.
   - Calculation of RPN – RPN = S.O.D

     Where: S -Severity, O – Occurrence, D - Detection.
3. Prioritization by RPN.
4. Prioritization by severity.
5. Creation of extended FMEA.
   - Include costs and calculate new parameters S, O, D.
   - Calculation of extended RPN.
   - Prioritization by extended RPN
6. Use of the DEMATEL method to specify severity.
   - Evaluation of the use of DEMATEL.

RESULTS AND DISCUSSION

Classical conventional process FMEA (PFMEA):

- the globally most widely used method for risk analysis in the production process,
- the aim is to define possible failures in relation to functional requirements, to estimate the probability of occurrence of the causes of failures and their detection and to take actions for the most significant risks,
- importance in quality management systems.

Table 1 *Basic information about process and failures*

Proces X	Failure	Nf	IFC [€]	WoC [€]
	F1	200	10	20
	F2	30	20	40
	F3	20	20	30
	F4	20	30	40
	F5	5	200	280

Where: Nf – number of failures, IFC – internal failure costs, WoC - no-casualty costs.

Creating a process FMEA. The occurrence is determined based on the number of causes of the failures. The severity is determined based on the consequence of the failure. The detection is determined based on the control method.

Table 2 *Conventional FMEA – prioritization by RPN*

Failure	Cl	Consequences	S	Causes	O	Current process	D	RPN	Cl
F1	I	Co1	2	Ca1	9	Cp1	5	90	I/II
F2	II	Co2	4	Ca2	3	Cp2	4	48	III
F3	III	Co3	4	Ca3	2	Cp3	5	40	IV/V
F4	IV	Co4	5	Ca4	2	Cp4	4	40	IV/V
F5	V	Co5	9	Ca5	2	Cp5	5	90	I/II

The classification based on the priority risk number is in the last column. This is a classic conventional evaluation based on RPN and the actions are taken according to the prioritization. The VDA approach is often focused on the severity of the failure consequence. The prioritization changes in this case as follows:

Table 3 *Conventional FMEA – prioritization by severity*

Failure	Cl	Consequences	S	Causes	O	Current process	D	RPN	Cl
F1	I	Co1	2	Ca1	9	Cp1	5	90	V
F2	II	Co2	4	Ca2	3	Cp2	4	48	III/IV
F3	III	Co3	4	Ca3	2	Cp3	5	40	III/IV
F4	IV	Co4	5	Ca4	2	Cp4	4	40	II
F5	V	Co5	9	Ca5	2	Cp5	5	90	I

Here we can already see that failure F5 will be solved first, but the priority of solving failure F1 has changed, because it has high occurrence despite the minor consequence. Some manufacturers consider RPN as a cosmetic number. What matters most is how important the consequence is.

Therefore, many practitioners require clarification of the individual FMEA criteria, as we can see the double interpretation brings uncertainty in serious decisions. Costs are very important for every manufacturer. If we include them in the FMEA, we can refine the determination of severity and thus reduce the subjectivity of the evaluation of these criteria. Nguen and Bujna are dealing with this (Nguyen et al., 2016; Bujna et al., 2019, Holota et al., 2016).

We can consider prevention costs, internal and external costs.Internal costs (IFC) were the costs of scrap, rework, retest, failure analysis, downtime and yield losses, etc. External costs (EFC) will not be considered in the study. They represent complaints to customers. If they existed, we would add them to the study. WoC represents "no-casualty costs" and are mainly in the form of complaints and handling these complaints. IFCs and WOCs are in Table 1.

then:

PO (occurrence probability of the mode) is based on the classical O (occurrence) parameter:

$$PO = \frac{O}{10} = \frac{9}{10} = 0{,}9 \qquad (1)$$

The PD (detection probability of the mode) is based on the conventional D (detection) parameter of the conventional PFMEA. In its determination there is already a significant difference compared to PFMEA. We calculate it according to the formula:

$$PD = \frac{(10 - D)}{9} = \frac{(10 - 5)}{9} = 0{,}56 \qquad (2)$$

For SI (severity level of internal failure costs), we start from already mentioned internal costs (IFC) and their share in the minimum costs of FC_{min} . It should be added that we are talking about the costs that make up the smallest entry of all costs (IC, EC, SC) for all failures listed in the PFMEA.

$$SI = \frac{IFC}{FC\,min} = \frac{10}{10} = 1{,}0 \qquad (3)$$

For SE (severity level of external failure costs), we start from the already mentioned external costs (EFC), in our case from WoC, and their share to the minimum costs of FC_{min}.

$$SE = \frac{WoC}{FC\,min} = \frac{20}{14} = 0{,}5 \qquad (4)$$

If we do not take into account the full external costs, we do not take into account the probability of a casualty caused = 0.

Final ERPN calculation for extended FMEA is calculated according to:

$$ERPN = PO.ST.[\,PD.SI + (1 - PD).(\,poc.SC + (1 - poc).SE\,)] \qquad (5)$$

$$ERPN = 0{,}9.2.[\,0{,}56.1{,}0 + (1 - 0{,}56).(0.0 + (1 - 0).0{,}5)] = 3{,}68$$

Table 4 *Extended FMEA*

Failure	Conventional FMEA - RPN						Extended FMEA - ERPN						
		S(ST)	**O**	**D**	**RPN**	**Cl.**	**PO**	**PD**	**SI**	**SE**	**poc**	**ERPN**	**Cl.**
F1	I	2	9	5	90	I/II	0.9	0.56	1	0.5	0	1.4	IV
F2	II	4	3	4	48	III	0.3	0.67	2	0.8	0	1.9	III
F3	III	4	2	5	40	IV/V	0.2	0.56	2	0.6	0	1.1	V
F4	IV	5	2	4	40	IV/V	0.2	0.67	3	0.8	0	2.3	II
F5	V	9	2	5	90	I/II	0.2	0.56	20	28	0	42.4	I

Benefits

- inclusion of the cost of materiality of the failure,
- objectification of the severity criteria,
- objectification of RPN,
- time, cost, and human capacity saving.

Another way to refine the results is to consider that one failure can cause multiple failures. Also, we mean that there is an interaction between the failures. One failure can cause several other failures. We can use various analyzes. As an example, I will use the DEMATEL matrix (Tsai et al, 2017; Bujna et al., 2019). In our study, failures 1 and 5 are independent of other failures, but there is a relationship between failures 2, 3 and 4. The intensity of relation is in Table 5.

Table 5 *Comparison square of the DEMATEL method*

Numeral	**Definition**
0	No influence
1	Low influence
2	Medium Influence
3	High influence
4	Very high influence

The team of experts involved in the creation of the FMEA assesses the interrelationships between failures (or causes of failures).

Table 6 *Step 1 - generating the direct-relation matrix (A)*

Index A	**F1**	**F2**	**F3**	**F4**	**F5**
F1	0	0	0	0	0
F2	0	0	3	3	0
F3	0	3	0	4	0
F4	0	4	4	0	0
F5	1	1	1	1	0

Calculating the normalized direct-relation matrix (N). Use the column vectors and maximum values as the baseline for normalization (k).

$$k = \frac{1}{max_{1 \le i \le n} \sum_{j=1}^{n} x_{ij}} \tag{6}$$

$$N = k.A \tag{7}$$

Table 7 *Use the column vectors and maximum values as the baseline for normalization*

ΣN$_i$	**ΣN$_{ij}$**	**A**
0	8	0.125
6		
7		
8		
4		

Table 8 *Step 2 - Normalized direct-relation matrix N*

Index N	**F1**	**F2**	**F3**	**F4**	**F5**
F1	0	0	0	0	0
F2	0	0	0.375	0.375	0
F3	0	0.375	0	0.5	0
F4	0	0.5	0.5	0	0
F5	0.125	0.125	0.125	0.125	0

We calculate the total relation matrix T. Matrix T is an n $_x$ n matrix and it is calculated as follows:

$$T = \lim_{n \to \infty} (N + N^2 + ... + N^k) = N.(1 - N) \tag{8}$$

where I represent the identity matrix.

Table 9 *Step 3 - Calculate the total-relation matrix*

Index N	F1	F2	F3	F4	F5
F1	0	0	0	0	0
F2	0	1.9091	2.1818	2.1818	0
F3	0	2.4242	2.1515	2.4848	0
F4	0	2.6667	2.6667	2,3333	0
F5	0.1250	1	1	1	0

We calculate the values in each row and column. We sum the values in each row and column in the total-relation matrix (T). We let D_i be the sum of the i-th column and R_{jj} be the sum of the j-th row. Thus, the D_i and R_i values comprise both indirect and direct influences.

$$D_i = \sum_{j=1}^{n} t_{ij} (i+1,2,...,n) \quad (9)$$

$$R_i = \sum_{j=1}^{n} t_{ij} (i+1,2,...,n) \quad (10)$$

Table 10 *Summary of the prominence and relation*

D	**R**	**D+R**	**D-R**
0	0.1250	1.1250	-0.1250
6.2727	8	14.2727	-1.7273
7.0605	8	15.0605	-0.9395
5.3334	5.6666	11	0.3332
3.1250	0	3.1250	3.1250
Average		8.92	0.13

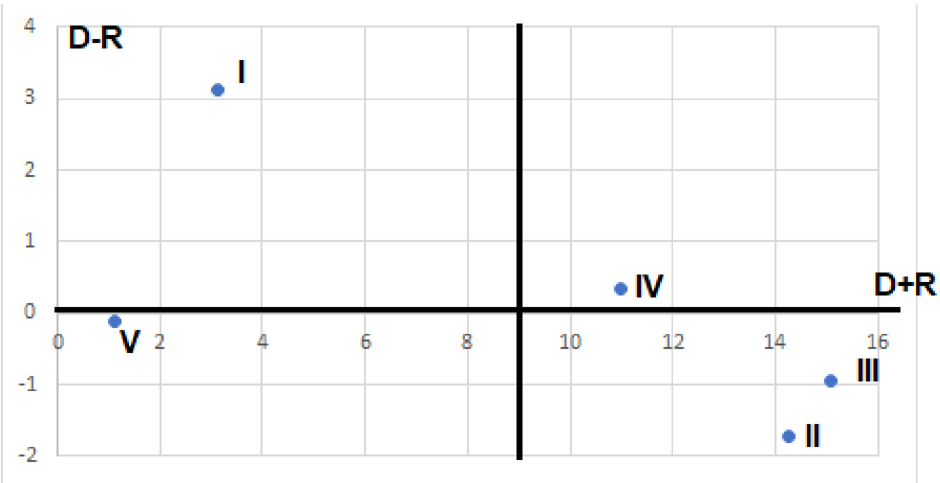

Fig. 1 Relational diagram

The division of causes of failures according to their significance:

1. High prominence and high relation. Failure F4 is the actuating factors for solving problems.
2. Low prominence and high relation. Failure F1 is relatively independent.
3. Low prominence and low relation. Failure F5 is relatively independent.
4. High prominence and low relation. Failures F2 and F3 are effect factors, and thus they cannot be directly improved.

DEMATEL's results showed the need to include these results in determining the severity category S, as DEMATEL determined three errors of similar severity F2, F3 and F4 with different meanings.

CONCLUSION

The conventional FMEA method has several shortcomings. For instance, the severity (S), occurrence (O), and detection (D) indicators are discrete ordinal scales of measure; the calculation by multiplication is inappropriate and it ignores the relative importance between S, O, and D and assumes that they are assigned equal weight, which might not be true in practice. (Chang, Cheng, 2011).

Therefore, the aim of the paper was to point out the possibility of specifying individual indicators. The paper shows various variations of the solution to this problem.

Applying the extended FMEA analysis offers a refinement of the results of the conventional PFMEA, which has a significant effect on improving the quality of the resulting products, time savings, improving overall safety and, last but not least, reducing operating costs. We will mainly achieve the objectification of parameters for the creation of extended RPN.

Applying the DEMATEL model will provide us with an overview of binding identified failures through their bonds. Failures are sorted by their bindings to other failures in the prioritization of whether they affect other failures more in proportion to how they are influenced by other failures.

REFERENCES

[1] Alrifaey, M., Hong, T., Supeni E., et al. (2019) Identification and Prioritization of Risk Factors in an Electrical Generator Based on the Hybrid FMEA Framework. February 2019. Energies 12(4):649. DO - 10.3390/EN12040649.

[2] Bujna, M., Kiełbasa, P., (2019) Objectification of fmea method parameters and their implementation on production engineering. In 7thTAE2019. Trends in agricultural engineering 2019. Praha: Česká zemědělská univerzita, 2019, s. 75--80. ISBN 978-80-213-2953-9

[3] Bujna, M., Kotus, M., Matušeková, E., (2019) Using the DEMATEL model for the FMEA risk analysis. Cz OTO 2019, 1(1),550-557. SCIENDO

[4] Chang, K., Cheng, C., (2011) Evaluating the risk of failure using the fuzzy OWA and DEMATEL method. J Intell Manuf, 22 (2) (2011), pp. 113-129. DO - 10.1007/s10845-009-0266-x.

[5] Girmanová, L., Šolc, M., Kliment, J., et al. (2017) Application of Six Sigma Using DMAIC Methodology in the Process of Product Quality Control in Metallurgical Opeeration. Acta Technologica Agriculturae.20(4). 104-109.

[6] Holota T., Hrubec J., Kotus M., et al. (2016) The management of quality costs analysis model. Ser-bian journal of management. 11(1),119-127.ISSN 1452-4864.

[7] Korenko, M., et al. (2015) Risk analysis at work in manufacturing organization. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis,63(5), 1493-1497.

[8] Kotus, M., Drlička, R., Mikuš, R., Žarnovský, J., (2019) Hazard analysis and risk assessment in metal cutting process. In MAPE - Multidisciplinary aspects of production engineering. Part 1. Zabrze: Wydawnictwo Panova, 2019, s. 382--391. ISBN 978-3-11-067482-8 (brož.).

[9] Polák, P., Prístavka, M., Kollárová, K. (2015) Evaluating the effectiveness of pro-duction process using pareto analysis. Acta technologica agriculturae. 18(1)18-21. ISSN 1335-2555.

[10] Prístavka, M., Beloev, H., Kročko, V. (2014) Quality control in production processes. Angel Kanchev University of Ruse, Bulgaria.

[11] Prístavka, M., Beloev, H., (2015). Engineering of Products Quality. 1. vyd., Ruse: Angel Kanchev University of Ruse, 2015. 186s . ISBN 978-954-712-655-8

[12] Nguyen, T., Shu, M., Hsu, B., (2016) Extended FMEA for sustainable manufacturing: An empirical study in the non-woven fabrics industry. Sustainability, 8(9), 939
[13] Tsai, S., Zhou, J., Gao, Y., et al. (2017) Combining FMEA with DEMATEL models to solve production process problems. Deng Y, ed. PLoS ONE. 2017. 12(8):e0183634. doi:10.1371/journal.pone.0183634.
[14] Žitňák, M., Macák, M., Korenko, M., (2014) Assessment of risks in implementing automated satellite navigation systems.Research in agricultural engineering. 60, 16-24.

CONTACT

Marián Bujna, Department of Quality and Engineering Technologies, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic, marian.bujna@uniag.sk

Plamen Kangalov, Department of Repair and Reliability, Agrarian and Industrial Faculty, University of Ruse, 8, Studentska Str., 7017 Ruse, Bulgaria, e-mail: kangalov@uni-ruse.bg