OBJECTIFICATION OF FMEA METHOD PARAMETERS AND THEIR IMPLEMENTATION ON PRODUCTION ENGINEERING

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Abstract
We applied the conventional PFMEA (process Failure mode and effect analysis) and identified the RPN risk number on production engineering (the work process on the lathe). Then we added the costs of failures to the method and applied Extended FMEA. After determining the costs and calculations, we identified the ERPN (extended risk priority number). We compared the individual methods and we also compared the proportion of failures in total risk generation (RPN - ERPN). We proposed an action. Finally, we evaluated the applicability of individual methods and models. The ERPN, in contrast to the conventional PFMEA, specifies the risk number. After including the costs necessary for elimination of the failures and costs arising from failures, we have obtained another risk prioritization. The use of the economic effect of the FMEA brings not only an increase in the quality and reduction of defective products, but also the influence of the financial costs on the creation of the risk number.

Key words: *PFMEA; extended risk number; increase quality; economic aspect, suggested action.*

INTRODUCTION

An FMEA (Failure mode and effect analysis) is an engineering analysis done by a cross-functional team of subject matter experts that thoroughly analyses product designs or manufacturing processes, early in the product development process. Its objective is finding and correcting weaknesses before the product gets into the hands of the customer. (*Jankajová, Kotus, Holota & Zach, 2016; Žitňák, Macák, & Korenko, 2014; Tsai, Zhou, Gao, 2017*).

FMEA being the most widely used risk assessment method in Slovakia and globally in the world, is a part of quality improvement models and methods. Therefore, our findings are used in most manufacturing organizations to improve processes. We can say that the presented methodology, even without modifications, can be used (*Korenko, Földešiová & Beloev, 2015; Girmanová, Šolc, Kliment, Divoková & Mikloš 2017).*

Applying the EFMEA (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 (less downtime due to malfunctions or failures and subsequent repairs), improving overall safety and, last but not least, reducing operating costs (*Nguyen, Shu, & Shu, 2016; Holota, Hrubec, Kotus, Holienčinová & Čapošová, 2016; Polák, Prístavka & Kollárová, 2015).*

The aim of the paper is to objectivising criteria of FMEA (Failure Mode and Effect Analysis) and consequently their application within our study. The used manufacturing process is the Doosan V-Puma Doom PUMA V550R.

MATERIALS AND METHODS

In this paper, we focused on the risk analysis of the Doosan PUMA V550R lathe (tab. 1).

The component used in brakes in the automotive industry consists of the following processes: preparation of base material, turning (diameters, thickness, grooves), milling, hole drilling, finishing operations, packaging. Our task was to evaluate the production process itself.

The analysis of the work on this lathe was chosen based on the need to reduce the number of defective products. In this post we focused only on turning diameters.

The Doosan Lathe is designed for treating material and performing operations such as:

- external turning - removal of material from the outer surface of the workpiece,
- internal turning - removal of material from the inner surface of the workpiece,
- threading - removal of material from the workpiece surface to form a thread.

Tab. 1 Doosan lathe technical specifications

Manufacturer	**Doosan Infracore CO., LTD Korea**	Spindle speed	20 - 20 000 RPM
Model type	PUMA V550R	X axis travel	390 mm
Serial No	MT0013-001161	Y axis travel	780 mm
Year	2011	Rapid traverse rates X,Y	12/16 m/min
Power	50.04 kW	Turret	8 positions
Chuck - average	450 mm	Machine weight	ca 9000kg

Basic methodology:

- application of the conventional FMEA process method,
- application of the extended FMEA,
- comparison of the FMEA methods and models and making conclusions.

The minimized steps of applying conventional process FMEA *(IEC 60812:2006)*:

1. Review the process
2. Brainstorm potential failure modes (tab. 3)
3. List potential effects of each failure (tab.3)
4. Determination of failure causes for each single failure (tab. 3)
5. Assign Severity, Occurrence and Detection rankings (tab. 5)
6. Calculate the RPN =Severity x Occurrence x Detection (tab. 5)
7. Take action (tab. 5)

Tab. 2 Minimized rating of severity, occurrence and detection *(IEC 60812:2006)*

No.	**Aspect**	**1**	**Rating Values -------->**	**10**
1.	Severity	insignificant	-------->	catastrophic
2.	Occurrence	extremely unlikely	-------->	inevitable
3.	Detection	absolutely certain to detect	-------->	no control exists

The steps of ERPN *(Nguyen, Shu, & Shu, 2016).*

1. After we create a PFMEA, we determine - internal failure costs (IFC) - IFC are the costs of scrap, rework, retest, failure analysis, downtime and yield losses, etc.
2. We determine external failure costs (EFC) - as a part of external costs (EFC), we consider cost-free costs; it means a part called WoC – without-casualty costs or CC – casualty costs. This includes the costs of handling complaints from customers that have occurred in almost all cases of failures and are included in this study.
3. We calculate the occurrence probability of the mode – PO (1). PO is based on the classical O (occurrence) parameter and is calculated according to:
$$PO = \frac{O}{10} \quad (1)$$
4. We calculate the detection probability of the mode – PD (2). The PD is based on the conventional D (detection) parameter of the conventional PFMEA.
$$PD = \frac{(10-D)}{9} \quad (2)$$
5. We calculate SI (3)- severity level from an economic perspective in internally dealing with the mode; thus, it closely relates to so-called "internal failure costs IFC".
$$SI = \frac{IFC}{FCmin} \quad (3)$$
FC_{min} - minimum costs by all failures and causes.
6. We calculate SE (4)- severity level from an economic perspective in externally dealing with the

mode.

$$SE = \frac{WoC}{FCmin} \quad (4)$$

7. We calculate SC (5)- severity level of the external failure costs. We place this point in the procedure only if we consider casualty costs – CC.

$$SC = \frac{CC}{FCmin} \quad (5)$$

8. We determine poc - probability of a casualty caused. The *poc* is either 0 at WoC costs and 1 at CC costs, as there is a breakdown on the machine and a break in the process.
9. Final ERPN (6) calculation for the extended FMEA is calculated according to:

$$ERPN = PO.ST.[PD.SI + (1 - PD).(poc.SC + (1 - poc).SE)] \quad (6)$$

10. All parameters (according to procedure 1-9) will be included into the table 4 and 5.
11. We make conclusions and compare the RPN calculated for the conventional PFMEA with the calculated ERPN (fig. 1).

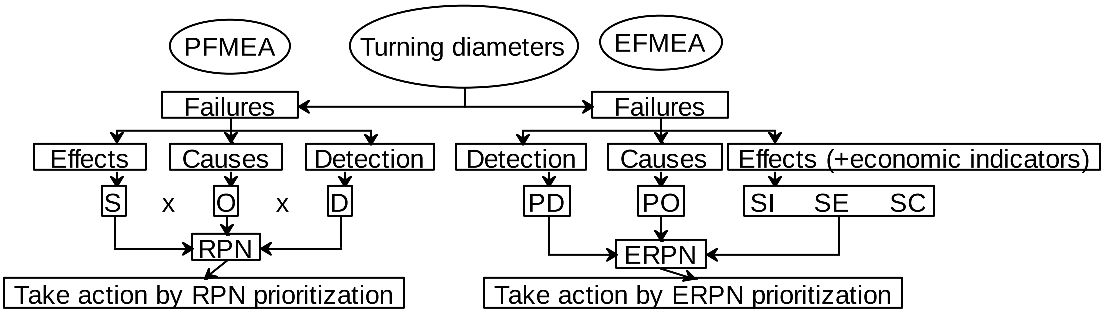

Fig. 1 The steps of PFMEA and EFMEA

RESULTS AND DISCUSSION

When FMEA is applied to a manufacturing process, this procedure is known in industry as the Process FMEA, or PFMEA *(IEC 60812:2006)*.

Based on methodology steps for process FMEA and ERPN we create the table 3, 4 and 5.

Tab. 3 Minimized conventional PFMEA for Operation – Turning diameters *(Bujna, Kotus & Matušeková, 2019)*

Failure	Effects	Causes	Suggested action
Outside diameter is below the tolerance issue	Parts are out of tolerance Customer complaint	Too high feed rate	Set according to the cover sheet
Outside diameter is above the tolerance issue	Customer complaint Scrap Unmountable parts Termination of contract due to frequent complaints	Too low feed rate	Set according to the cover sheet
Inside diameter is below tolerance	Customer complaint Scrap Unmountable parts Termination of contract due to frequent complaints	Cutting blade is worn out	Replace worn out cutting blade. Replace supplier
Inside diameter is above tolerance	Customer complaint Parts are outside specification	Incorrectly chosen measurement method or measurement device	Choose the right measurement method and measuring device
Pitch diameter is below tolerance	Customer complaint Parts are outside specification	Infeed turned off late	Set according to the cover sheet

Thickness of the pitch is above the tolerance	Customer complaint Parts are outside specification	Cutting blade is worn out	Replace worn out cutting blade
Chamfer of the piston ring ID/OD	Rework	The use of manual chamfering	Complete a cover sheet
Concentricity is too high	Customer complaint Parts outside specification	Incorrect measurement methodology	Continuous measurement of units
Pitch radius is too large	Customer complaint Parts are outside specification	Incorrectly selected cutting blade	Set according to the cover sheet
Incorrect chamfer width	Customer complaint Parts are outside specification	Incorrectly set in-feed	Set according to the cover sheet
Roughness height	Customer complaint Parts are outside specification	Feed too high	Set according to the cover sheet
Unturned outer diameter	Rework	Skipped operation	Retrain staff

Tab. 4 Preparatory table for ERPN calculation for operation Turning diameters

Failure	**IFC**	**WOC**
Outside diameter is below the tolerance issue	50	110
Outside diameter is above the tolerance issue	105	150
Inside diameter is below tolerance	50	160
Inside diameter is above tolerance	90	110
Pitch diameter is below tolerance	56	110
Thickness of the pitch is above the tolerance	73	110
Chamfer of the piston ring ID/OD	74	140
Concentricity is too high	80	110
Pitch radius is too large	90	110
Incorrect chamfer width	86	110
Roughness height	40	100
Unturned outer diameter	50	140

In the tab. 4 we determined the costs that arise as a result of the Turning diameters operation. Internal costs (IFC) were the costs of scrap, rework, retest, failure analysis, downtime and yield losses, etc. As a part of external costs (EFC), we considered cost-free costs; it means a part called WoC - without-casualty costs. This includes the costs of handling complaints from customers that occurred in almost all cases of failures and are included in this study.

Example for the first line of tab.4:

IFC – by the first failure we assume that the component could be reworked, so no major damage occurs, only the costs for the re-make and a certain time loss – the quantified amount - 50, - €.

FC_{min} – we recorded minimum costs by failure "Roughness height" - 40, - €. FC_{min} is also used to calculate SI (severity level of internal failure costs), SE (severity level of external failure costs), and SC (severity of external fatalities by fatal losses).

WoC represents "no-casualty costs" and are mainly in the form of complaints and handling these complaints. In our study they were of 110, - €.

Tab. 5 Extended FMEA – the determination of ERPN for operation Turning diameters

Failure	Conventional PFMEA - RPN					Extended FMEA - ERPN						
	S(ST)	**O**	**D**	**RPN**	**Cl.**	**PO**	**PD**	**SI**	**SE**	**poc**	**ERPN**	**Cl.**
Outside diameter is below the tolerance issue	7	3	4	84	5/6	0.3	0.667	1.25	2.75	0	3.68	8
Outside diameter is above the tolerance issue	9	3	4	108	3	0.3	0.667	2.63	3.75	0	8.10	3
Inside diameter is below tolerance	9	7	2	126	2	0.7	0.889	1.25	4	0	9.80	1
Inside diameter is above tolerance	7	3	2	42	10	0.3	0.889	2.25	2.75	0	4.84	6
Pitch diameter is below tolerance	7	3	5	105	4	0.3	0.556	1.4	2.75	0	4.20	7
Thickness of the pitch is above the tolerance	7	5	2	70	7	0.5	0.889	1.83	2.75	0	6.75	4
Chamfer of the piston ring ID/OD	4	2	6	48	8/9	0.2	0.444	1.85	3.5	0	2.21	12
Concentricity is too high	6	4	2	48	8/9	0.4	0.889	2	2.75	0	5.00	5
Pitch radius is too large	7	2	1	14	12	0.2	1.000	2.25	2.75	0	3.15	9/10
Incorrect chamfer width	7	5	5	175	1	0.5	0.556	2.15	2.75	0	8.46	2
Roughness height	7	3	4	84	5/6	0.3	0.667	1	2.5	0	3.15	9/10
Unturned outer diameter	4	2	2	16	11	0.2	0.889	1.25	3.5	0	1.20	11

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

Based on Tab. 5 (it's just part of the whole study) we can say the following conclusions. After the ERPN was determined, we obtained different results than when determining the classical RPN. Importantly, the proportion of individual failures in the overall risk figure was significantly different. As described in the methodology section, the main objective was to reduce the number of defective products in the turning process, where there was the greatest loss in the production. After the introduction of conventional PFMEA, the percentage of defective products decreased from 5.2% to 3.72%. The organization's management was still dissatisfied. We decided to apply an extended FMEA (EFMEA) after a thorough study. EFMEA has only been tested in one particular case in China. Although the application of the EMFEA lasts longer, after a number of staffs training it is a minimum of time losses. It's important to say that by different failures prioritization by ERPN, we focused on suggesting and applying action to failures that were with lower priority solutions by conventional PFMEA.

Benefits of EFMEA:

- Reduction of defective products below 2.5%,
- inclusion of costs in the analysis - an overview of the financial losses for each product failure (defect),
- large use of analysis results,
- significantly reducing of scrap, reworks …,
- increasing operation efficiency.

CONCLUSIONS

Why have we dealt with the ERPN? However, the conventional approach fails to provide satisfactory explanation of the aggregate effects of a failure from different perspectives such as technical severity, economic severity, and production capacity in some practical applications. This can be explained by the fact that the ERPN considers the severity of failures from not only a technical perspective but also an economic one including internal and external costs for any failures undetected before the products are delivered to customers.

Extended FMEA offers an efficient and effective identification of key failure modes. From them, we can easily deduce the root causes and propose corrective measures to reduce the ERPN, there-by minimizing the impact of the failures, or completely eliminating them. Appropriately designed and applied measures increase our production productivity, do not interrupt it and thus do not increase costs. The low failure rate of the processes not only significantly decreases the waste of related resources in terms of materials, labour, and time, thereby reducing the overall cost of the manufacturing operations, but also assures the production capacity and quality of the products, which are actually the key factors for the sustainable survival and development of an industrial manufacturer in the fierce competition market these days. There are several answers why - delivering the product to customers within a specified time, expected product quality, customer confidence, competitiveness.
The benefits of EFMEA are described in the work of Nguyen (*Nguyen, Shu & Shu, 2016*). The performance of their extended index ERPN was tested in an empirical case at a non-woven fabric's manufacturer. Analytical results indicated that the proposed approach (EFMEA - ERPN) outperforms the traditional one (PFMEA - RPN) and remarkably reduces the percentage of defective fabrics from about 2.41% before the trial period to 1.13%, thus significantly reducing wastes and increasing operation efficiency, thereby providing valuable advantages to improve organizational competition power for their sustainable growth.
This study is for the management of engineering technology organizations a sign that the organization prospers.

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