USING THE DEMATEL MODEL FOR THE FMEA RISK ANALYSIS

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Abstract: Technological progress has brought a large amount of complex machinery into the work processes, which represents a potential source of serious injuries, accidents, or breakdowns. The aim of this paper is to follow new trends in the FMEA and their use in our study. We have chosen the Turning Machine Doosan V-Puma Doosan PUMA V550R Machining Centre with manufacturing diameters and mechanical machining operations. We have created the FMEA team, which participated in the entire evaluation and analysis. We identified possible failures and causes of failures in the given operations. We applied the conventional PFMEA and identified the RPN risk number. We also used DEMATEL model. Using DEMATEL matrices, we identified a binding between the individual failures and the causes of the failures. Some failures will become the main cause of other failures and the causes of the failures; some arise as a result of other failures or causes of failures. Finally, we evaluated the applicability of individual methods and models. By the DEMATEL model we clarified the significance and bindings between individual failures.
Keywords: safety, risk management, work process, quality production

1. INTRODUCTION

A risk assessment is not only an important step in ensuring a safe and healthy work environment, it is a legal requirement. It needs to be conducted before employee's complete work on current, new or unknown parts, processes or materials. We must consider the possible causes of harm and what steps to take in preventing the harm in the first place. If our business has fewer than 5 employees, you don't have to document anything, but you must have considered hazards and control measures (Korenko et al., 2015; Prístavka et al., 2014; Tureková, 2016; Knop et al., 2018)
Failure Modes and Effects Analysis (FMEA) is methodology for analyzing potential reliability problems early in the development cycle where it is easier to take actions to overcome these issues, thereby enhancing reliability through design. FMEA is used to

identify potential failure modes, determine their effect on the operation of the product, and identify actions to mitigate the failures. A crucial step is anticipating what might go wrong with a product. While anticipating every failure mode is not possible, the development team should formulate as extensive a list of potential failure modes as possible (Bujna and Beloev, 2015; Girmanová et al., 2017; Žitňák et al., 2014)

DEMATEL ((Decision-Making Trial and Evaluation Laboratory) clarifies the complex relationships between factors and provides solutions by com- paring these factors in the system, using matrix operations to calculate the direct and indirect causal relationships and extent of influence, and quantifying the extent of mutual influence between factors (Tsai S-B. et al., 2017).

2. METHODOLOGY OF RESEARCH

In the monograph, we focused on the risk analysis of the Doosan PUMA V550R lathe. Applying the conventional FMEA process method:

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

Table 1

Rating of severity, occurrence and detection

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

Source: (Nguyen et al., 2016)

The calculation procedures of DEMATEL can be summarized into the following steps (Tsai et al., 2017; Chen et al., 2016; Deng et al., 2014; Luthra et al., 2016;):

1. Establishing the measurement scale and determining the causal relationships List and define the various factors involved in a complex system through a literature review, brainstorming session, or expert survey. Design a scale to demonstrate the extent of influence of these factors and employ pair-wise comparison to elucidate the causal relationships between the factors.
2. Establishing a direct-relation matrix

$$x = \begin{bmatrix} 0 & x_{12} & \Lambda & x_{1n} \\ M & 0 & \Lambda & M \\ M & M & O & M \\ x_{n1} & x_{n2} & \Lambda & 0 \end{bmatrix} \qquad (1)$$

We determine the presence and extent of influence relationships between the factors. We use the results to create a direct-relation matrix, where values in the matrix represent the extent of influence between the factors. Set the values on the diagonal line in the matrix to zero.

3. Calculating the normalized direct-relation matrix
   Use the column vectors and maximum values as the baseline for normalization.

$$\lambda = \frac{1}{\max_{1 \le i \le n} \sum_{j=1}^{n} x_{ij}} \tag{2}$$

$$N = \lambda \cdot X \tag{3}$$

4. Calculating the direct/indirect-relation matrix (T) or the total-relation matrix:

$$T = \lim_{n \to \infty}(N + N^2 + .. + N^k) = N \cdot (1 - N) \tag{4}$$

where I represent the identity matrix.
5. Calculating the values in each row and column
Sum the values in each row and column in the total-relation matrix (T). 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.

$$D_i = \sum_{j=1}^{n} t_{ij(} \, (i = 1,2,...,n \tag{5}$$

$$R_i = \sum_{j=1}^{n} t_{ij(} \, (i = 1,2,...,n \tag{6}$$

6. Illustrating the DEMATEL cause-and-effect diagram
Attribute k is either a cause or effect attribute when $(D_k - R_k)$ is a positive or negative value. The size of the $(D_k + R_k)$ represents the extent of the attribute's cause or effect. Based on the coordinates in $(D_k + R_k)$ and $(D_k - R_k)$, k can be categorized into four categories:
   1. Positive $(D_k - R_k)$ and large $(D_k + R_k)$ values: k is a cause factor and an actuating factor for solving the problem.
   2. Positive $(D_k - R_k)$ and small $(D_k + R_k)$ values: k is an independent factor and influences only a small number of other factors.
   3. Negative $(D_k - R_k)$ and small $(D_k + R_k)$ values: k is an independent factor and is influenced by only a small number of factors.
   4. Negative $(D_k - R_k)$ and large $(D_k + R_k)$ values: k is a core problem that requires resolution. However, it is an effect attribute, and thus it cannot be directly improved.
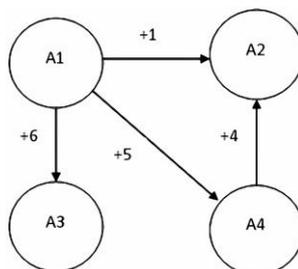
Fig. 1 Relationship by DEMATEL (Tsai et al., 2017)

3. RESULTS

During turning, in terms of turning the diameter of a given component, we identified twelve defects, where we determined the consequences and causes of these defects (tab. 2).

Table 2
PFMEA for Operation – Turning diameters

Failure	Consequences	S	Causes	O	D	RPN
Outside diameter is below the tolerance issue	Parts are out of tolerance Customer complaint	7	Too high feed rate	3	4	**84**
Outside diameter is above the tolerance issue	Customer complaint Scrap Unmountable parts Termination of contract due to frequent complaints	9	Too low feed rate	3	4	**108**
Inside diameter is below tolerance	Customer complaint Waste Unmountable parts Termination of contract due to frequent complaints	9	Cutting blade is worn out	7	2	**126**
Inside diameter is above tolerance	Customer complaint Parts are outside specification	7	Incorrectly chosen measurement method or measurement device	3	2	**42**
Pitch diameter is below tolerance	Customer complaint Parts are outside specification	7	Infeed turned off late	3	5	**105**
Thickness of the pitch is above the tolerance	Customer complaint Parts are outside specification	7	Cutting blade is worn out	5	2	**70**
Chamfer of the piston ring ID/OD	Rework	4	The use of manual chamfering	2	6	**36**
Concentricity is too high	Customer complaint Parts outside specification	6	Incorrect measurement methodology	4	2	**24**
Pitch radius is too large	Customer complaint Parts are outside specification	7	Incorrectly selected cutting blade	2	1	**14**
Incorrect chamfer width	Customer complaint Parts are outside specification	7	Incorrectly set infeed	5	5	**175**
Roughness height	Customer complaint Parts are outside specification	7	Feed too high	3	4	**84**
Unturned outer diameter	Rework	4	Skipped operation	2	2	**16**

Suggested actions for failures:

1., 2., 5., 9., 10., 11. Set according to the cover sheet

3. Replace worn out cutting blade. Replace supplier

4. Choose the right measurement method and measuring device

6. Replace worn out cutting blade

7. Complete a cover sheet

8. Continuous measurement of units

12. Retrain staff

Table 4
Initial direct-relation matrix X for operation 1

Index X	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
I	0	0	4.5	0	1.8	4.5	0	1.8	0	5	5.4	0
II	0	0	1.5	0	0	1.5	1	1.8	0	5	0	0
III	4.2	1.8	0	2	0	5.4	4.2	2	4	1	1.8	0
IV	0.6	0.6	3.5	0	0	3.5	4.2	5.4	4.2	4.5	0.6	2.1
V	4.2	0	3.1	0	0	0.7	1.2	3.6	2.7	3.5	4.2	0
VI	4.2	1.8	5.4	2	0	0	4.2	2	4	1	2.5	0
VII	1.9	0.7	0	0	1.3	0	0	0	0	0.3	1.9	1.7
VIII	0.6	0.6	3.5	4	0	3.5	4.2	0	4.2	4.5	0.6	0
IX	4.8	2.3	3.1	5.2	0	5.8	3.2	5.2	0	3	4.8	0
X	3	3	3.7	0	1.9	4.5	0	1.9	0	0	3	0
XI	5.4	0	4.5	0	1.8	4.5	0	1.8	0	5	0	0
XII	0	0	0	5.2	0	0	0.2	4.8	0	0	0	0

Table 5
Use the column vectors and maximum values as the baseline for normalization

Σxi (1)	23	10.8	26.4	29.2	23.2	27.1	7.8	25.7	37.4	21	23	10.2
Σxij	37.4											
λ (2)	0.026738											

Example for the first row and the third column:

$$N = \lambda \cdot X = 0.027 \cdot 4,5 \cong 0.12 \qquad (7)$$

Table 6
Normalized direct-relation matrix N

Index N (3)	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
I	0.00	0.00	0.12	0.00	0.05	0.12	0.00	0.05	0.00	0.13	0.14	0.00
II	0.00	0.00	0.04	0.00	0.00	0.04	0.03	0.05	0.00	0.13	0.00	0.00
III	0.11	0.05	0.00	0.05	0.00	0.14	0.11	0.05	0.11	0.03	0.05	0.00
IV	0.02	0.02	0.09	0.00	0.00	0.09	0.11	0.14	0.11	0.12	0.02	0.06
V	0.11	0.00	0.08	0.00	0.00	0.02	0.03	0.10	0.07	0.09	0.11	0.00
VI	0.11	0.05	0.14	0.05	0.00	0.00	0.11	0.05	0.11	0.03	0.07	0.00
VII	0.05	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.05	0.05
VIII	0.02	0.02	0.09	0.11	0.00	0.09	0.11	0.00	0.11	0.12	0.02	0.00
IX	0.13	0.06	0.08	0.14	0.00	0.16	0.09	0.14	0.00	0.08	0.13	0.00
X	0.08	0.08	0.10	0.00	0.05	0.12	0.00	0.05	0.00	0.00	0.08	0.00
XI	0.14	0.00	0.12	0.00	0.05	0.12	0.00	0.05	0.00	0.13	0.00	0.00
XII	0.00	0.00	0.00	0.14	0.00	0.00	0.01	0.13	0.00	0.00	0.00	0.00

Table 7
Total-relation matrix T

Index T (4)	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
I	0.14	0.06	0.26	0.06	0.08	0.27	0.09	0.14	0.09	0.25	0.24	0.01
II	0.06	0.03	0.10	0.03	0.02	0.11	0.07	0.08	0.04	0.17	0.05	0.00
III	0.24	0.10	0.16	0.12	0.04	0.30	0.22	0.16	0.19	0.16	0.17	0.02
IV	0.16	0.08	0.25	0.09	0.04	0.27	0.23	0.26	0.21	0.25	0.14	0.07
V	0.24	0.05	0.23	0.06	0.04	0.18	0.12	0.19	0.15	0.22	0.22	0.01
VI	0.25	0.10	0.29	0.12	0.04	0.18	0.22	0.16	0.19	0.17	0.19	0.02
VII	0.08	0.03	0.04	0.02	0.05	0.04	0.02	0.03	0.02	0.05	0.08	0.05
VIII	0.15	0.08	0.24	0.18	0.03	0.25	0.22	0.11	0.20	0.24	0.13	0.02
IX	0.31	0.14	0.30	0.23	0.05	0.38	0.24	0.28	0.13	0.27	0.28	0.02
X	0.19	0.12	0.22	0.05	0.08	0.24	0.09	0.13	0.08	0.11	0.17	0.01
XI	0.27	0.06	0.26	0.06	0.08	0.27	0.09	0.14	0.09	0.25	0.12	0.01
XII	0.04	0.02	0.07	0.17	0.01	0.07	0.07	0.18	0.05	0.07	0.04	0.01

Thus, the D_i (5) and R_i (6) values comprise both indirect and direct influences.

Table 8
Summary of the prominence and relation of the 12 indices

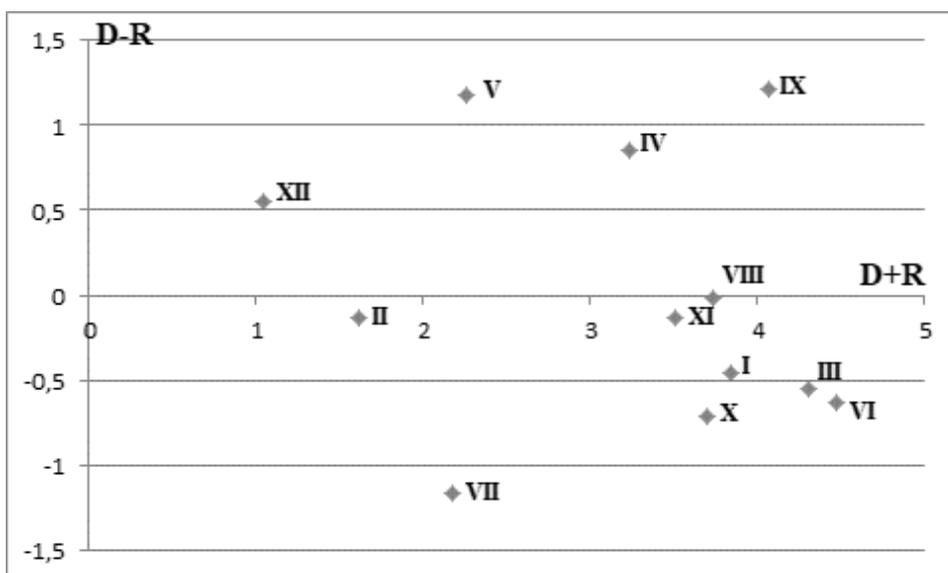| D	R	DpR	DmR
1.69	2.15	3.84	-0.46
0.74	0.87	1.62	-0.13
1.88	2.43	4.30	-0.55
2.05	1.19	3.24	0.86
1.72	0.54	2.26	1.17
1.92	2.55	4.47	-0.63
0.50	1.67	2.17	-1.16
1.86	1.88	3.73	-0.02
2.64	1.43	4.06	1.21
1.49	2.20	3.69	-0.71
1.69	1.82	3.50	-0.13
0.80	0.24	1.04	0.55

Fig. 2 Relational diagram of the 12 indices

4. DISCUSSION

Failures are sorted by their bindings to other failures in the prioritization of whether they affect other failures more (they cause other failures) in proportion to how they are influenced by other failures (resulting from other failures).

The division of failures according to their significance:

1. High prominence and high relation: The indices in this quadrant comprise IV, V, IX and XII. These indices are the core cause factors influencing the other items. Thus, they are the actuating factors for solving problems.
2. Low prominence and high relation: The indices in this quadrant comprise (no failure form our study) and slightly influence a few of the other indices. Thus, they are relatively independent.
3. Low prominence and low relation: The indices in this quadrant comprise (no failure form our study) and are slightly influenced by the other indices. Thus, they are relatively independent.
4. High prominence and low relation: The indices in this quadrant comprise I, II, III, VI, VII, VIII, X and XI and are effect factors that are influenced by the other items. Although these indices require improvement, they are effect factors, and thus they cannot be directly improved.

The dependence between RPN and the DEMATEL would be the subject of further studies.

5. CONCLUSION

We can use the risk analysis is to apply matrix operations to calculate factors' causal relationships and extent of influence - DEMATEL.

Reasons, why to use DEMATEL:

- for the Conventional FMEA, we identify all failure modes with a degree of severity, occurrence, and detection,
- for the Extended FMEA (wasn't the aim of this paper), we specify a particular method of costs incurred for malfunctions and their impact within the internal or external costs,
- when using DEMATEL technology, we not only identify the failure causes, but we also look at how the failure mode could be the cause of another failure,
- we monitor how malfunctions affect one another,
- we may have a problem with a relatively high RPN, but at the same time, the DEMATEL model will show us that this failure will not cause another failure, i.e., it is not the cause of another failure mode,
- we may have a problem with a relatively low RPN, but at the same time, the DEMATEL model will show us that this failure will cause a number of other failures, i.e., it is the cause of other failure modes,
- there may be other situations, but we have only described the marginal ones.

We use a model DEMATEL. DEMATEL gave us the answers to better understand the bindings between the individual failures. As part of the FMEA analysis, it is common for one failure to cause another one that actually results from its consequence, and this effect may change to the cause of another failure, etc. We use a model DEMATEL. DEMATEL gave us the answers to better understand the bindings between the individual failures. As part of the FMEA analysis, it is common for one failure to cause another one that actually results from its consequence, and this effect

may change to the cause of another failure, etc. Why use DEMATEL? It is precisely because if we know that within the given failure we are also talking about the main cause with bindings to other failures, we can take this into account when evaluating the failure mode by FMEA. However, the direct relationship between DEMATEL and the calculated RPN or ERPN is our goal in the further studies.

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