USING DEMATEL MODEL TO REMOVE UNCERTAINTIES IN DECISION MAKING IN PFMEA ANALYSIS

Adrián GULA[1], Marián BUJNA[1], Chia Kuang LEE[2]

[1]Institute of Design and Engineering Technologies, Faculty of Engineering, Slovak University of Agriculture in Nitra
[2]Faculty of Industrial Management, Universiti Malaysia Pahang Al-Sultan Abdullah.

Abstract
The main aim of this paper was to demonstrate the advantages of using a hybrid model consisting of PFMEA and DEMATEL analysis, especially in the decision-making part of PFMEA, which results in proposal of corrective actions. The evaluation team first created PFMEA analysis, which was oriented at selected system. After careful consideration of results obtained from PFMEA, where we observed very high RPN values, mainly due to the unusually high significance values, we decided to focus primarily on the significance assessment in terms of assessing the interrelationships of identified failure modes. To do this, DEMATEL model was used. After applying DEMATEL, we found that optimization (reduction of severity S) is necessary in parts of failure modes FM7 and FM8. Although this did not impact change of prioritization in terms of proposal of corrective actions according to RPN (mainly because of high detection D value, which we did not assess). In other analyses this change may result in a major impact on final PFMEA evaluation. This is because RPN is a product of three criteria, and any change in one of the criteria causes a change in RPN itself.
Key words: *PFMEA; DEMATEL; failure mode; assembly; industrial platform.*

INTRODUCTION
Manufacturers demand that their products are of high quality with little to no defects. Quality is a critical evaluation criterion in these manufacturing companies *(Markulik et al., 2022)*. PFMEA *(Process Failure Mode and Effect Analysis)* is one of many quality management tools in use. PFMEA solely focuses on the process and assembly and helps the companies save costs associated with solving problems. The end goal of PFMEA is to have a perfect and failure-free process *(Banduka et al., 2018)*.
The use of such a method is often criticised because of its potential shortcomings. These negatively affect its operation and limit its overall application potential *(Liu, 2016)*. For this reason, researchers are constantly trying to improve the method with respect to its performance or to propose a completely new method for risk prioritisation *(Bujna et al., 2023)*. The FMEA method is often combined with other models and methods to give organisations better perspectives on the system, especially the risk prioritisation. Combination of these methods results in what is called MCDM - Multiple Criteria Decision Making *(Bujna et al., 2023)*.
In our research, the PFMEA method and DEMATEL *(Decision Making Trial and Evaluation Laboratory)* model, which is one of the most basic methods of MCDM, were combined. This model is used to better understand and visualize relationships between factors using specific matrices and graphs *(Barretta et al., 2023)*. This model can convert independent relationships into a set of cause-and-effect results using the matrices and finds the critical factors of the system using the influence diagram *(Si et al., 2018)*.
The main aim of this paper is to show the advantages of using DEMATEL model due to the uncertainties that PFMEA can provide in the analysis. We hypothesize that DEMATEL model will help to address the shortcomings of PFMEA, particularly in terms of efficient proposal of corrective actions.

MATERIALS AND METHODS
The platform, shown in Figure 1, is assembled from theS355JR steel from several parts, which are gradually assembled in the assembly process into sub-assemblies, then groups until final product. This paper deals with the assembly process of the support structure of the platform. This is the most important part of the whole platform as it ensures its stability, functionality and safety.
The structure of the platform consists of 4 supporting columns, one of which is formed by two U 160 profiles. There are longitudinally welded together to form a closed profile. P 10 sheets are then welded

ISBN 978-80-213-3541-7

to both ends of the column, which allows the load of the structure to be distributed evenly over a larger floor area but also facilitates and refines the assembly. The supporting columns are connected by horizontal and transverse struts, which are key components of the structure as they distribute the load, increasing the rigidity, stability and overall safety of the platform. The horizontal struts are made of U 120 profiles, and the transverse struts are made of L profiles.

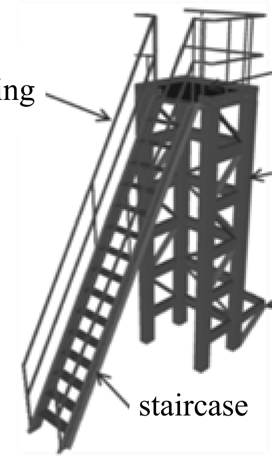

Fig. 1 3D model of the platform

As these are stationary platforms, they are mounted at precisely defined locations, on anchor points measured by a surveyor. The crane is then used to transport the already welded columns to the required points, where they are placed at the defined locations and welded to the anchor points. Horizontal struts are then mounted on these for better stability of the structure. In this step, the struts are bent in half and welded in place. Subsequently, reinforcements are also welded to the supporting columns to connect the horizontal struts and the supporting columns. In addition to the horizontal struts, transverse struts are also used in the construction. Other elements of the platform, such as stairs, flooring, railings, etc., are subsequently installed after the support structure is assembled.
Generalised steps to PFMEA analysis according to many authors are as follows *(Plinta et al., 2021)*:

1. Determining the scope of the analysis.
2. Assembling the evaluation team.
3. Planning and preparation of PFMEA.
4. Analysis of potential failure modes.
5. Risk analysis – it is important to determine the risk within the PFMEA by evaluating three criteria – the severity, occurrence and detection – to determine the necessary priority of corrective actions:
   a. severity *(S)* – rated on a 10-point scale, it is determined without regard to occurrence or detection,
   b. occurrence *(O)* – rated on a 10-point scale, it is determined without regard to severity or detection,
   c. detection *(D)* - rated on a 10-point scale, it is determined without regard to severity or occurrence.
6. Calculation of RPN – in general, the prioritization of failure modes for corrective action is determined by the Risk Priority Number - RPN, which is obtained by multiplication of S, O and D of the failure mode *(equation 1)*:

$$RPN = S \cdot O \cdot D \quad (1)$$

Tsai et al. *(2017)* defines these generalised steps of DEMATEL:

1. Creating a team - selecting system evaluation experts.

2. Determination of the direct-relation matrix X *(equation 2)* – elected experts will determine the strength of relations between individual effects of failure modes and their causes. The individual relationships are rated on a scale from 0 to 6, where 0 indicates no impact and 6 maximum impact.

$$X = \begin{bmatrix} 0 & x_{12} & \cdots & x_{1n} \\ \vdots & 0 & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & 0 \end{bmatrix} \quad (2)$$

3. Determination of normalised direct-relation matrix N – column vectors and maximum values of *(equation 3)* are used as the basis for the normalisation of the matrix *(equation 4)*.

$$\lambda = 1/max_{1 \le i \le n} \sum_{j=1}^{n} x_{ij} \quad (3)$$

$$N = \lambda X \quad (4)$$

4. Determination of total relation matrix T *(equation 5)*.

$$T = \lim_{n \to \infty} \left(N + N^2 + .. + N^k \right) = N(I - N) \quad (5)$$

where I is identity matrix.

5. Calculation of significance and relation for each criterion *(equation 6 and 7)*

$$D_i = \sum_{j=1}^{n} t_{ij} \quad (6)$$

$$R_j = \sum_{i=1}^{n} t_{ij} \quad (7)$$

Based on the above equations, the values of each column and row of the total relationship matrix T are summed. D_i *(equation 6)* is the sum of the i-th column and R_j *(equation 7)* is the sum of the j-th row. These variables account for both indirect and direct effects.

6. Construction of DEMATEL digraph – based on the $D_i + R_j$ and $D_i - R_j$ datasets.

RESULTS AND DISCUSSION

In this paper we focused on the analysis of only one part of the whole assembly, namely the support structure. An evaluation team was assembled which consisted of 3 authors of the paper *(university)* and 4 workers from the field. The first part of the analysis resulted in FMEA analysis *(Table 1)*.

Tab. 1 PFMEA installation of supporting columns

Process	**Failure mode**	**Effect**	**S**	**Possible cause**	**O**	**Inspection**	**D**	**RPN**	**Corrective action**	**P**
Installation of supporting columns	FM1 incorrect position of supporting columns	assembly of follow-up parts impossible	6	worker error	2	inspection and test plan	2	24	staff training, tech. procedure	7
	FM2 incorrect orientation of supporting columns	assembly of follow-up parts impossible	6	worker error	3	inspection and test plan	2	36	staff training, tech. procedure	5
	FM3 exceeding tolerance for vertical orientation of the columns	assembly of follow-up parts impossible	6	worker error	2	inspection by a surveyor	1	12	staff training, tech. procedure	8
	FM4 columns not properly welded to the built-in elements	structural failure	10	welder error	3	visual check	1	30	staff training, tech. procedure	6
	poor external quality of welded joints	structural failure	10	FM5 welder error	5	visual check	2	100	WPQR, WPS, CWJ	3
			10	FM6 damaged welding machine	3	inspection and test plan	2	60	calibration and control plan	4
		structural failure	10	FM7 welder error	5	inspection and test plan	8	400	WPQR, WPS, CWJ	1

	poor structural quality of welded joints		10	FM8 damaged welding machine	3	inspection and test plan	8	240	calibration and control plan	2

where *S* is severity; *O* is occurrence, *D* is detection, *RPN* is risk priority number and *P* is prioritization.

The RPN values *(Table 1)* are very high, especially given the high significance assigned. These errors have significant impact on the overall stability and safety of the entire platform. Therefore, in the next stage, we focused on this part and verified their significance using the DEMATEL model by assessing their mutual influence. Each failure mode was abbreviated to FM. In the case of two causes, we also divided the fault itself in terms of causes *(FM5 to FM8)*.
Table 2 is devoted to the initial direct-relation matrix of each fault occurring within the system.

Tab. 2 Direct-relation matrix X

X	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8
FM1	0	4	4	3	3	0	3	0
FM2	6	0	1	1	1	0	1	0
FM3	0	0	0	0	1	0	1	0
FM4	0	0	0	0	6	0	1	0
FM5	0	0	4	4	0	4	6	0
FM6	0	0	4	4	6	0	6	0
FM7	0	0	0	5	6	3	0	4
FM8	0	0	0	4	6	0	6	0

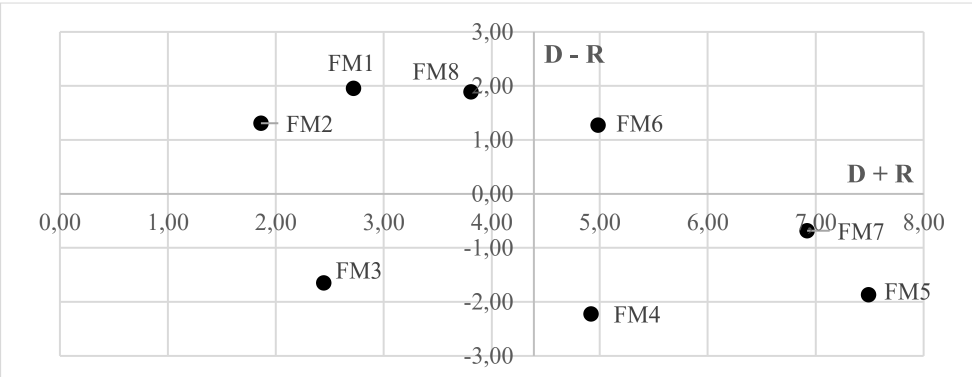

Fig. 2 DEMATEL digraph

As the digraph in Figure 2 shows, the horizontal vector *(D + R)* represents the degree of significance between the factors of the whole system. This vector indicates the influence of the factors on the whole system, but also the influence of other factors of the system on a particular factor. From this perspective, the factors FM5, FM7, FM6 and FM4 can be considered as significant factors. Factors FM8, FM1, FM3 and FM2 can be considered insignificant, with FM2 being the least significant.
The vertical vector *(D – R)* represents the degree of influence of the factor on the system, with a positive value of D – R representing ta causal variable, or cause, while a negative value of D – R represents the effect, or consequence, of the factor on the system. In this regard, the factors FM8, FM1, FM2 and FM6 can be considered as the influential factors, while FM7, FM3, FM5 and FM4 can be considered as the less influential ones. We refer to these less influential factors as effects.
The digraph itself can be then divided into four quadrants:

- Q1 – high significance and strong linkage – FM6 is present, which is a major causal factor that negatively affects other components of the system; therefore, it can be defined as a trigger factor.
- Q2 – low significance and strong linkage – FM8, FM1 and FM2 are present, these factors moderately affect other system elements but individually are independent.

- Q3 – low significance and weak linkage – FM3 is present, this factor is moderately influenced by other system elements but is relatively independent.
- Q4 – high significance and weak linkage – FM5, FM7 and FM4 are present, these factors are defined as direct consequences of other factors, and they cannot be directly influenced by corrective actions.

Based on the DEMATEL model, we can conclude that FM5 and FM6 have correctly assigned high significance in the FMEA analysis because they are significant factors. In addition, FM6 is a factor that significantly affects other failure modes, such as FM4, FM5 and FM7 – also significant factors *(see Table 2)*.
For FM7 and FM8, we consider lowering the significance value, since FM7 is indeed a significant factor and affects FM5 and FM6, however is also significantly affected by other failure modes. FM8 is a non-significant failure mode even though it affects significant, but non-causal factors. In this case, these modes will remain as the modes with the highest RIPN and will be prioritized for corrective actions. This is however due to the low detectability of the fault. For the other systems evaluated, such a change would cause more significant changes.
n real-world conditions, complications associated with the PFMEA method may arise. In some cases, the method reaches its limitations if multiple failure modes with the same RPN are identified. Although PFMEA is regarded as an objective method and in fact it is the most widely used risk analysis method ever, some authors talk about its subjectivity. According to Thurnes et al. *(2015)*, PFMEA is limited to common expectations of the occurrence of failures and usually does not consider the interconnections between these failures. Other important limitations regarding RPN and its variables S, O and D are defined by the authors *(Chang, 2016; Lo et al., 2020)* as follows, namely that S, O and D are equally important; RPN only considers S, O and D; different combinations of S, O and D can generate the same RPN results; and the mathematical calculation of RPN is sensitive to changes in S, O and D.
The DEMATEL model was used in this work in combination with the PFMEA method to address its aforementioned shortcomings. This is because PFMEA cannot effectively identify which factors are influenced by other factors and vice versa. As a result, the most important issues may not be properly evaluated. Chang *(2016)* used DEMATEL to prioritize the failures within the FMEA analysis.
Tsai, et al. *(2017)* suggest using a system rating scale from 0 to 4. In this paper, a rating scale from 0 to 6 is used because this scale gives more options to evaluate the links between failure modes. According to Bujna, et al. *(2023)*, the success of applying the DEMATEL model to a system evaluation is mainly dependent on the input data that the evaluation team is working with. It is advisable that the members selected for the team are involved in the process to which the model is applied.

CONCLUSIONS

The aim of this paper was to study failure modes that can occur within the assembly process of a process platform, specifically its supporting columns.
The PFMEA method, which is one of the most widely used methods for risk analysis, was used to analyse the different failure modes. Combined with the DEMATEL model, it creates an extended method by which risks can be better prioritised, leading to the proposal of corrective actions more quickly and efficiently. PFMEA prioritisation is done solely based on the RPN. In the PFMEA analysis, failure modes with high significance were identified and consequently the resulting RPNs were also very high. Therefore, we verified the correct value assignment by assessing the correlations of the failure modes using the DEMATEL model.
As a result, the significance *(S)* value for the observed failure modes was optimized. Although it did not have a major impact on the RPN in this case *(due to high detectability)*, in other cases, given that the RPN is very often sensitive to a change in the value of either S, O, or D, it can have a major impact on the prioritisation for efficient design of measures.

ACKNOWLEDGEMENT

This study was supported by Ministry of Education, Science, Research and Sport of the Slovak Republic by the grant VEGA: 1/0691/23

REFERENCES

1. Banduka, N., Tadic, D., Macužic, I., & Crnjac, M. *(2018)*. Extended process failure mode and effect analysis *(PFMEA)* for the automotive industry: The FSQC-PFMEA. Advances in Production Engi-neering And Management, 13*(2)*, 206–215. https://doi.org/10.14743/APEM2018.2.285
2. Barretta, R., Taherdoost, H., & Madanchian, M. *(2023)*. Multi-Criteria Decision Ma-king *(MCDM)* Methods and Concepts. Encyclopedia 2023, Vol. 3, Pages 77-87, 3*(1)*, 77–87. https://doi.org/10.3390/ENCYCLOPEDIA3010006
3. Bujna, M., Lee, C. K., Kadnár, M., Korenko, M., & Baláži, J. *(2023)*. New Possibili-ties of Using DEMATEL and ERPN in the New PFMEA Hybrid Model. Ap-plied Sciences 2023, Vol. 13, Page 3627, 13*(6)*, 3627. https://doi.org/10.3390/APP13063627
4. Chang, K. H. *(2016)*. Generalized multi-attribute failure mode analysis. Neuro-computing, 175*(PartA)*, 90–100. https://doi.org/10.1016/J.NEUCOM.2015.10.039
5. Liu, H.-C. *(2016)*. FMEA Using Uncertainty Theories and MCDM Methods. FMEA Using Uncertainty Theories and MCDM Methods, 13–27. https://doi.org/10.1007/978-981-10-1466-6_2
6. Lo, H. W., Shiue, W., Liou, J. J. H., & Tzeng, G. H. *(2020)*. A hybrid MCDM-based FMEA model for identification of critical failure modes in manufacturing. Soft Computing, 24*(20)*, 15733–15745. https://doi.org/10.1007/s00500-020-04903-x
7. Markulik, Š., Petrík, J., Šolc, M., Blaško, P., Palfy, P., Sütőová, A., & Girmanová, L. *(2022)*. Analysis of Fault Conditions in the Production of Prestressed Concrete Sleepers. Applied Sciences 2022, Vol. 12, Page 928, 12*(2)*, 928. https://doi.org/10.3390/APP12020928
8. Plinta, D., Golinska, E., & Dulina, L. *(2021)*. Practical Application of the New Ap-proach To FMEA Method according to AIAG and VDA Reference Manual. Http://Komunikacie.Uniza.Sk/Doi/10.26552/Com.C.2021.4.B325-B335.Html, 23*(4)*, B325–B335. https://doi.org/10.26552/COM.C.2021.4.B325-B335
9. Si, S. L., You, X. Y., Liu, H. C., & Zhang, P. *(2018)*. DEMATEL Technique: A Sys-tematic Review of the State-of-the-Art Literature on Methodologies and Appli-cations. Mathematical Problems in En-gineering, 2018*(1)*, 3696457. https://doi.org/10.1155/2018/3696457
10. Thurnes, C. M., Zeihsel, F., Visnepolschi, S., & Hallfell, F. *(2015)*. Using TRIZ to Invent Failures – Concept and Applica-tion to go Beyond Traditional FMEA. Procedia Engineering, 131, 426–450. https://doi.org/10.1016/J.PROENG.2015.12.439
11. Tsai, S. B., Zhou, J., Gao, Y., Wang, J., Li, G., Zheng, Y., Ren, P., & Xu, W. *(2017)*. Combining FMEA with DEMATEL models to solve production process problems. PLoS ONE, 12*(8)*. https://doi.org/10.1371/journal.pone.0183634

Corresponding author:
doc. Ing. Marián Bujna, PhD., Institute of Design and Engineering Technologies, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, Nitra, 94976, Slovakia, phone: +421 037 6414762, e-mail: marian.bujna@uniag.sk