Acta Technologica Agriculturae 3
Nitra, Slovaca Universitas Agriculturae Nitriae, 2025, pp. 149–158

PROPOSAL FOR USE OF DEMATEL MODEL IN COMBINATION WITH FMEA AND FMECA METHODS

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

[1]Slovak University of Agriculture in Nitra, Faculty of Engineering, Institute of Design and Engineering Technologies, Nitra, Slovakia, xgula@uniag.sk (A.G.), robert.drlicka@uniag.sk (R.D.)
[2]Universiti Malaysia Pahang Al-Sultan Abdullah, Faculty of Industrial Management, Pahang, Malaysia, chia@umpsa.edu.my

*correspondence: marian.bujna@uniag.sk

The elimination of time, cost, and material losses is the ultimate goal of any organisation. Reliability can also negatively impact these losses; therefore, our aim is to use tools which can prevent this from occurring. In this paper, a combination of the FMEA, FMECA, and DEMATEL methods was used to identify the critical points of the system to propose corrective actions more effectively. The study identified two failure modes FM1 and FM2 with five effects (E_i) and causes (C_i). It was found that FM2 achieved a higher RPN value in FMEA, meanwhile FM1 was evaluated as a failure mode with higher criticality (CA). Since the basis of RPN and CA calculations are variables S (severity of effects) and O (occurrence of causes), DEMATEL was used to evaluate the relations between E_i and C_i. A new model was created to better visualise the relations between each E_i and C_i. Then, these factors were classified into quadrants according to the DEMATEL model cause-and-effect digraph and based on direct influence matrix, the quantification of these factors was proposed. This innovative visualisation solution allowed us to identify FM1 (with E_1 and E_3 effects as well as C_1 and C_3 causes) as a priority for corrective action.

Keywords: technology; RPN; criticality; DEMATEL digraph; visualization model; effectivity

Failure Mode and Effects Analysis (FMEA) is widely used in manufacturing industries in the phases of the product life cycle. By identifying failure modes, the team can then design products or processes around those failures and virtually remove them from the system with a minimum effort and resource expenditure, thus reducing time and costs (Gulati, 2020).

Despite it being the most widely used method of identifying potential failure modes in manufacturing industries, the usage of such a method is often criticised by scientists due to its drawbacks, which negatively affect its operation and limit its overall application possibilities. The mathematical formula used to calculate the priority itself has no scientific basis and its usage is therefore questionable (Nguyen et al., 2016).

Failure Mode, Effects, and Criticality Analysis (FMECA) is a critical aspect of the design process, from concept through to development. FMECA must be applied iteratively, reflecting the iterative nature of the design process. It is deemed necessary to tailor the requirements for FMECA to each individual process or product and it is important that the FMECA method must contribute to meaningful decision made within the system (MIL-STD-1629 A, 1980).

The inherent limitations of FMEA reduce its effectiveness in practical applications. These drawbacks then reduce the effectiveness of the method itself, and many theories and models have been proposed to remove them. Some of the drawbacks defined by Liu et al. (2013) are:

- FMEA is considered subjective by some;
- S, O, and D are equally important;
- Risk priority number (RPN) calculation is sensitive to the changes of S, O, and D;
- RPN is the sole output for failure classification.

The Decision-Making Trial and Evaluation Laboratory (DEMATEL) can be applied to construct a network relation design to examine internal relations among each attribute of a system (Alinezhad and Khalili, 2019). It is especially useful in analysing the cause-and-effect relationships among the components of a system (Kuzu, 2023). It can confirm interdependence among factors and aid in the development of a map to reflect relative relationships within them. This can be used to investigate and solve complicated and intertwined problems (Si et al., 2018). DEMATEL is one of the multiple-criteria decision making (MCDM) based on asymmetric linguistic comparison matrices (Šmidovnik and Grošelj, 2023). Table 1 provides a detailed overview of the use of the DEMATEL model in previous scientific studies.

Based on the literature review (Table 1), the main aim of this paper is to use the DEMATEL model as a tool to validate the FMEA and FMECA methods in decision making for corrective actions. It is necessary to consider all the criteria that make up the RPN as a basis for method evaluation. The aim is to develop a model to visualise the links between the evaluated criteria of the FMEA and FMECA methods to find critical points in technology reliability. We anticipate that this combination will serve as a preparation for effective prioritisation for efficient proposal of corrective action.

Table 1 DEMATEL model in combination with FMEA and FMECA in previous studies

Authors	Method	DEMATEL usage
Shen et al. (2014)	DEMATEL-ISM + FMECA	– analysis of the combined effect of related failures
Wang et al. (2016)	Imp. FMECA + DEMATEL + ICR	– failure prioritisation of improved fmeca
Wang et al. (2014)	FMECA + DEMATEL	– complex impact of the mode and cause of failure
Mzougui et al. (2020)	FMECA + AHP + DEMATEL	– evaluation of the new factor of "dependence" among risks
Luo et al. (2022)	FMECA + DEMATEL	– correlations among critical failure causes
Wang et al. (2022)	FMECA + DEMATEL + VIKOR	– study of the dependence among failure modes
Boral et al. (2024)	FMECA + IT2F DEMATEL + fuzzy MAIRCA + fuzzy MARCOS	– calculation of weights as well as causal dependencies among risk factors
Ahmed et al. (2021)	FMECA + ELECTRE + DEMATEL	– highlighting the most influencing failures within each risk class
Rana et al. (2022)	FMECA + AHP + DEMATEL	– calculation of the interdependencies of hazards
Jou et al. (2016)	FMECA + OWGA + DEMATEL	– more accurate calculation of the criticality analysis
Liu et al. (2019)	FMEA + DEMATEL (integrated fuzzy logic)	– investigation of the causal degrees of failure modes and causes
Lo et al. (2020)	FMEA + DEMATEL + VIKOR + COPRAS + GRA + TOPSIS	– identification of critical failure modes
Kuchekar et al. (2024)	FMEA + DEMATEL + SAW + VIKOR + GRA + TOPSIS	– ranking of failure modes
Bujna et al. (2024)	FMEA + FTA + DEMATEL	– determination of the reliability level
Bujna et al. (2023)	PFMEA + DEMATEL+ ERPN	– as a tool for model prediction
Cheshmberah et al. (2020)	FMEA + DEMATEL	– to understand and effectively implement models
Rahmadani and Suparno (2021)	FMEA + DEMATEL-ANP	– considering supplier risk in the decision process
Budiraharjo et al. (2023)	FMEA + FTA + DEMATEL	– selection of a reference for mitigation planning
Liu et al. (2023)	FMEA + D-S + DEMATEL-TODIM	– prioritisation of potential failure modes
Bujna et al. (2019)	FMEA – DEMATEL	– identification of links between individual failures and causes of failures
Akhtar et al. (2024)	FMEA + DEMATEL	– allowing for unveiling crucial faults
Lai et al. (2023)	FMEA + DEMATEL + MADM	– intricate analysis of the interconnectedness and impact of various risk factors

Material and methods

The main subject of the analysis is the usage of the DEMATEL model in combination with the FMEA and FMECA methods. The FMECA method combines the FMEA and CA (Criticality Analysis) methods. The approach to this method is determined by the action plan requirements of every organisation. Generalised steps to FMEA can be defined as follows (MIL-STD-1629 A, 1977; Plinta et al., 2021; STN EN IEC 60812, 2019):

1. Scope of FMEA: The object where we applied the analysis is a wagon for transporting containers and swap bodies. The production process consists of welding, assembly, surface treatment, assembly of the braking system, and output quality control. MIG/MAG welding is the predominant method used in the production of wagons, which we focused on in this research.
2. Creation of FMEA team: The evaluation team consisted of 4 authors of the article, who led the entire research, and 7 welding experts. The qualitative part of FMEA was mainly influenced by the welding experts.
3. Planning and preparation of FMEA: The team was familiar with the analysed system – welding technology.
4. Analysis of potential failures: Identifying failure modes is a key attribute of building a quality analysis.
5. S, O, and D variables and RPN calculation: The FMEA team evaluates the severity of failure mode S, its occurrence O, and the detection rating of the failure mode D (in scale 1–10). Then, the RPN is calculated according to Eq. (1):

$$RPN = S \cdot O \cdot D \tag{1}$$

6. Preventive and corrective actions: Based on the RPN, the prioritisation of failure modes occurs, and corrective actions are then set in place with the aim of reducing the impact of said failures.

Generalised steps to FMECA can be defined as follows (MIL-STD-1629 A, 1977; Plinta et al., 2021; STN EN IEC 60812, 2019):

1. FMEA.
2. Failure probability/failure rate data source: We based our calculations directly on the frequency of effects

and causes of failure modes on the number of all units produced over a certain period.

3. Failure effect probability (β): In the case of multiple effects, we determined the beta based on the frequency of effects of the specific failure mode.
4. Failure mode ratio (α): This ratio is the probability expressed as a decimal fraction that the part or item will fail in the identified mode. If all the potential failure modes of a particular part or item are listed, the sum of α values for that part or item are all equal to one.
5. Part failure rate (λ_p): This is the ratio between the number of failures per unit of time and is usually expressed as the number of failures per monitored time in hours.
6. Operating time (t): It is listed in hours of the part or item during its lifetime.
7. Failure mode criticality number (C_{fm}) and effect criticality number (C_e): The value of C_e is calculated using Eq. (2) and it is a measure of frequency of the effects of failure mode. The value of C_{fm} is calculated using Eq. (3) and it is a number of system failures of a specific type expected due to items or parts failure modes.

$$C_e = \beta \cdot \alpha \cdot \lambda_p \cdot t \tag{2}$$

$$C_{fm} = \sum_{n=1}^{j} C_m \tag{3}$$

Steps to DEMATEL

Similarly to FMEA, DEMATEL is also a team-based method with appointed experts from their respective fields. The steps to DEMATEL can be defined as follows (Thakkar, 2021):

1. Appointment of expert panel and criteria: In this step, an expert panel from their respective fields must be appointed.
2. Construction of initial direct-relation matrix **X:** Eq. (4) – the matrix is created by pairwise comparisons between challenges and criteria. The scale for this comparison is 0–6, where 0 means no relation and 6 is the maximum relation.

$$X = \begin{bmatrix} 0 & x_{12} & \cdots & x_{1n} \\ \vdots & 0 & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & 0 \end{bmatrix} \tag{4}$$

3. Construction of normalised initial direct-relation matrix **N,** Eq. (6) – every element in matrix N lays between the values 0 and 1. Column vectors λ, shown in Eq. (5), are also used in this step.

$$\lambda = \frac{1}{\max_{1\le i\le n} \sum_{j=1}^{n} x_{ij}} \tag{5}$$

$$N = \lambda \cdot X \tag{6}$$

4. Construction of total relation matrix **T,** Eq. (7):

$$T = \lim_{n\to\infty}(N + N^2 + ... + N^k) = N(I - N) \tag{7}$$

where: I – identity matrix; N – normalised direct-relation matrix

5. Prominence and relation calculation for each criterion, Eq. (8) and Eq. (9):

$$D_i = \sum_{j=1}^{n} t_{ij} - D_i \tag{8}$$

– is a sum of each row of **T** matrix

$$R_i = \sum_{i=1}^{n} t_{ij} - R_j \tag{9}$$

– a sum of each column of T matrix

$D_i + R_j$ – called prominence, while D_i - R_j is called relation

6. Cause and effect diagram (Fig. 1) is constructed by mapping the datasets $D_i + R_j$ and D_i - R_j.

Building of the evaluation model:

1. Evaluation by the basic FMEA and FMECA methods.
2. DEMATEL cause-and-effect assessment.
3. Classification of causes-and-effects into DEMATEL quadrants (Fig. 1).
4. Creation of visual model using quadrants and relations – linkages are defined (Fig. 1) based on the direct-relation matrix.
5. Interpretation of model results.

Results and discussion

Welding is very important in the evaluated process because the most of production consists of welded parts. The team of experts identified issues within the FMEA model (Table 2). In this paper, the latter has been divided into a qualitative model (Table 2) and quantitative model (Table 3).

Table 2 contains the labels for each failure mode (FM), effect (E), and cause (C) with a respective numerical index. In the following sections, we will consider only these abbreviated designations. It can be concluded that we have identified two failure modes with five effects and causes for both failures.

The quantitative FMEA model is shown directly in the quantitative FMECA model in Table 3, which expresses

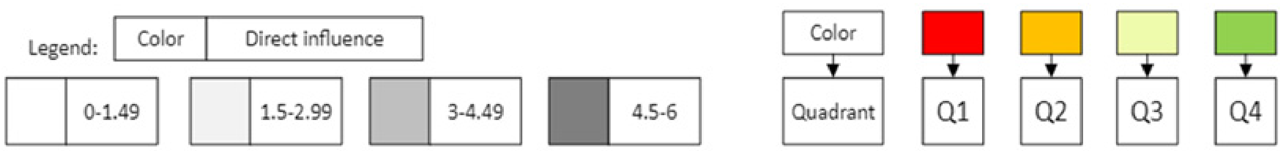

Fig. 1 Usage of quadrants and relations in visualisation model building

Table 2 Qualitative FMEA model

Process	Failure mode	Effect	Cause	Detection	Action
Welding	FM1 welding parameters	E1 weld overlap	C1 high welding current	visual control	lower the welding current
		E2 surface pore	C2 insufficient cleaning of welded materials	capillary test	inspect welded surfaces before welding begins
		E3 burnt base material	C3 high welding power	visual control	lower the welding power
		E4 weld undercut	C4 arc too long, high voltage	visual control	lower the welding voltage
		E5 spatter	C5 high current at the start of welding	visual control	reduce the current when welding starts
	FM2 incorrect welding process	E6 short weld joint	C6 early weld termination	visual control	welder retraining in reading drawings
		E7 insufficient quantity of cover layers	C7 small diameter of additional material	welder inspections	regular staff training
		E8 poor restart	C8 incorrect electrode position	inspection of procedures	regular staff training
		E9 irregular weld surface	C9 incorrect burner routing	visual control	welder inspections
		E10 cold laps	C10 too narrow of a weld gap	measurement	maintain the specified welding gap

FM – failure mode; E – effect; C – cause

Table 3 Quantitative FMEA model

FM	Effects	n_E	S	Causes	O	D	RPN	R	λ_p (h^{-1})	α	β	*t* (h)	C_E	C_{FM}	R
	E1	30	4	C1	7	2	56	9	0.65		0.10	807.5	30		6
	E2	82	3	C2	10	4	120	5–7	0.65		0.27	807.5	82		3
FM1	E3	15	10	C3	4	4	160	4	0.65	0.59	0.05	807.5	15	307	9
	E4	88	4	C4	10	3	120	5–7	0.65		0.29	807.5	88		2
	E5	92	1	C5	10	1	10	10	0.65		0.30	807.5	92		1
	E6	12	9	C6	3	4	108	8	0.65		0.06	807.5	12		10
	E7	26	6	C7	6	6	216	2	0.65		0.12	807.5	26		7
FM2	E8	78	5	C8	10	4	200	3	0.65	0.41	0.36	807.5	78	214	5
	E9	81	4	C9	10	3	120	5–7	0.65		0.38	807.5	81		4
	E10	17	9	C10	4	8	288	1	0.65		0.08	807.5	17		8

FM – failure mode; n_E – frequency of effects; S – severity; O – occurrence; D – detection; RPN – risk priority number; R – ranking; λ_p – failure rate; α – failure mode probability; β – effect probability; *t* – total production time; C_E – effect criticality; C_{FM} – failure mode criticality

the criticality of each effect, and this also evaluates both the reliability of the technology and the quality of its output.

Based on Table 3, we can conclude that the FMEA RPN evaluation identified the FM2 failure mode as a priority for corrective action. Four of its five effects were among the effects with the highest RPN.

The criticality analysis (C_{fm}), however, yielded the first contradiction with FMECA, which often happens in practice. The criticality of FM1 effects was 1.5 times higher than that of FM2. Three FM1 effects were rated as the most critical. Paradoxically, the severity value of the effects (*S*) was on average 1.5 times lower for FM1. The initial estimate confirms that the RPN, unlike C_{fm}, includes the detectability of the causes of failure modes. The latter was on average almost twice lower for FM1 effects and causes than for FM2 effects and causes.

However, this statement is not sufficient and that is why we decided to use the DEMATEL model. We did not only consider the interactions between the effects, but also the causes, thus creating a more comprehensive model.

Table 4 shows the direct-relation matrix of causes, which is composed of the average rating of relations between causes by the evaluators – experts (i.e. welding supervisor, welding engineers, and welding operators). We use the column vectors and maximum values as the basis for standardisation (Table 4).

By solving the normalised and total matrices, the digraph can be constructed (Fig. 2).

According to Fig. 2, we can conclude that no cause is found in quadrant 1 (Q1), where the priority factors for needed solutions are usually located. Q1 combines significant and causal factors (affecting other causes).

Table 4 Direct-relation matrix **X** of causes and standardisation values

X	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	$\sum x_i$	max $\sum x_i$	λ
C1	0.00	0.75	5.25	4.25	5.25	2.25	0.75	1.75	0.25	1.25	21.7	23.5	0.043
C2	0.75	0.00	0.75	1.25	1.00	0.75	0.00	0.50	0.75	1.25	7		
C3	5.50	0.75	0.00	3.75	4.75	2.00	1.25	1.00	1.00	0.50	20.5		
C4	4.75	1.00	5.75	0.00	4.50	2.00	0.75	2.25	2.00	0.50	23.5		
C5	5.75	1.00	6.00	4.75	0.00	1.25	0.50	0.75	0.50	0.75	21.25		
C6	1.25	1.25	0.50	0.25	0.50	0.00	1.00	2.00	2.50	1.75	11		
C7	3.25	2.00	2.50	2.50	2.75	1.75	0.00	2.00	0.75	2.00	19.5		
C8	0.75	0.75	0.75	3.50	2.50	4.75	1.75	0.00	3.50	1.25	19.50		
C9	0.75	0.50	1.75	3.50	2.00	4.50	1.50	2.75	0.00	0.75	18		
C10	1.75	2.00	1.75	1.25	2.75	1.00	1.50	2.00	2.00	0.00	16		

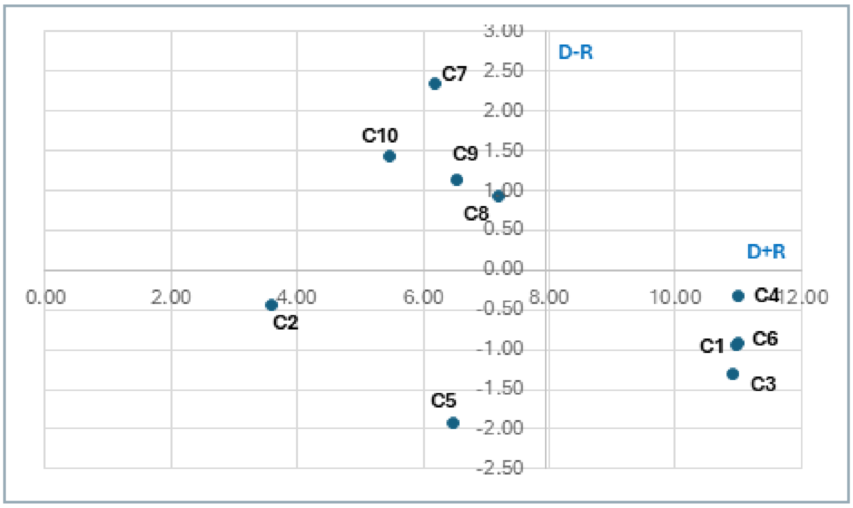

Fig. 2 DEMATEL model relations for causes of failure modes

Causes C8, C7, C9, and C10, although causal, are of low significance, and causes C2 and C5 are influenced (effect of other causes) with low significance.

The construction and assessment of relations between the effects of failure modes with the DEMATEL model was carried out in a similar manner. The base matrix is shown in Table 5.

By solving the normalised and total matrices, the DEMATEL digraph can be constructed as previously mentioned (Fig. 3).

According to Fig. 3, we can conclude that the most severe effects from

Table 5 Direct-relation matrix X of effects and standardisation values

X	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	$\sum x_i$	max $\sum x_i$	λ
E1	0.00	1.25	4.50	2.00	1.00	1.00	1.25	3.00	4.50	2.50	21.00	27	0.037
E2	1.50	0.00	2.25	3.00	1.50	2.25	2.00	1.50	2.50	1.50	18		
E3	5.00	2.25	0.00	3.25	0.75	1.50	2.25	3.00	3.00	1.50	22.5		
E4	1.50	1.50	3.00	0.00	2.50	1.75	1.25	0.50	1.75	1.25	15		
E5	0.75	0.75	1.25	1.75	0.00	0.75	0.75	1.50	1.25	1.50	10.25		
E6	0.75	1.50	1.50	1.75	1.50	0.00	3.75	3.25	2.75	2.50	19.25		
E7	1.25	1.00	1.00	1.75	1.00	3.50	0.00	1.75	3.50	1.75	16.5		
E8	3.25	1.25	2.50	1.75	1.25	2.75	0.50	0.00	5.75	4.00	23		
E9	4.75	3.00	2.50	2.25	2.00	2.25	2.25	5.50	0.00	2.50	27.00		
E10	1.75	2.00	1.50	2.00	1.00	3.75	1.00	3.00	0.75	0.00	16.75		

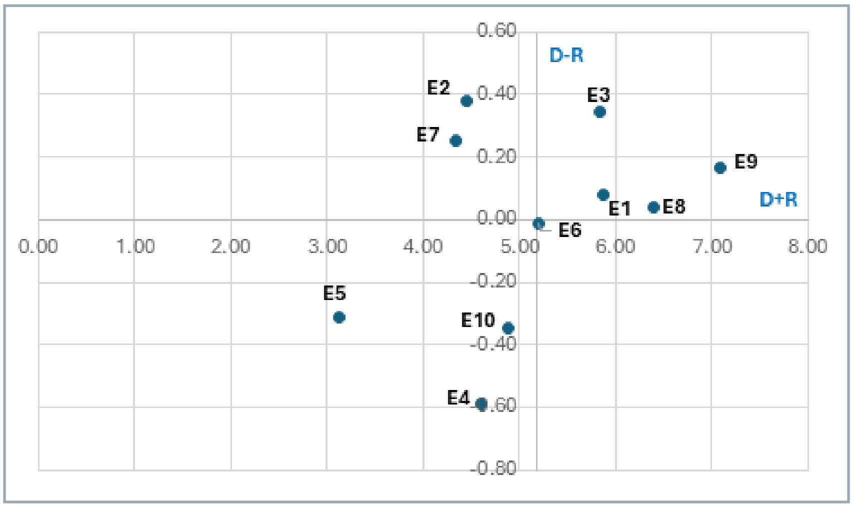

Fig. 3 DEMATEL model relations for effects of failure modes

the DEMATEL model perspective are E9, E3, E8, and E1, since they are located in Q1. These effects are labelled as significant and causal (affecting other effects and failure modes). Effects E7 and E2 (located in Q2), although causal, are of low significance, and effects E10, E5, and E4 are influenced (effects of other causes) and of low significance (Q3). Effect E6 located in Q4, although being significant, is also influenced by other effects.

By solving the DEMATEL model, we obtained two additional variables for our comprehensive model. The results are projected in Fig. 4.

Figure 4 shows a comprehensive model for visualising the results of analysis done by each tool. Causes (C_i), as the source of failure modes with the corresponding DEMATEL quadrant, are on the left. These are the causes of two failure modes (FMi) with different effects (E_i) with DEMATEL quadrant assignment. In the columns on the right, RPN rating as a result of FMEA evaluation and criticality rating as a result of criticality analysis are present.

It was previously determined that FM1 is a failure mode with lower priority in terms of the RPN for corrective actions, but also a higher criticality of developed effects. According to DEMATEL results (Figs 3 and 4), FM1 has two effects classified in Q1 (E1 and E3), three causal (E1, E2, and E3) and two with high significance (E1 and E3) overall. FM2 also has two effects classified in Q1 (E8 and E9), three causal (E7, E8, and E9) and three with high significance (E6, E8, and E9). Based on Fig. 3, the effect labelled E6 lies almost perfectly at the intersection of *x* and *y* axes; therefore, it is almost completely independent and can be excluded from further evaluation. According to this evaluation, it is not possible to determine a more significant error.

If causes are taken into consideration (we already know that none of them belongs to Q1), FM1 is made of three significant causes, but they are all influenced by other causes. FM2 is made up of up to four causes, however, only one significant.

So far, we have not been able to determine, even by using the DEMATEL model, which fault is more significant and should be prioritised. From this point on, we will discuss the factors included in Q1, which are effects E1, E3, E8, and E9, as shown in Fig. 5.

Figure 5 consists of the strength of relations of the direct influence of each factor to other factors based on the construction of the direct-relation matrix (Tables 4 and 5). We simplify this analytical scheme (Fig. 6) to show only highly significant (4.5–6) and significant (3–4.49) relations.

Figure 6 shows that the effects of FM1 and FM2 equally affect (are the cause) six other effects, three for FM1 and FM2 each. The effects of FM1 (E1 and E3) affect five effects of Q1 (causal and significant) with two very significant and three significant relations, respectively. The FM2 effects (E8 and E9) affect four Q1 effects with three very significant and one significant relation. Again, it is difficult to prioritise because the effects of both failures act on each other.

Based on Fig. 6, if focus is on the causes of these effects (influencing the occurrence of failures with specific effects), they are significant, but, on the other hand, not causal enough. Nevertheless, the causes (C1 and C3) of FM1 influence the occurrence of effects (E3 and E1) of said failure classified in Q1 by high significance.

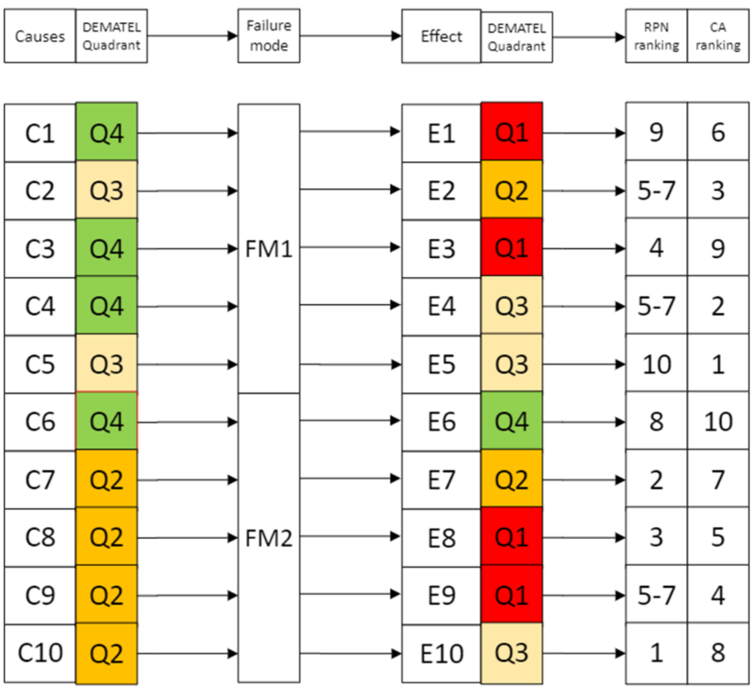

Fig. 4 Summary model for visualising FMEA, FMECA, and DEMATEL results

Fig. 5 Model of interactions between the most important effects

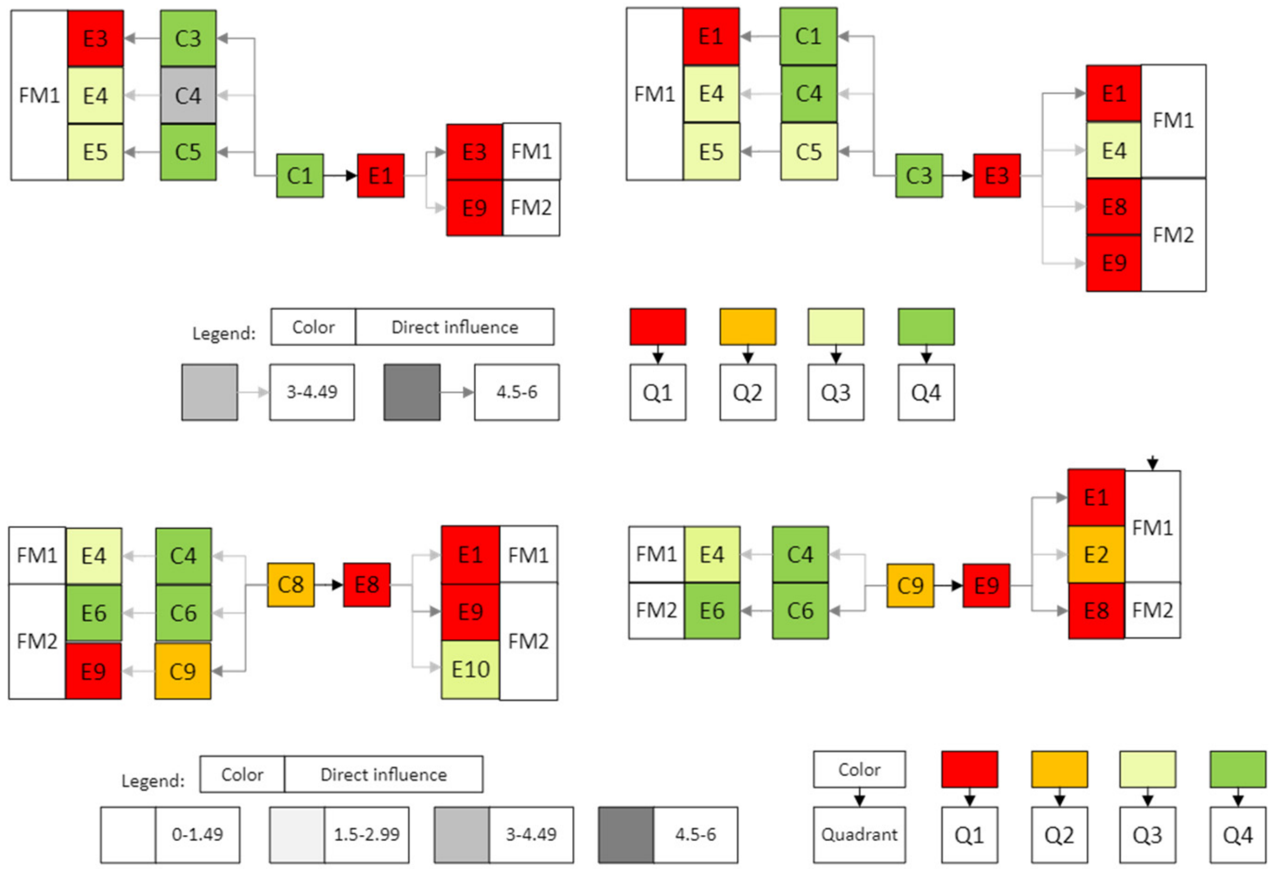

Fig. 6 Effects and causes analysis based on relation quantification

For FM2, only one cause (C8) affects one effect (E9) classified in Q1, however, only by a significant relation.

It is only through such a detailed analysis that we have concluded that addressing the failure mode labelled FM1 should be a priority for us to take corrective action to increase the reliability and efficiency of the evaluated technology with implication for the quality of production (especially the interplay of C1 and E1 with C3 and E3).

This paper is an extension of research concluded by authors Bujna and Lee in the use of the DEMATEL model. Bujna et al. (2019) first used DEMATEL to prioritise failure modes based on an assessment of the causes of failures. Then, they proposed the usage of the DEMATEL model as a prediction tool for the estimation of FMEA analysis (Bujna et al., 2023). DEMATEL was also used to find critical points to determine the reliability of technical systems (Bujna et al., 2024).

Liu et al. (2019) employed the DEMATEL technique to measure the correlation effects between failure modes and causes. We assessed this correlation between the effects and causes of failure modes not only by using the FMEA analysis, but also by the criticality evaluation of the FMECA method. Therefore, we can consider this use as innovative.

Wang et al. (2014) may have used this combination of tools in their analysis; however, it was a modified FMECA method with an improved criticality value.

Shen et al. (2014) used the DEMATEL model in their study to calculate the degree of correlation between failure subsystems, to analyse the combined effect of related failures, and to obtain the degree of correlation by using the directed graph and matrix operations. Finally, FMECA was used to perform a qualitative hazard analysis of critical subsystems, to determine the critical failure mode, and to clarify the direction of reliability improvement. We first focused on the application of the FMEA/FMECA methods because they form the basic analysis within several tools and models that are commonly used in almost every industry and manufacturing organisation. Then, used the strengths of the DEMATEL model as defined within our search.

Kamis et al. (2024) extended the similarity-influence-network algorithm by integrating a cause-effect visualisation procedure inspired by the DEMATEL approach. In our study, we chose a custom visualisation model that included the classification of effects and causes into DEMATEL quadrants and considered the impact on other effects or causes of failure modes through the strength of relations, which were defined based on the direct-relation matrix. Our next research task will be to search for an algorithm to describe the model.

Conclusion

In this paper, the DEMATEL model was used for discrepancy that arose in the use of the FMEA and FMECA methods. We identified failure modes with multilevel effects and their respective causes, with FM2 being the priority for corrective action according to the RPN and FM1 being more critical according to FMECA. Given the methods used, we decided to use the DEMATEL model to assess relations between the effects and causes of failure modes, which is always very challenging. We have supported the problem addressed with a detailed literature review and this also shows that the use of the DEMATEL model in this way has been minimal.

Conclusions of this study:

- FMEA requires, especially for critical processes, a throughout analysis of each criterion (S, O, and D).
- If FMECA is used to determine the criticality of effects (CA), it is needed to keep in mind that CA does not consider the detectability D.
- Detectability D is a criterion that is impossible to include in the DEMATEL investigation.
- Focusing the DEMATEL model solely on causes or effects may be insufficient. The subject of the DEMATEL analysis should be based on the needs of conducted analysis. A very complex model will emerge, which is very demanding (time and knowledge wise) on the team.
- The results of model must be transformed into basic analysis and optimised accordingly.
- A new visualisation model was created for finding critical points. This model includes the classification of causes and effects into DEMATEL quadrants and considers the impact on other effects or causes of each failure mode through the strength of relations which are defined using direct-relation matrix.

Based on the findings, further research is required:

- To resolve to the greatest extent possible the failure detection methods, as we cannot include them in our proposed models. This means to propose measures to reduce the detectability D in the first step.
- For the factors included in Q1 with identified relations (based on Fig. 6 – E1, E3, E8, and E9), the DEMATEL results should increase their severity. In our research, only effect E3 had a high severity (S) value in FMEA.
- The aim of further research is to add another MCDM tool and develop a hybrid model.
- The next aim of further research is to use neural networks in analyses (Dahham et al., 2023; Khessro et al., 2022). These outputs from the DEMATEL analysis (e.g., the influence matrix, the net cause-and-effect relations for each factor) can serve as input data for a neural network.

The methodology used in this work is generally applicable to assess the reliability and quality of various systems and technologies. A limitation of the research, which is due to the limitations of DEMATEL, is the selection of experts (evaluators), mainly in terms of their analytical skills and the number of experts appointed into the team. However, this step is statistically verified in DEMATEL.

Acknowledgement

This research work has been supported by the Ministry of Education, Science, Research and Sport of the Slovak Republic by the grant VEGA no. 1/0691/23.

References

AHMED, U. – CARPITELLA, S. – CERTA, A. 2021. An integrated methodological approach for optimising complex systems subjected to predictive maintenance. In Reliability Engineering & System Safety, vol. 216, article no. 108022. DOI: https://doi.org/10.1016/j.ress.2021.108022

AKHTAR, M. J. – NASEEM, A. – AHSAN, F. 2024. A novel hybrid approach to explore the interaction among faults in production process with extended FMEA model using DEMATEL and cloud model theory. In Engineering Failure Analysis, vol. 157, article no. 107876. DOI: https://doi.org/10.1016/j.engfailanal.2023.107876

ALINEZHAD, A. – KHALILI, J. 2019. DEMATEL method. In ALINEZHAD, A. – KHALILI, J. (eds). New Methods and Applications in Multiple Attribute Decision Making (MADM). Cham : Springer, 233 pp. eISBN 978-3-030-15009-9. DOI: https://doi.org/10.1007/978-3-030-15009-9_15

BORAL, S. – CHATURVEDI, S. K. – LIU, Y. – HOWARD, I. 2024. Integrated fuzzy MCDM frameworks in risk prioritization of failure modes. In KARANKI, D. R. (ed.). Frontiers of Performability Engineering. Singapore : Springer, 687 pp. eISBN 978-981-99-8258-5. DOI: https://doi.org/10.1007/978-981-99-8258-5_14

BUDIRAHARJO, R. – SARNO, R. – WIJAYA, D. R. – PRASETYO, H. N. – WASPADA, I. 2023. IMARA: A new approach to multi-attribute risk assessment based on event data weighting (case study in a container terminal). In IEEE Access, vol. 11, pp. 62292–62306. DOI: https://doi.org/10.1109/ACCESS.2023.3287781

BUJNA, M. – KOTUS, M. – MATUŠEKOVÁ, E. 2019. Using the DEMATEL model for the FMEA risk analysis. In System Safety: Human – Technical Facility – Environment, vol. 1, no. 1, pp. 550–557. DOI: https://doi.org/10.2478/czoto-2019-0070

BUJNA, M. – LEE, C. K. – KADNÁR, M. – KORENKO, M. – BALÁŽI, J. 2023. New possibilities of using DEMATEL and ERPN in the new PFMEA hybrid model. In Applied Sciences, vol. 13, no. 6, article no. 3627. DOI: https://doi.org/10.3390/app13063627

BUJNA, M. – PRÍSTAVKA, M. – LEE, C. K. – STRÁPEKOVÁ, Z. – KAPELA, K. – MALICEVIC, Z. 2024. Determining the reliability level by combining FMEA, FTA and DEMATEL tools. In Agricultural Engineering, vol. 28, no. 1, pp. 251–276. DOI: https://doi.org/10.2478/agriceng-2024-0016

CHESHMBERAH, M. – NADERIZADEH, A. – SHAFAGHAT, A. – NOKABADI, M. K. 2020. An integrated process model for root cause failure analysis based on reality charting, FMEA and DEMATEL. In International Journal of Data and Network Science, vol. 4, no. 2, pp. 225–236. DOI: https://doi.org/10.5267/j.ijdns.2019.12.003

DAHHAM, G. A. – AL-IRHAYIM, M. N. – AL-MISTAWI, K. E. – KHESSRO, M. K. 2023. Performance evaluation of artificial neural network modelling to a ploughing unit in various soil conditions. In Acta Technologica Agriculturae, vol. 26, no. 4, pp. 194–200. DOI: https://doi.org/10.2478/ata-2023-0026

GULATI, R. 2020. Maintenance and Reliability Best Practices. (3rd ed). Norwalk : Industrial Press, 768 pp. eISBN 978-0-8311-3647-5. Available at: https://app.knovel.com/hotlink/khtml/id:kt012RU8B2/maintenance-reliability/waste-analysis

JOU, Y.-T. – YANG, K.-H. – LIAO, M.-L. – LIAW, C.-S. 2016. Multi-criteria failure mode effects and criticality analysis method: A comparative case study on aircraft braking system. In International Journal of Reliability and Safety, vol. 10, no. 1, pp. 1–21. DOI: https://doi.org/10.1504/IJRS.2016.076338

KAMIS, N. H. – SHAMUDIN, N. A. A. – KILICMAN, A. – KADIR, N. A. – YUSOFF, B. 2024. A hybrid fuzzy approach of similarity-influence-network and DEMATEL: Visualization and analysis. In Malaysian

Journal of Fundamental and Applied Sciences, vol. 20, no. 2, pp. 424–434. DOI: https://doi.org/10.11113/mjfas.v20n2.3343

KHESSRO, M. K. – HILAL, Y. Y. – AL-JAWADI, R. A. – AL-IRHAYIM, M. N. 2022. Greenhouse energy analysis and neural networks modelling in Northern Iraq. In Acta Technologica Agriculturae, vol. 25, no. 4, pp. 205–210. DOI: https://doi.org/10.2478/ata-2022-0030

KUCHEKAR, P. – BHONGADE, A. S. – REHMAN, A. U. – MIAN, S. H. 2024. Assessing the critical factors leading to the failure of the industrial pressure relief valve through a hybrid MCDM-FMEA approach. In Machines, vol. 12, no. 11, article no. 820. DOI: https://doi.org/10.3390/machines12110820

KUZU, A. C. 2023. Application of fuzzy DEMATEL approach in maritime transportation: A risk analysis of anchor loss. In Ocean Engineering, vol. 273, article no. 113786. DOI: https://doi.org/10.1016/j.oceaneng.2023.113786

LAI, K.-K. – LIN, S.-W. – LO, H.-W. – HSIAO, C.-Y. – LAI, P.-J. 2023. Risk assessment in sustainable production: Utilizing a hybrid evaluation model to identify the waste factors in steel plate manufacturing. In Sustainability, vol. 15, no. 24, article no. 16583.

DOI: https://doi.org/10.3390/su152416583

LIU, H.-C. – LIU, L. – LIU, N. 2013. Risk evaluation approaches in failure mode and effects analysis: A literature review. In Expert Systems with Applications, vol. 40, no. 2, pp. 828–838. DOI: https://doi.org/10.1016/j.eswa.2012.08.010

LIU, S. – GUO, X. – ZHANG, L. 2019. An improved assessment method for FMEA for a shipboard integrated electric propulsion system using fuzzy logic and DEMATEL theory. In Energies, vol. 12, no. 16, article no. 3162. DOI: https://doi.org/10.3390/en12163162

LIU, Z. – BI, Y. – LIU, P. 2023. A conflict elimination-based model for failure mode and effect analysis: A case application in medical waste management system. In Computers & Industrial Engineering, vol. 178, article no. 109145. DOI: https://doi.org/10.1016/J.CIE.2023.109145

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. In Soft Computing, vol. 24, pp. 15733–15745. DOI: https://doi.org/10.1007/s00500-020-04903-x

LUO, X. – HE, H. – ZHANG, X. – MA, Y. – BAI, X. 2022. Failure mode analysis of intelligent ship positioning system considering correlations based on fixed-weight FMECA. In Processes, vol. 10, no. 12, article no. 2677. DOI: https://doi.org/10.3390/PR10122677

MIL-STD-1629 A:1980. Procedures for performing a failure mode, effects and criticality analysis. Available at: Procedures for Performing a Failure Mode, Effects and Criticality Analysis.

MZOUGUI, I. – CARPITELLA, S. – CERTA, A. – EL FELSOUFI, Z. – IZQUIERDO, J. 2020. Assessing supply chain risks in the automotive industry through a modified MCDM-based FMECA. In. Processes, vol. 8, no. 5, article no. 579. DOI: https://doi.org/10.3390/PR8050579

NGUYEN, T.-L. – SHU, M.-H. – HSU, B.-M. 2016. Extended FMEA for sustainable manufacturing: An empirical study in the non-woven fabrics industry. In Sustainability, vol. 8, no. 9, article no. 939. DOI: https://doi.org/10.3390/su8090939

PLINTA, D. – GOLINSKA, E. – DULINA, L. 2021. Practical application of the new approach to FMEA method according to AIAG and VDA reference manual. In Communications, vol. 23, no. 4, pp. B325–B335. DOI: https://doi.org/10.26552/COM.C.2021.4.B325-B335

RAHMADANI, M. – SUPARNO, 2021. Risk analysis for sustainable supplier selection. In Journal of Physics: Conference Series, vol. 1726, article no. 012005. DOI: https://doi.org/10.1088/1742-6596/1726/1/012005

RANA, S. – NAIR, K. S. – PAUL RUSSEL, U. S. – VINOD, M. 2022. Optimum investigation and priority ranking of hazards in aviation maintenance. In Proceedings of the 2022 Second International Conference on Interdisciplinary Cyber Physical Systems (ICPS), Chennai, India, pp. 176–181. DOI: https://doi.org/10.1109/ICPS55917.2022.00040

SHEN, G.-X. – SUN, S.-G. – ZHANG, Y.-Z. – WANG, Z.-Q. – CHEN, B.-K. – MA, C. 2014. System failure analysis based on DEMATEL-ISM and FMECA. In Journal of Central South University, vol. 21, pp. 4518–4525. DOI: https://doi.org/0.1007/s11771-014-2456-8

SI, S.-L. – YOU, X.-Y. – LIU, H.-C. – ZHANG, P. 2018. DEMATEL technique: A systematic review of the state-of-the-art literature on methodologies and applications. In Mathematical Problems in Engineering, vol. 2018, no. 1, article no. 3696457. DOI: https://doi.org/10.1155/2018/3696457

ŠMIDOVNIK, T. – GROŠELJ, P. 2023. Solution for convergence problem in DEMATEL method: DEMATEL of finite sum of influences. In Symmetry, vol. 15, no. 7, article no. 1357. DOI: https://doi.org/10.3390/SYM15071357

STN EN IEC 60812:2019. Failure modes and effects analysis (FMEA and FMECA).

THAKKAR, J. J. 2021. Multi-Criteria Decision Making. Singapore : Springer, 390 pp. eISBN 978-981-33-4745-8. DOI: https://doi.org/10.1007/978-981-33-4745-8

WANG, X. – ZHANG, Y. – SHEN, G. 2016. An improved FMECA for feed system of CNC machining center based on ICR and DEMATEL method. In The International Journal of Advanced Manufacturing Technology, vol. 83, pp. 43–54. DOI: https://doi.org/10.1007/s00170-015-7551-y

WANG, X. – GAO, X. – XING, Z. – QIN, Y. – JIA, L. 2014. Application of DEMATEL in metro door system reliability research. In 2014 10th International Conference on Reliability, Maintainability and Safety (ICRMS), Guangzhou, China, pp. 618–622. IEEE. DOI: https://doi.org/10.1109/ICRMS.2014.7107270

WANG, Z. – WANG, R. – DENG, W. – ZHAO, Y. 2022. An integrated approach-based FMECA for risk assessment: Application to offshore wind turbine pitch system. In Energies, vol. 15, no. 5, article no. 1858. DOI: https://doi.org/10.3390/EN15051858