Decision Making in Manufacturing and Services
Vol. 20 • 2026 • No. 1 • pp. 35–48

Multidimensional Identification of Key Problems of a Production Company

Weronika Derechowska*

Abstract. This paper presents the application of multi-criteria analysis to support decision-making in the manufacturing industry, where resources are limited and problems are multifaceted. The DEMATEL method is employed, in which experts assess the direct impacts of problems on one another. By applying a threshold to the total influence matrix and computing the prominence (s^+) and relation (s^-) indices, the method generates a cause-and-effect diagram that clearly distinguishes factors that act as primary causes from those that serve as effects. An empirical case study conducted at an automotive components company reveals that the key problems requiring priority attention are the limited use of modern methodologies (e.g., Lean Manufacturing), high employee turnover, and frequent machine downtime. The findings illustrate that while several issues are present, only a few exhibit substantial causal impacts that, when addressed, can lead to significant improvements across the organisation. All in all, this work provides a framework for identifying critical factors in industrial decision-making processes.

Keywords: DEMATEL, manufacturing companies' problems, problem-solving, decision making, direct and indirect influence, pairwise comparison

Mathematics Subject Classification: 90B50, 90B30, 90B70, 91B06

JEL Classification: C44, M11, L23, L62

Submitted: April 22, 2025

Revised: September 17, 2025

1. INTRODUCTION

In situations where available resources are insufficient to solve all existing problems, it becomes necessary to prioritise the most critical factors (problems) that have the most significant impact on others. Such a situation often occurs in manufacturing companies; therefore, this work attempts to answer how multi-criteria analysis can be used

* Student of AGH University of Krakow, Faculty of Management, Krakow, Poland, e-mail: weronika.derechowska@gmail.com.

DOI: https://doi.org/10.7494/dmms.2026.20.1.6931

to support decision-making on the order in which problems should be solved. For this purpose, a study was conducted to identify problems encountered in a specific company using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method.

DEMATEL belongs to the group of paired comparison methods. It consists of comparing all possible variants of a given action. These comparisons are conducted within a specific context and determine how and to what extent the two variants are related. In a formalised approach, a qualitative, ordinal rating scale is usually used to evaluate the differences between the compared variants. The results of the comparison are presented in the form of a matrix, where the element a_{ij} expresses the degree of connection between the i-th element and the j-th element:

$$\mathrm{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{1}$$

The paired comparison methods were developed scientifically in the first half of the 20th century. In 1956, George Miller developed the 7±2 rule, a crucial step in the development of paired comparison methods (Ginda, 2015).

DEMATEL is widely used to evaluate factors across various fields of manufacturing activity. For example, it has been applied to assess and prioritise barriers to implementing Maintenance 5.0 (Aallam et al., 2024), as well as to identify Industry 4.0 technologies that can be effectively integrated with Six Sigma to achieve the most significant benefits possible (Ibrahim & Kumar, 2024).

Among other methods of multi-criteria analysis, we can mention the analytic hierarchy process (AHP), analytic network process (ANP), technique for order preference by similarity to ideal solution (TOPSIS), elimination and choice translating reality (ELECTRE), and preference ranking organisation method for enrichment evaluations (PROMETHEE) (Tzeng & Huang, 2011). The DEMATEL method is often combined with other pairwise comparison methods, either in parallel or in serial arrangements. The parallel arrangement involves the independent application of different methods, followed by a comparison of the results through sensitivity analysis. In contrast, the serial arrangement uses the output of one method as the input for the next. DEMATEL is commonly used in parallel with methods such as the Analytic Hierarchy Process (AHP), Zero Unitary Method (ZUM), Wrocław Numerical Taxonomy (TNW), and Satisfied Importance Analysis (SIA). Among the various applications of the DEMATEL method, its combination with the Analytic Network Process (ANP) method is particularly notable (Ginda, 2015).

Many applications of these methods can be found in the literature, with numerous examples drawn from industry and engineering. For instance, Singh and Sharma (2023) used as many as three methods – AHP, DEMATEL, and TOPSIS – to analyse the impact of multi-agent technology on the efficiency of manufacturing companies. Broniewicz and Ogrodnik (2021) employed a combination of the DEMATEL, REMBRANDT, and multi-criteria optimisation and compromise solution (VIKOR – vise kriterijumska optimizacija i kompromisno resenje) methods to evaluate the environmental impact of a road investment within the context of sustainable development. DEMATEL stands out from other multi-criteria analysis methods because it does not assume independence between criteria and considers the feedback effect of a factor on itself (i.e., if x affects y, y affects z, and z affects x, then the impact of x on x is also considered) (Falatoonitoosi et al., 2014).

2. CHARACTERISATION OF THE DEMATEL METHOD

The DEMATEL method was developed in the 1970s at the Battelle Memorial Institute in Geneva by Emilio Fontela and André Gabus, as part of a project aimed at identifying the structure of contemporary global problems in terms of their cause-and-effect relationships. The objective was to support problem-solving by determining which issues, when resolved, would facilitate the effective resolution of others (Dytczak & Ginda, 2013; 2015).

The method is used to identify relationships among elements and classify them as causes or effects. The core concept in DEMATEL is direct influence, determined through pairwise comparisons. Relationships between pairs of elements can be either unidirectional (x affects y, but y does not affect x) or bidirectional (x affects y and y affects x). Comparisons are conducted on an ordinal scale, where the lowest value, 0, represents no influence. Subsequent values are expressed as consecutive integers, with the highest value indicating maximum influence. Intermediate values reflect increasing levels of impact. A total influence structure is generated from the direct influence structure, accounting for both direct and indirect effects (Ginda, 2015).

The original five-point scale proposed by Fontela and Gabus is used in the example presented below, where the levels represent varying degrees of influence from the first factor on the second:

0 = no direct impact,
1 = slight impact,
2 = significant impact,
3 = very large impact,
4 = extremely large impact.

The influence assessments are recorded in the direct-relation matrix $\mathbf{X}^*$, which is based on the concept of an incidence matrix (Table 1) and reflects expert evaluations.

Table 1. *Example of direct impact matrix X^**

X^*	1	2	3	4	5
1	0	4	2	1	0
2	3	0	2	0	0
3	0	2	0	0	1
4	2	3	0	0	0
5	0	0	0	2	0

When the evaluation is performed by a group of experts, each of them provides a separate direct impact matrix $X^{*(v)}$, and the direct impact structure X^* is aggregated according to the formula (Ginda, 2015):

$$\underset{i,j=1,2\ldots n}{\forall} \quad X^* = \frac{1}{V}\sum_{v=1}^{V} X^{*(v)}, \tag{2}$$

where v denotes the expert number, and V denotes the number of experts. The direct impact matrix is normalised – each element is divided by the maximum row sum (Ginda, 2015):

$$X = \frac{1}{max_{i=1,2\ldots n}\left\{\sum_{j=1}^{n} x_{ij}^{*}\right\}}, \tag{3}$$

where x_{ij} denotes the assessment of the direct impact of the i-th subsequent factor on the j-th subsequent factor, and n denotes the number of factors. The indirect impact ΔX is calculated according to the formula (Ginda, 2015):

$$\Delta X = X^2(I - X)^{-1} \tag{4}$$

where I is an $n \times n$ identity matrix. The total-relation T is expressed by the sum of the direct impact X and the indirect impact ΔX (Ginda, 2015):

$$T = X + \Delta X = X(I - X)^{-1}, \tag{5}$$

To achieve greater clarity in the results, a threshold value for total influence, denoted as θ, can be applied. This threshold indicates that any total influence value below θ is considered negligible. The value of θ can be set arbitrarily or determined based on statistical characteristics of the dataset, such as the mean, quartiles, percentiles, or deviation from the mean. In practice, more advanced methods for clarifying the structure of total influence are also used, such as the maximum mean de-entropy algorithm (Li & Tzeng, 2009).

The value of the elements of the reduced total influence structure t_{ij} is determined according to the formula:

$$\underset{i,j=1,2\ldots n}{\forall} \quad \overline{t_{ij}} = \begin{cases} t_{ij}, & t_{ij} \geq \theta \\ 0, & t_{ij} < \theta \end{cases} \tag{6}$$

The threshold value equal to the third quartile was adopted: $\theta = 0.699$.

Table 2 presents the structure of the reduced total impact of factors. Values below the threshold value are omitted.

Table 2. *Example of a reduced total impact matrix*

T	1	2	3	4	5
1	0	1.2790	0.8295	0	0
2	0.7680	0.6996	0.7050	0	0
3	0	0	0	0	0

Table 2 (cont.)

T	1	2	3	4	5
4	0.7932	1.0938	0	0	0
5	0	0	0	0	0

After applying the threshold value, the strong influence of factors 1 and 4 on factor 2 became more apparent. Moreover, all relationships involving factor 5 and other factors had intensities below the threshold and were therefore excluded from the graph.

To determine the role of each element, two indicators are calculated: prominence (s^+) and relation (s^-). The first indicator, s^+, reflects the overall importance of a component. For the i-th factor, it is calculated as the sum of the i-th row and i-th column in matrix T. Thus, the more intensively a factor relates to other factors, whether it influences them or is influenced by them, the higher its s^+ value.

The second indicator, s^-, determines whether a factor is causal or effectual. For the i-th factor, s^- is calculated as the difference between the sum of i-th row and the sum of the i-th column of matrix T. If a factor influences others more than they influence it, s^- takes a positive value, indicating a causal nature. Conversely, if others influence a factor more than it influences them, s^- takes a negative value, indicating an effectual nature.

The values of these indicators can be computed using Formulas (7) and (8) (Ginda, 2015).

$$\underset{i,j=1,2\ldots n}{\forall} \quad s_i^+ = \sum_{j=1}^{n} t_{ij} + \sum_{j=1}^{n} t_{ji}, \tag{7}$$

$$\underset{i,j=1,2\ldots n}{\forall} \quad s_i^- = \sum_{j=1}^{n} t_{ij} - \sum_{j=1}^{n} t_{ji}. \tag{8}$$

Table 3 presents the values of the s^+ and s^- indices. As can be seen, the second factor has the highest value of the prominence index (s^+) while also having the lowest value of the relation index (s^-). The fourth factor obtained the maximum s^- value. The fifth factor has the lowest value of the prominence index. In the table, maximum values are highlighted in green, and minimum values in yellow.

Table 3. *Values of s^+ and s^- indices*

Factor	s^+	s^-
C1	5.78	+0.45
C2	6.33	–1.50
C3	3.72	–1.18
C4	3.59	+1.69
C5	1.53	+0.55
max	6.33	+1.69
min	1.53	–1.50

Figure 1 presents the cause-and-effect graph based on the DEMATEL method. The horizontal axis (abscissa) represents the s^+ index, while the vertical axis (ordinate) represents the s^- index. The vertical axis intersects the horizontal axis at the midpoint between the maximum and minimum values of the s^+ index. The diagram facilitates the extraction and clustering of factors. This placement divides the coordinate system into four quadrants of the s^-–s^+ space:

- The first quadrant contains points representing the most critical factors; they are highly interconnected with other factors and act as causes.
- The second quadrant includes causal factors that are less strongly related to other factors.
- The third quadrant represents the least significant factors, which are effect-type and only weakly connected to others.
- The fourth quadrant also contains effect-type factors, but in this case, they are more strongly related to other factors.

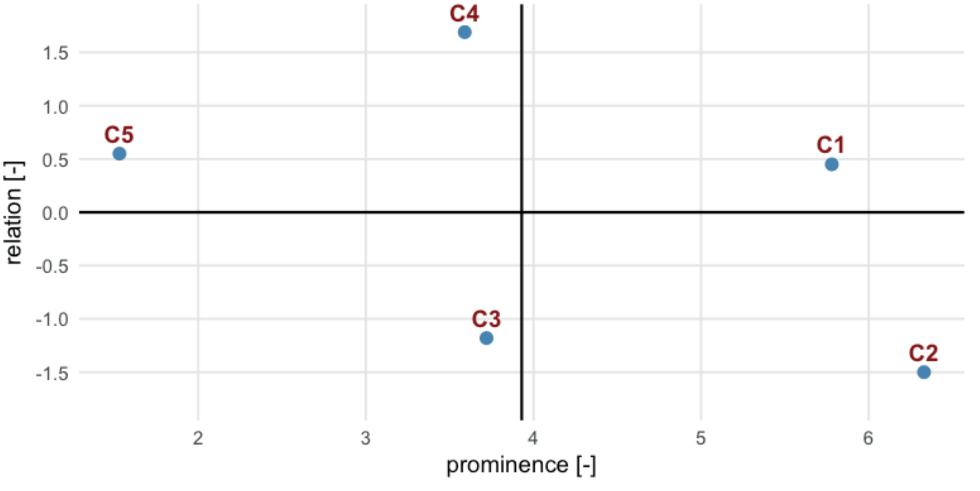

Fig. 1. *Cause-and-effect diagram*

The cause-and-effect diagram indicates that the most critical factor is the first factor (C1), as it shows strong connections to other factors and a causal relationship. It is worth noting that although C1 did not achieve the highest value in either the prominence (s^+) or relation (s^-) index, its position in the first quadrant of the coordinate system qualifies it as the most critical factor.

The fourth factor (C4), located near the vertical axis, is also relatively important. It has a moderate level of connection with other factors but exhibits a very strong causal character. The fifth factor (C5) is also causal in nature; however, due to its weak relationships with other factors, its overall importance is low. The second (C2) and third (C3) factors clearly function as effects influenced by different factors.

3. CASE DESCRIPTION

The analysed manufacturing company operates in the automotive industry, producing components for several car manufacturers. Using generative artificial intelligence and one's own experience, examples of potential problems that may arise in a manufacturing company were identified. Based on employees' opinions, one problem from each group was selected as the most frequent in the company. Table 4 presents these problems, with the most common ones in the surveyed company highlighted in bold (Długaj, 2024).

Table 4. *Examples of problems that a manufacturing company could encounter*

Group	Group description	Sample problems
1	Staffing issues	**High employee turnover**
		Lack of qualified technical staff
		Conflicts within production teams
		Low employee motivation and engagement
		Recruitment challenges
2	Financial issues	High unit production costs
		Low wages
		Cash flow problems
		Contractual penalties for delays or poor quality
3	Quality issues	**Low quality of raw materials and components**
		High level of production defects
		A large number of complaints and returns
		Costly product recalls
4	Image and relationship issues	Problems with supplier relationships (e.g., lack of trust)
		Negative media and online reviews
		Loss of customer trust
		Poor relations with trade unions
		Lack of employer visibility (employer branding)
5	Logistics and supply issues	**Delays in raw material deliveries**
		Supply chain disruptions (e.g., COVID, war, raw material crises)
		Low supplier flexibility
		Warehouse management errors
6	Technical and machinery issues	Outdated machinery and equipment
		Insufficient maintenance and inspections
		Long changeover times
		Machine downtime and breakdowns
		Low level of automation

Table 4 (cont.)

Group	Group description	Sample problems
7	Documentation and information flow issues	Limited access to technical documentation
		Outdated work instructions
		Errors in shift-to-shift communication
8	Production planning issues	**Inaccurate demand forecasts**
		Overproduction or shortages
		Frequent schedule changes
9	Organisational and managerial issues	Lack of leadership and decision-making
		No clear procedures or work standards
		Overly rigid organisational structure
		Poor layout of workstations, not aligned with the processing sequence
10	Training and development issues	Lack of onboarding training systems
		Insufficient training on machine and system operation
		Lack of managerial competence development
		Low awareness of quality and safety among employees
		No career development plans → talent drain
11	Cultural and communication issues	**Poor horizontal communication (between departments)**
		Lack of trust between employees and management
		Low workplace safety culture
		Resistance to change and innovation
12	Innovation and product development issues	**Lack/low use of modern methods (e.g., Lean)**
		No investment in R&D
		Limited cooperation with research institutions

The expert group assessing the impact of the problems on one another consisted of three individuals: a production planner, a quality department employee, and a trainee. Each expert evaluated the direct influence of one problem on another using a five-point scale (0–4) and produced a direct impact matrix $X^{*(v)}$. These matrices were aggregated using Formula (2), and the results were rounded up to the nearest integers. In this way, the general structure of direct impact X^* was obtained and expressed in matrix form (Table 5).

The matrix was then normalised using Formula (3). Next, the indirect impact, ΔX, was calculated according to Formula (4), and the total impact matrix, T (see Table 6), was determined using Formula (5). To improve the clarity of the total impact structure, the threshold $\theta_1 = 0.1727$ was applied, equal to the average total impact value. The reduced total impact matrix is presented in Table 7.

Table 5. *Direct impact matrix X**

X^*	1	2	3	4	5	6	7	8	9	10	11	12
1	0	3	3	3	1	1	1	1	0	4	2	2
2	4	0	2	2	1	1	0	1	0	4	2	2
3	1	2	0	4	1	2	0	2	0	3	0	1
4	1	3	0	0	0	0	0	0	0	0	1	0
5	1	2	3	2	0	0	0	4	0	2	0	0
6	1	3	1	2	2	0	0	2	0	4	0	2
7	2	2	0	1	1	0	0	1	1	4	0	1
8	1	1	1	0	0	0	0	0	0	3	0	1
9	1	2	1	0	0	0	1	1	0	3	0	1
10	2	3	1	2	0	0	0	3	0	0	0	1
11	1	2	0	2	1	1	0	1	1	1	0	1
12	1	2	3	3	3	3	2	2	1	2	1	0

Table 6. *Total impact matrix T*

T	1	2	3	4	5	6	7	8	9	10	11	12
1	0.2236	0.4380	0.3211	0.4128	0.1800	0.1528	0.0821	0.2664	0.0243	0.4975	0.1893	0.2385
2	0.3760	0.2969	0.2789	0.3603	0.1743	0.1486	0.0412	0.2567	0.0220	0.4823	0.1876	0.2339
3	0.2075	0.3173	0.1399	0.3712	0.1439	0.1591	0.0251	0.2486	0.0121	0.3671	0.0750	0.1541
4	0.1202	0.2187	0.0608	0.0826	0.0414	0.0333	0.0109	0.0576	0.0071	0.1038	0.0863	0.0510
5	0.1858	0.2769	0.2554	0.2607	0.0915	0.0630	0.0184	0.3168	0.0083	0.3025	0.0610	0.0959
6	0.2335	0.3832	0.2161	0.3159	0.2006	0.0844	0.0322	0.2819	0.0157	0.4469	0.0839	0.2133
7	0.2384	0.2885	0.1345	0.2190	0.1299	0.0619	0.0280	0.1935	0.0591	0.3927	0.0675	0.1454
8	0.1490	0.1878	0.1469	0.1349	0.1529	0.0484	0.0183	0.1189	0.0084	0.2864	0.0439	0.1140
9	0.1677	0.2459	0.1493	0.1441	0.0707	0.0547	0.0684	0.1634	0.0119	0.3129	0.0524	0.1283
10	0.2336	0.3208	0.1780	0.2615	0.1329	0.0673	0.0254	0.2680	0.0115	0.2184	0.0721	0.1437
11	0.1724	0.2636	0.1192	0.2410	0.1658	0.1012	0.0234	0.1737	0.0578	0.2356	0.0592	0.1306
12	0.2496	0.3759	0.3008	0.3837	0.1312	0.2282	0.1240	0.2877	0.0667	0.4076	0.1323	0.1441

Table 7. *Reduced total impact matrix for* $\theta_1 = 0.1727$

T	1	2	3	4	5	6	7	8	9	10	11	12
1	0.2236	0.4380	0.3211	0.4128	0.1800	0	0	0.2664	0	0.4975	0.1893	0.2385
2	0.3760	0.2969	0.2789	0.3603	0.1743	0	0	0.2567	0	0.4823	0.1876	0.2339
3	0.2075	0.3173	0	0.3712	0	0	0	0.2486	0	0.3671	0	0
4	0	0.2187	0	0	0	0	0	0	0	0	0	0

Table 7 (cont.)

T	1	2	3	4	5	6	7	8	9	10	11	12
5	0.1858	0.2769	0.2554	0.2607	0	0	0	0.3168	0	0.3025	0	0
6	0.2385	0.3832	0.2161	0.3159	0.2006	0	0	0.2819	0	0.4469	0	0.2138
7	0.2384	0.2885	0	0.2190	0	0	0	0.1935	0	0.3927	0	0
8	0	0.1878	0	0	0	0	0	0	0	0.2864	0	0
9	0	0.2459	0	0	0	0	0	0	0	0.3129	0	0
10	0.2336	0.3208	0.1780	0.2615	0	0	0	0.2680	0	0.2184	0	0
11	0	0.2636	0	0.2410	0	0	0	0.1737	0	0.2356	0	0
12	0.2496	0.3759	0.3008	0.3837	0	0.2282	0	0.2877	0	0.4076	0	0

Figure 2 presents a directed graph illustrating the reduced structure of total influence with factors represented by numbered vertices. The vertices of the graph, V_x, represent the assessed factors, while the arcs, E_x, represent the relationships between the compared factors (Ginda & Maślak, 2015). The subsequent colours illustrate the correspondence between a given factor and its total influence.

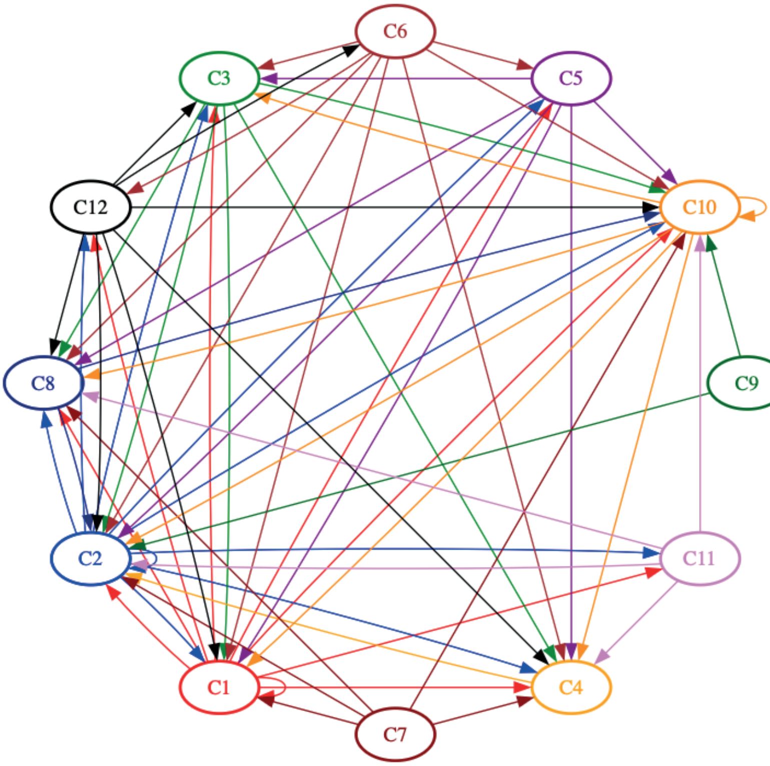

Fig. 2. *Reduced total impact structure for* $\theta_1 = 0.1727$

Next, the prominence index (s⁺) and relation index (s⁻) were calculated for the individual components using Formulas (7) and (8), respectively. The second factor exhibited the strongest connections with other factors, while the ninth factor showed the weakest. The seventh factor demonstrated the highest level of causality, whereas the third factor was the most influenced by others. All index values are presented in Table 8, with the maximum values highlighted in green and the minimum values in yellow. Figure 3 presents the cause-and-effect diagram.

Table 8. *Values of s^+ and s^- indices*

Factor		s^+	s^-
C1	High employee turnover	5.58	+0.47
C2	Low wages	6.47	–0.75
C3	Low quality of raw materials and components	4.52	–0.08
C4	Loss of customer trust	4.06	–2.31
C5	Delays in raw material deliveries	3.55	+0.32
C6	Machine downtime and breakdowns	3.71	+1.30
C7	Outdated work instructions	2.46	+1.46
C8	Inaccurate demand forecasts	4.04	–1.22
C9	Poor layout of workstations not aligned with processing sequence	1.87	+1.26
C10	Insufficient training on machine and system operation	5.99	–2.12
C11	Poor horizontal communication (between departments)	2.85	+0.63
C12	Lack / low use of modern methods e.g. Lean Manuacturing	4.62	+1.04
	max	6.47	+1.46
	min	1.87	–2.31

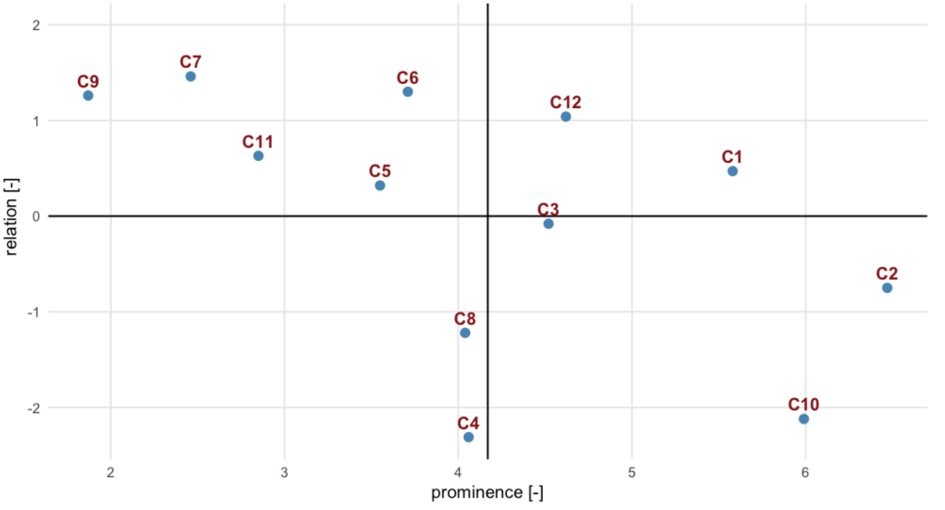

Fig. 3. *Cause-and-effect diagram*

4. RESULTS

The most important factors are those in the first quadrant of the coordinate system: the first (C1) and twelfth (C12) factors. The third factor (C3) could also be considered essential. Still, since its relation index value is close to zero (–0.08), it is more of a neutral factor, despite having strong connections with other factors. The sixth (C6), seventh (C7), and ninth (C9) factors exert a significant influence on others, though only the relation index of the sixth factor is noteworthy. The fifth (C5) and eleventh (C11) factors have positive relation indices, but their s^{-} indices are small, and their s^{+} indices are below average, indicating they have limited significance. The fourth (C4) and eighth (C8) factors fall into the third quadrant, suggesting they are effects of other causes and have moderate connections to other factors.

Among the remaining three factors in the fourth quadrant, only the second (C2) and tenth (C10) factors clearly act as effects, with strong relationships to other factors. The third factor (C3), on the other hand, has a small negative relation index, suggesting its neutral character.

No factor exhibited high values for both the s^{+} and s^{-} indices simultaneously. This suggests that the causes of problems in the manufacturing industry are specific. Seven factors demonstrate causality, four are effects, and the third is neutral. As per Formula (8), the sum of the relation indices for all factors equals zero (see Formula (9)).

$$\sum_{i=1}^{n} s_i^{-} = \sum_{i=1}^{n}\left(\sum_{j=1}^{n} t_{ij} - \sum_{j=1}^{n} t_{ji}\right) = \sum_{i=1}^{n}\sum_{j=1}^{n} t_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{n} t_{ji} = 0 \tag{9}$$

Therefore, the sum of positive relation indicators is equal in absolute value to the sum of negative relation indicators, i.e., Formulas (10) and (11) with their consequences in Formula (12).

$$a = \sum_{i=1}^{n} s_i^{-} \text{ , for } s_i^{-} > 0 \tag{10}$$

$$b = \sum_{i=1}^{n} s_i^{-} \text{ , for } s_i^{-} < 0 \tag{11}$$

$$a + b = \sum_{i=1}^{n} s_i^{-} = 0 \to a = -b \tag{12}$$

Therefore, in absolute terms, the average value of the relation index for causes is lower than the average value for effects. This suggests that there are many causes, each having a small impact, and fewer effects, each significantly influenced by other factors.

Based on the analysis conducted using the DEMATEL method, it can be concluded that the key problems facing the company are:

- C1: High employee turnover,
- C6: Machine downtime and breakdowns,
- C12: Lack/low use of modern methods (e.g., Lean Manufacturing).

5. CONCLUSIONS

The analysis presented in this paper provides a solid foundation for more in-depth research to objectively identify the key multidimensional problems faced by enterprises in the automotive industry. The conducted analysis demonstrated the simplicity and adequate usability of the basic version of the DEMATEL method, using the traditional integer scale of direct influence. However, it is recommended to apply additional multi-criteria analysis methods for further study on this topic.

The practical aspects of the research highlight significant opportunities for future improvement. For instance, the data used to perform the DEMATEL analysis – identifying the most essential company problems and the strengths of the direct connections – were gathered from a limited group of employees. This introduces a risk of subjectivity, as the results may reflect the researcher's personal perceptions. For example, machine downtime may not be perceived as excessive by higher-level managers but may appear more significant to lower-level employees. Similarly, Lean Manufacturing may be more widely implemented within the company than employees perceive, as their opinions may be based on limited personal involvement in the Lean philosophy. Therefore, it is advisable to continue this analysis in the future, utilising more diverse data sources to achieve a more accurate understanding of the problem structure affecting companies.

ACKNOWLEDGEMENTS

I would like to thank my supervisors, Grzegorz Ginda and Katarzyna Gdowska, for their support.

REFERENCES

Aallam M., Cherrafi A., Zekhini K. & Elfezazi S. (2024). A fuzzy DEMATEL approach for exploring barriers to the successful implementation of Maintenance 5.0 in the manufacturing industry. In: Kahraman C., Cevik Onar S., Cebi S., Oztaysi B., Tolga A.C. & Ucal Sari I. (Eds.), *Intelligent and Fuzzy Systems. INFUS 2024*. Lecture Notes in Networks and Systems, **1089**, pp. 658–665. **DOI:** https://doi.org/10.1007/978-3-031-67195-1_73.

Broniewicz E. & Ogrodnik K. (2021). A comparative evaluation of multi-criteria analysis methods for sustainable transport. *Energies*, **14**(16), 5100. **DOI:** https://doi.org/10.3390/en14165100.

Długaj W. (2024). *Wielowymiarowa identyfikacja kluczowych problemów wybranego przedsiębiorstwa* [Bachelor's Thesis]. Krakow: AGH University of Krakow, Faculty of Management.

Dytczak M. & Ginda G. (2013). Is explicit processing of fuzzy direct influence evaluations in DEMATEL indispensable. *Expert Systems with Applications*, **13**(12), pp. 5027–5032. **DOI:** https://doi.org/10.1016/j.eswa.2013.02.034.

Dytczak M. & Ginda G. (2015). Miejsce metody DEMATEL w rozwiązywaniu złożonych zadań decyzyjnych. *Zeszyty Naukowe Wyższej Szkoły Bankowej we Wrocławiu*, **15**(5), pp. 631–644. **URL:** https://bazekon.uek.krakow.pl/rekord/171405075 [22.04.2025].

Falatoonitoosi E., Ahmed S. & Sorooshian S. (2014). Expanded DEMATEL for determining cause and effect group in bidirectional relations. *The Scientific World Journal*, **2014**, 103846. **DOI:** https://doi.org/10.1155/2014/103846.

Ginda G. (2015). *Metody porównywania parami w budownictwie i dziedzinach pokrewnych*. Wrocław: Dolnośląskie Wydawnictwo Edukacyjne.

Ginda G. & Maślak M. (2015). *Wybrane metody analizy eksperckiej w wielokryterialnej ocenie parametrów determinujących bezpieczeństwo w pożarze*. Kraków: Wydawnictwo Politechniki Krakowskiej.

Ibrahim A. & Kumar G. (2024). Selection of Industry 4.0 technologies for Lean Six Sigma integration using fuzzy DEMATEL approach. *International Journal of Lean Six Sigma*, **15**(5), pp. 1025–1042. **DOI:** https://doi.org/10.1108/ijlss-05-2023-0090.

Li C.-W. & Tzeng G.-H. (2009). Identification of a threshold value for the DEMATEL method using the maximum mean de-entropy algorithm to find critical services provided by a semiconductor intellectual property mall. *Expert Systems with Applications*, **36**(6), pp. 9891–9898. **DOI:** https://doi.org/10.1016/j.eswa.2009.01.073.

Singh V. & Sharma S.K. (2023). Applying hybrid approach of AHP, DEMATEL, and TOPSIS to study the impact of multiagent technology on the performance of manufacturing organizations. *IEEE Transactions on Engineering Management*, **71**, 9299–9313. **DOI:** https://doi.org/10.1109/tem.2023.3293948.

Tzeng G. & Huang J. (2011). *Multiple Attribute Decision Making Methods and Applications*. Boca Raton: CRC Press. **DOI:** https://doi.org/10.1201/b11032.