Contribution of the MCDM techniques in the maintenance function: PROMETHEE VS TOPSIS & Criticality matrix

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Abstract

This work falls within industrial maintenance decision-making process. In this context, the identification of the most critical equipment is usually handled in maintenance studies using classical risk assessment methods such as criticality matrix and Pareto diagram. Knowing that criticality depends on many factors, the framework of Multi-Criteria Decision Making (MCDM) techniques is well suited for the prioritization of critical equipment.

In this article, we propose a classification of industrial equipment following a comparative approach between PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluation), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) and the criticality matrix method. The prioritization of the 12 pieces of equipment considered, in the studied gas complex, is carried out according to fundamental and essential criteria in maintenance which are reliability, productivity and costs. In order to ensure the consistency of the judgments, the evaluation of the behavior of each piece of equipment in relation to these 3 criteria was carried out using industrial history data.

Keywords: MCDM, PROMETHEE, TOPSIS, Criticality matrix, Maintenance, Prioritization.

1. Introduction

The maintenance function is recognized by manufacturers and scientists as a key lever for controlling risks and optimizing company performance. In this context, the maintenance decision-making process is located at several levels involving foremost, identification of most critical equipment. This decision problem is usually handled in industrial maintenance studies using classical risk assessment methods, such as criticality matrix and Pareto diagram. In addition to these methods, Multi-Criteria Decision Making (MCDM) techniques are well suited for critical equipment prioritization, such as PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluation) and TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution).

Aim of this work is to confront PROMETHEE with TOPSIS and criticality matrix methods on an industrial case. The case study consists in conducting a criticality analysis on a sample of 12 pieces of equipment, taken from a production line located in a gas complex. The prioritization is carried out according to fundamental and essential criteria in maintenance which are reliability, productivity and costs. In order to ensure consistency of judgments, the behavior evaluation of each piece of equipment with respect to these 3 criteria is carried out using real history data.

The methodological support of proposed approach integrates sequential steps of any multi-criteria analysis approach, which we have grouped under two modules. The first module concerns evaluation of each piece of equipment with respect to the criteria, sanctioned by a performance table. The second module defines criteria aggregation approach achieved through implementation of the three methods falling under complete and partial aggregation. Final result is the equipment classification according to their criticality degree.

The three methods used are presented in the second section. Section 3 is devoted to the classification of considered 12 pieces of equipment by establishing first, the performance table and then implementing the three methods: Criticality matrix, PROMETHEE and TOPSIS. Finally, discussion of the results will follow the results interpretation along with some concluding remarks.

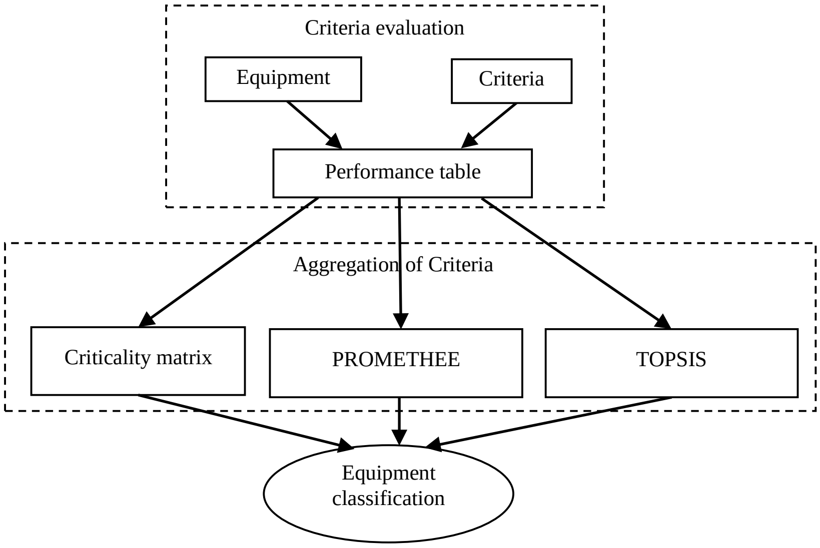

Figure 1 - Methodological support of the proposed approach

2. Description of the methods

2.1 Criticality matrix method

The complete aggregation approach consists in assembling all the performance particularities across the different criteria in a single function, through a single synthesis criterion (Mena, 2000). Following this definition, we consider criticality matrix method as a complete aggregation approach. In this method, based on the Farmer's diagram principle (DESPUJOLS, 2009), the criticality takes into account both the probability of failures occurrence (O) and their consequences' severity (S).

The criticality C, per criterion, is defined as the product of the failure' occurrence probability O and its severity S:

$$C = O\,x\,S \tag{1}$$

The overall criticality Cr of each piece of equipment is then calculated by multiplying the criticalities per criterion:

$$Cr = \Pi\, Ci\ (i = 1 \text{ to } n),\ (n = \text{number of criteria}) \tag{2}$$

Criticality analysis using this method allows to integrate as many criteria in the calculation of the equipment criticality and to prioritize them, accordingly. The most critical degree is characterized by the lowest criticality value Cr.

2.2 PROMETHEE method

PROMETHEE (Brans & De Smet, 2016; Brans & Vincke, 1985; do Carmo Mendonça et al., 2018; Mavrotas & Rozakis, 2009) is an outranking method which falls under partial aggregation of the criteria ; the process is as follows:

- Specification of relative weights w_i of each criteria reflecting their importance in the decision process, and definition of the alternative's local preferences per criterion (alternatives represent equipments in the case under-study).
- Determination of the preference function $F\ (a, b)$, expressing preference of the alternative a over the alternative b according to a specified criterion, defined on its optimization sense and its type.
- Calculation of the index $\pi\ (a, b)$ representing over-classification degree between the alternatives a and b according to whole set n of criteria:

$$\pi(a, b) = \frac{\sum_{i=1}^{n} F_i\ (a,b)\ \text{x}\ w_i}{\sum w_i} \tag{3}$$

- Calculation of outcoming flow $\phi^+(a)$ and incoming flow $\phi^-(a)$, reflecting, respectively, the strength and weakness of the alternative a over the remaining alternatives x :

$$\phi^+(a) = \frac{\Sigma\, \pi(a,x)}{(m-1)} \tag{4}$$

$$\phi^{-}(a) = \frac{\Sigma\, \pi(x,a)}{(m-1)} \tag{5}$$

where m is the number of the considered alternatives.

- Calculation of the net flow $\phi(a)$ allowing to rank alternatives accordingly, where highest value represents the best alternative, while the lowest value represents the worst alternative:

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a) \tag{6}$$

2.3 TOPSIS method

TOPSIS (Özcan et al., 2017) is a compensatory method based on the total aggregation of the criteria, described as follows:

- Construction of the so-called decision matrix $(X_{ij})_{m\times n}$, where m is the number of alternatives and n is the number of criteria ; intersection of each alternative with a criterion is filled with a X_{ij} value representing its initial local preference (input data).
- Derivation of the normalized decision matrix $(R_{ij})_{m\times n}$ by rescaling inputs according to equation (7):

$$R_{ij} = \frac{X_{ij}}{\sqrt{\sum_{k=1}^{m} X_{ij}^{2}}} \tag{7}$$

- Calculation of the weighted normalized decision matrix $(V_{ij})_{m\times n}$ using the following equation:

$$V_{ij} = R_{ij} \times w_j \tag{8}$$

where w_j is the relative weight of the criterion j.

- Identification of ideal solution V_j^{+} and anti-ideal solution V_j^{-}, in each column:

$$V_j^{+} = (max\, V_{ij} \mid j \in J^{+}), (mix\, V_{ij} \mid j \in J^{-}) \tag{9}$$

$$V_j^{-} = (min\, V_{ij} \mid j \in J^{+}), (max\, V_{ij} \mid j \in J^{-}) \tag{10}$$

where $J^{+} = \{j = 1,2, \dots n \mid j\}$ is associated with beneficial criteria which are subject of maximization.
$J^{-} = \{j = 1,2, \dots n \mid j\}$ is associated with non-beneficial criteria which are subject of minimization.

- Calculation of distance separating each alternative from the ideal and the anti-ideal solutions, using equations 11 and 12, respectively.

$$S_i^{+} = \sqrt{\sum_{j=1}^{n}(V_{ij} - V_j^{+})^2} \tag{11}$$

$$S_i^{-} = \sqrt{\sum_{j=1}^{n}(V_{ij} - V_j^{-})^2} \tag{12}$$

where $i = 1, 2, 3, \dots m$.

- Calculation of the performance score P_i for each alternative using equation (13), allowing to rank the alternatives accordingly:

$$P_i = S_i^{-} / (S_i^{-} + S_i^{+}) \tag{13}$$

where $0 \le Pi \le 1$ and $i = 1, 2, 3, \dots m$.

3. Equipment prioritization

3.1 Criteria evaluation

The problem is to prioritize 12 pieces of equipment, belonging to a production train in a gas complex, in order to assign the priority maintenance actions. In this context, the alternatives or actions are the 12 pieces of equipment ([E1], [E2], …, [E12]) and the criteria retained are related to their reliability, the production losses they generate and their impact on the costs. Each criterion was evaluated through a 4 levels judgement scale (Table 2) from the most to the least critical, according to a probability of occurrence (O) and a severity (S). These two parameters were expressed, under each criterion, using the relevant history data (Table 1).

Table 1 – Thresholds of the parameters O and S per criterion

Scale per criterion			**1**	**2**	**3**	**4**
Reliability	MTBF (Hours) Availability (%)	O S	≤ 250 ≤ 80%	≤ 1000 > 250 > 80% ≤ 85%	≤ 2000 > 1000 > 85% ≤ 95%	> 2000 > 95%
Production	Stops/year Shortage (%)	O S	≥ 3 > 5	< 3 ≥ 1 ≤ 5 > 2	< 1 > 0 ≤ 2 > 0	= 0 = 0
Cost	ABC Analysis Cost / Global cost	O S	A: 20-50 ≥ 0.075	B: 30-15 < 0.075 ≥ 0.01	C: 50-5 < 0.01 > 0.002	 ≤ 0.002

The data used (Noureddine & Noureddine, 2012) allow to produce the performance table (Table 2) which permits to evaluate each piece of equipment coded in the criteria space according to the two parameters O and S. The final evaluations per criterion were obtained by introducing the notion of criticality C, by criterion, which is defined as the product of the probability of occurrence of the failure by its gravity ($C = P \times G$).

Table 2 – Performance table

Code	**Designation**	**Criticality (C)**		
		Reliability	Production	Cost
[E1]	2nd stage compressor for MCR	16	9	1
[E2]	Combustible gas compressor turbine	16	16	1
[E3]	Reactivation Blower	16	16	1
[E4]	1st stage compressor for MCR	16	6	1
[E5]	Propane compressor	16	6	1
[E6]	Main exchanger	12	1	1
[E7]	Absorber column of MEA	16	9	2
[E8]	Combustible gas compressor	16	16	2
[E9]	Main lubricant oil pump	16	16	6
[E10]	Butane recycling pump	8	16	2
[E11]	Secondary Butane recycling pump	12	16	2
[E12]	Dust filter	16	3	4

The same performance table (table 2) is successively implemented in the three analyses performed by the criticality matrix, PROMETHEE and TOPSIS, under the same normalization conditions (same weighting for the 3 criteria: production, reliability and cost).

3.2 Criticality matrix analysis

It follows from Table 2, associated with equations (1) and (2), generating the criticality measurements of the equipment along with their ranking, presented in Table 3. The results obtained show the arrangement of the considered 12 pieces of equipment, according to their degree of criticality, following 9 classes.

Table 3 – Criticality matrix ranking

Equipment	*Cr*	Class
[E6]	12	1
[E4]	96	2
[E5]	96	
[E1]	144	3
[E12]	192	4
[E2]	256	5
[E3]	256	
[E10]	256	
[E7]	288	6
[E11]	384	7
[E8]	512	8
[E9]	1536	9

3.3 PROMETHEE analysis

For the implementation of the PROMETHEE method, we use the online Visual PROMETHEE software (Mareschal, 2012). The application of the method (equations (3), (4), (5) and (6)) gives the matrix (Figure 2), where the arrangement of the considered 12 pieces equipment is done according to a hierarchy of the net flow (ϕ), producing 9 classes.

PROMETHEE Flow Table

	Action	Phi	Phi+	Phi-
1	E6	0.7576	0.7879	0.0303
2	E4	0.2727	0.4242	0.1515
3	E5	0.2727	0.4242	0.1515
4	E1	0.1515	0.3636	0.2121
5	E10	0.0303	0.3939	0.3636
6	E11	-0.0606	0.3333	0.3939
7	E2	-0.0909	0.1818	0.2727
8	E3	-0.0909	0.1818	0.2727
9	E12	-0.0909	0.3333	0.4242
10	E7	-0.1515	0.2424	0.3939
11	E8	-0.3939	0.0606	0.4545
12	E9	-0.6061	0.0000	0.6061

3.4 TOPSIS analysis

For the implementation of the TOPSIS process, we used a matlab code (Bouchaala et al.). The application of the method (equations (7) to (13)) gives the performance scores which allow to classify the 12 pieces of equipment following their criticality order. As illustrated in Figure 3, we get 10 classes.

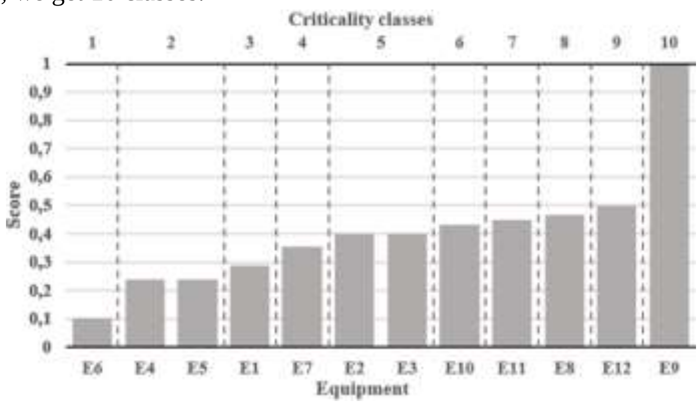

Figure 3 – TOPSIS ranking

4. Interpretation and discussion of the results

4.1 Comparison of the results

Table 4 presents the obtained criticality ranking according to the three methods used: criticality matrix, PROMETHEE, TOPSIS. Through the analysis of this table, we can distinguish the similarities and the differences between the results of the three methods.

- The pieces of equipment [E6], [E4-E5], [E1] and [E8] are classified in the same positions (1st, 2nd, 3rd, and 8th respectively) according to the three methods; criticality matrix, PROMETHEE and TOPSIS.
- [E9] is classified in the 9th position by PROMETHEE and criticality matrix, while it shows up in the 10th class in TOPSIS classification. Nevertheless, it is the least critical piece, in either cases.
- [E2-E3], [E7], [E10], [E11] and [E12] are classified differently in the 3 appraoches. [E2-E3] are in 6th position in PROMETHEE and 5th in both criticality matrix and TOPSIS. [E11] is in 5th position in PROMETHEE and 7th both in criticality matrix and TOPSIS. Respectively, [E7], [E10], [E12] are 7th, 4th, 6th in PROMETHEE but 6th, 5th, 4th in criticality matrix and 4th, 6th, 9th in TOPSIS.

Table 4 – PROMETHEE vs Criticality matrix & TOPSIS

Criticality classes	Obtained criticality ranking		
	Criticality matrix	***PROMETHEE***	***TOPSIS***
1	[E6]	[E6]	[E6]
2	[E4-E5]	[E4-E5]	[E4-E5]
3	[E1]	[E1]	[E1]
4	[E12]	[E10]	[E7]
5	[E2-E3] – [E10]	[E11]	[E2-E3]
6	[E7]	[E2-E3] – [E12]	[E10]
7	[E11]	[E7]	[E11]
8	[E8]	[E8]	[E8]
9	[E9]	[E9]	[E12]
10			[E9]

4.2 Discussion of the results

Then, 40% of the pieces of equipment ([E6], [E4-E5], [E1] and [E8]) are classified identically by the 3 methods. Also, 30% of the pieces of equipment ([E6], [E4-E5], [E1]) are identified as the most critical in classes 1, 2, 3 by the three methods.

The differences start from the 4th class. We first note that we get 9 classes by the criticality matrix and PROMETHEE, while we obtain 10 by TOPSIS. According to the input scores, [E10] is clearly more critical than [E2-E3], whereas these two pieces are less critical than [E11], as they perform slightly better. This falls in favor of the PROMETHEE classification unlike TOPSIS and the criticality matrix. Also, the positioning of [E12] in the penultimate class, in the TOPSIS classification rather than [E8], as in the PROMETHEE ranking, seems to be a misplacement. Although [E12] is as twice as efficient under the cost criterion, it remains more critical, as it is more than 5 times less efficient on the production criterion, while the equality dominates on the cost criterion. Consequently, it should be given a higher priority, and this is what we note in the PROMETHEE ranking where it appears in the 6th class next to [E2-E3]. From another side, [E8] has the closest local preferences to the ideal alternative ([E9]). So, it should be considered as the second least critical alternative after it, while it is more convenient to classify [E2-E3] close to [E8] as these are semi-copies; once again, this is the case in the PROMETHEE classification unlike TOPSIS and criticality matrix.

Finally, the fact of obtaining an additional class by TOPSIS, to move [E9] (the least critical according to the 3 methods) from the 9th class (PROMETHEE and criticality matrix) to the 10th (TOPSIS), is useless from the point of view of maintenance.

5. Conclusion

The multitude of factors involved in the maintenance function decisions makes MCDM techniques well-suited for this context. However, their increasing development in recent decades has led to the emergence of many methods posing a choice issue for decision-makers. This is where comparative studies contribute by providing more knowledge about the behavior of these methods and assisting the decision maker to choose the best-fitting technique to his problem.

In this work, we proposed to compare PROMETHEE with TOPSIS and the criticality matrix, within the framework of equipment prioritization. This level of decision is considered of a major importance because it is the base from which almost all the maintenance actions emanate. These three techniques are found to be commonly used, in this context.

The comparison showed that the three methods give an identical rate of 40%. For the rest of the differences, the results obtained using PROMETHEE seem overall more correct, as they respect better the chosen criteria weighting and shows less mis-assessments. As future perspectives of this work, we suggest conducting further comparisons with other MCDM techniques to provide more knowledge in this scope.

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