

Hybrid use of Borda count and PROMETHEE method for maintenance strategy selection problem

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Abstract. For long-term success, organizations and manufacturing companies must exploit the potential strengths of collective decision making in maintenance management. The maintenance strategy selection issue has been studied in a single decision-maker framework for a long time. This research is one of the first attempts at dealing with the enhancement of maintenance management through the participation of stakeholders in the decision making process. In this context, the author introduces a participatory multi criteria decision model that combines Borda count and PROMETHEE methodology to select the most appropriate maintenance strategy; in accordance with the decision makers' preferences on a set of strategies evaluated according to conflicting criteria. Therefore, the PROMETHEE II method is used to manage the individual decisions of each stakeholder, while the Borda count is in charge of collectively selecting the best maintenance strategy, taking as a starting point stakeholder's preferences being established thanks to PROMETHEE II. In the same context, the proposed model was applied to a real scenario: a textile company, and can be easily replicated in other industries.

Keywords: maintenance strategy selection, Borda count, PROMETHEE II method, multi criteria decision making, group decision support system, stakeholder participation

1. Introduction

Improving manufacturing performance has become a capital requirement in the face of current global competition and increasing customer demands.

Machines used in industries continually need maintenance. Thus, appropriate maintenance can extend their life and prevent costly breakdowns that can result in lost production, failed shipping schedules, and decreased customer satisfaction [23].

Over the years, different types of maintenance have been proposed to be successfully applied in a variety of sectors, such as the aviation, nuclear, and maritime industries.

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However, these strategies can be classified into more than a few categories: corrective maintenance, time based preventive maintenance, condition based maintenance, and predictive maintenance. Nevertheless, each maintenance strategy has its own characteristics, benefits, and drawbacks [7].

Definitely, the selection of the most suitable maintenance strategy for a specific machine or group of machines has shown to be a complex task, inclusive of distinct strategies evaluated in accordance with a set of conflicting criteria, such as reliability, service quality, risk, etc.

Multi criteria methodologies can be seen as the most scientific way to ensure an informed and justified decision for decision-makers [6].

The main paradigm of the maintenance selection process is the human factor, which cannot be avoided as the decisions are made by humans. However, a single decision maker (DM) may not be able to consider all relevant aspects of a decision or may not have all the required information [35]. Besides, multiple decision makers (DMs) could be required for a group decision making (GDM) process that involves multiple criteria.

The participation of decision makers in multi criteria maintenance strategy selection may greatly improve the quality of final decisions, but it also changes and complicates the focus of the problem by moving from a multi criteria decision making problem to a multiple criteria group decision making (MCGDM) issue [26].

Multi criteria group decision making has become quite popular in recent years. More realistic and adapted for real world problems, MCGDM approaches have successfully been studied and applied in different fields, such as engineering project management selection, green supplier selection, portfolio allocation, etc. [17]. However, there are very few studies devoted to the use of these approaches in the maintenance management field. In this context, the present research concerns the design of a multi criteria group decision making model that devotes itself to selecting the most appropriate maintenance strategy, in accordance with the decision makers' preferences on a set of strategies evaluated according to conflicting criteria.

The proposed model illustrates how the combination of the PROMETHEE II multi criteria method and the Borda voting mechanism provides a useful tool for selecting the best strategy in a multi criteria and multi stakeholder context. Therefore, the PROMETHEE method is used to manage individual decisions, while Borda count is in charge of determining a consensus group decision derived from the decision makers preferences.

The outline of this paper is as follows: An overview of existing works related to selection of maintenance strategy is provided in section 2. As for section 3, the motivations and main contribution of this work are depicted; some basic backgrounds on voting procedures are given in section 4. With regards to section 5, it is devoted to the description of the participatory multi criteria decision model, whilst a detailed case study is used to show the usefulness of the proposed model in section 6. Finally, section 7 provides the conclusions of the study.

2. Related works

During the last few years, the maintenance strategy selection (MSS) issue has received considerable attention. Various multi criteria models have been developed by researchers to select/ choose maintenance strategies for different equipment or system. A set of pertinent studies is summarized on Table 1.

Table 1. Proposed multi criteria methods for maintenance strategy selection in the literature.

Reference	Tools / Methodologies used	Application Area
[8] [27] [31]	AHP (Analytical Hierarchy Process)	-Italian oil refinery -Cement factory -Oil and gas sector
[9]	Fuzzy AHP	Manufacturing unit
[21]	Fuzzy TOPSIS method	Handling equipment (India)
[32]	Fuzzy simple additive weighting (SAW)	Material handling machine.
[20]	Fuzzy Delphi method	General equipment
[34]	AHP and TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) methods	Textile spinning
[5]	AHP and GP (Goal Programming)	Oil refinery (Centrifugal pumps)
[30]	AHP and FAHP methods	Cement manufacturer (Iran)
[3]	AHP, TOPSIS, and VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje) methods	Aviation context
[1]	DEMATEL (DEcision MAKing Trial and Evaluation Laboratory), FAHP and FTOPSIS methods	Industrial applications
[33]	ANP (Analytic Network Process) and Cost Risk Criticality Analysis Model	Renewable energy (wind turbine)
[2]	Fuzzy Delphi, fuzzy DEMATEL and fuzzy ANP methods	Petrochemical industry
[4]	DEMATEL, ANP and VIKOR methodologies	Distillation units of oil refinery plants
[15]	Combined method of BWM , TOPSIS and goal programming,	Production industry
[16]	Delphi, AHP and PROMETHEE methods	Ship machinery systems
[24]	Group decision-making methodology based on cloud DEMATEL-ANP	Mechanical application (meta-action unit)

3. Motivations and contribution

The emerging trend in current research is the integration of decision makers in the decision making process. This aspect, however, does not seem to have received much attention in the maintenance strategy selection literature. Indeed, it was seen that only one paper handled the participation of stakeholders in the decision making process [24]; almost all the maintenance strategy models suggested in the literature adopt conventional approaches based on single person decision making.

Primarily motivated by the lack of tools destined for integrating stakeholder's opinions in the selection of the maintenance strategy, the author develops a participatory decision model for identifying, incorporating, and considering decision makers' preferences to select the most appropriate maintenance strategy based on a set of criteria.

Unquestionably, the group selection of the best maintenance strategy is a challenging process because of the presence of a set of conflicting criteria and several stakeholders, each with their own objectives and preferences with regards to the maintenance strategies. In the light of such a perspective

- How determine decision maker preferences pertaining to the candidate strategies described by a set of criteria?
- Which methodology should be used to determine the best maintenance strategy while taking into count the decision makers' preferences ?
- How can we reach a consensus decision when there is disagreement and conflicts among decision-makers ?

Voting systems are regarded by GDSS (Group Decision Support System) researchers as a valuable mechanism for resolving disagreements, and the outcome of voting is regarded as the collective choice made by the group. On the other hand, multi criteria decision making (MCDM) methods provide a rich collection of techniques and procedures for revealing decision-makers' preferences along with taking into account multiple criteria. More to the point, the combination of both of these approaches may give a high-potential multi criteria group decision making tool to assist decision makers in choosing the best maintenance strategy.

Several voting methods have emerged, some of which are difficult to explain and which can elect different options or alternatives. In this respect, decision makers require procedures that are not mathematically complicated and that allow them to reconcile their different preferences to a common consensus. For such purposes, our choice is the Borda count that is described as a consensus based system rather than a majoritarian one, the Borda count is a quick and easy procedure that intends to elect broadly acceptable alternatives rather than those preferred by a majority [29]. The Borda system requires that decision makers arrange all the alternatives in a linear manner and state their preferences as a ranking of alternatives from top to bottom [14]. In this case,

- which multi criteria methodology employs to express the preferences of decision-makers as an ordered list?

The choice of the MCDA method in use has been shown to be very important since it has a significant effect on the final outcome. Through their structured process, sound mathematical foundation, and varied analytical and graphics tools, PROMETHEE (Preference ranking organization method for enrichment evaluations) multi criteria methods have been used in a variety of study fields; including education, agriculture, government, health care, tourism, and sports [11]. Despite the fact that they are very easy in concept and implementation compared to many other methods for multi criteria analysis, PROMETHEE methods are rarely used in strategy selection problems.

The family of PROMETHEE includes several methods that can be used for different kinds of problems .PROMETHEE I and II (for partial and complete rankings)[12], PROMETHEE III (interval order) and IV (continuous case) [13], PROMETHEE V (for constrained multi criteria selection), PROMETHEE VI (using interval values for human brain views), Gaia (visualization applications) [11], and PROMÉTHÉE GDSS (to take into account simultaneously a multitude of criteria expressed by several decision makers to get a global ranking of the alternatives) [25].

The PROMETHEE II method was identified as the most appropriate to be combined with Borda count since it provides a complete ranking of the alternatives from the best to the worst one according to several criteria [12]. In this context, the author develops an integrated group model based on PROMETHEE II and Borda system to enhance the selection of the best maintenance strategy. In virtue of which, the participatory model allows to

- Improve the effectiveness and quality of decision making through the incorporation of judgments and preferences of stakeholders into the decision making process.
- Represent the preferences of stakeholders concerning the potential maintenance strategies, taking into account quantitative and/or qualitative criteria, thanks to the PROMETHEE II method.
- Select the most suitable strategy in a participative context. The Borda voting procedure is used as support to find a consensus decision under the conflicting preferences of the decision makers. Besides, Borda count takes as input the stakeholders' individual preferences and produces as output the final (winner strategy) decision that represents the collective preference of the group.

4. Voting systems

Voting systems include a set of procedures and models addressed to aggregate individual inputs into collective outputs. Some voting procedures useful for group decision making are discussed in this section [14].

4.1. Plurality voting

Plurality voting is a very basic procedure commonly used for electing members of a legislative assembly or executive officers. Every voter selects one candidate, and the candidate(s) with the most votes wins [28].

4.2. Hare system

Hare is a voting method in which voters rank a set of candidates in order of preference [10].

- If a candidate is ranked first by more than 50% of the voters, then that candidate is declared the winner.
- If there is no candidate with a strict majority of first place votes, repeatedly delete the candidate or candidates that receive the fewest first place votes.

The first candidate to be ranked first by strict majority of voters is declared the winner, if there is no such candidate then the remaining candidate(s) are declared the winners.

4.3. Condorcet method

The notion of a Condorcet winner is among the most relevant ones in social choice. The Condorcet voting system uses a series of pairwise comparisons in order to determine the candidate, often called a 'dominant candidate' [19].

A candidate X wins the election if preferred by other voters in "head to head" comparison. Whenever there is a Condorcet winner, it has to be unique.

4.4. Borda count

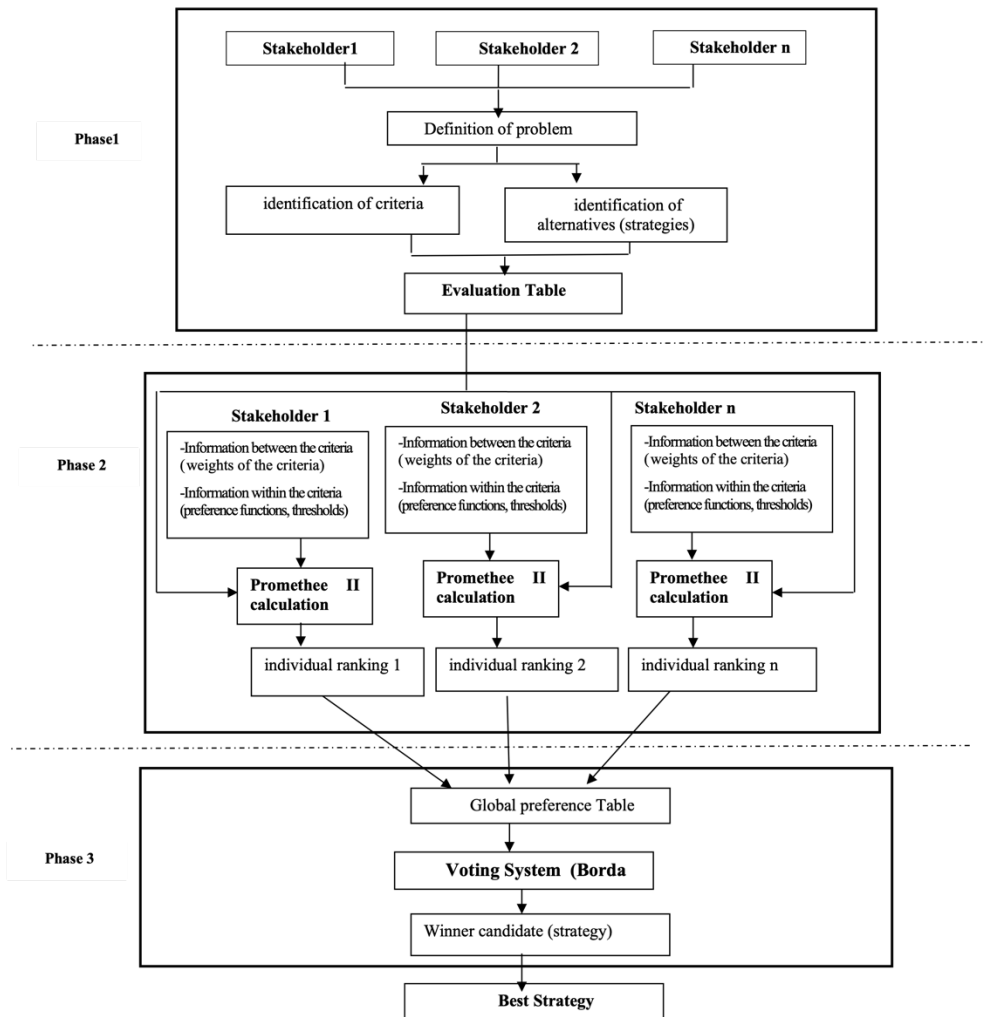
The Borda count is a voting method that gives each candidate a score based on each voter's preferences. The candidate(s) with the highest scores is the social choice [22].

The Condorcet and Borda methods are the most commonly used voting systems in group decision making because they satisfy many criteria like majority, neutrality, pareto, and monotonicity used for evaluating the quality of voting procedures [14].

Unlike the Condorcet method, which does not always produce a winner (a phenomenon known as the Condorcet paradox), the Borda count is a family of single winner election methods that allows for the selection of winners in any situation.

5. Participatory multi criteria decision model

The proposed participatory multi criteria decision model enables the selection of the most appropriate maintenance strategy in a multi stakeholder and multiple criteria context through the combination use of the PROMETHEE II multi criteria method and Borda voting system. The decision making model as illustrated in Figure1, operates in three main phases.

Figure 1. Participatory multi criteria decision model

5.1. Phase 1: data collection

Aims to clearly define the problem by the actors/stakeholders who are affected by the final choice of maintenance strategy. After significant discussion and interaction between the different stakeholders, the basic elements formalizing (alternatives, criteria, evaluations) the treated problem are identified.

5.1.1. Step 1: identification of strategies (alternatives)

The first element to be identified is the candidate strategies under consideration that decision makers regard as possible solutions for the decisional situation in progress.

5.1.2. Step 2: identification of criteria

Consists of drawing up a list of potential criteria that could be taken into account in the evaluation of strategies. The list of criteria prepared by the various decision makers should be as complete as possible and must verify the conditions of exhaustivity, consistency, and independence.

5.1.3. Step 3: evaluation of alternatives

The impact of each alternative on every criterion is evaluated; these evaluations (performances) are summarized in a table called a "performance matrix", the rows represent the alternatives (strategies), the columns represent the criteria, and the cells of the matrix indicate the performance (evaluation) of each alternative in terms of each criterion.

5.2. Phase 2: identification of individual preferences

Aims at capturing the stakeholders' preferences concerning the potential strategies according to a set of quantitative and/or qualitative criteria.

Stakeholders' individual preferences are expressed in total preorders (rankings); for this purpose, PROMETHEE II (Preference Ranking Organization METHod for Enrichment Evaluations) a powerful multi criteria method is used separately by each decision maker.

PROMETHEE II method is particularly well-fitted in our situation and offers the following advantages [11]:

- The simplicity of the use and the power of its preference functions.
- The mix potential uses both quantitative and/or qualitative criteria.
- Exploitation of the subjective parameters (weight, indifference, and preference thresholds) attributing a high level of effectivity to the decision support.

- Produces a complete ranking of all the alternatives, from the best to the worst one.
- The results are consistent, easy to understand, and require less information as compared with other methods.

5.2.1. Step 1: preferences articulation

In order to be conducted, the PROMETHEE II method requires as input the performance matrix completed with some elements of the decision maker's preference modeling [18]. These elements will consist of information between the criteria (criteria weight) and information within the criteria (preference functions and parameters in them).

- Stage 1: selection of the preference function

To model the decision maker's preferences according to each criterion, a preferred function must be defined. The preference function characterises the difference for a criterion between the evaluations obtained by two possible alternatives into a preference degree ranging from 0 to 1.

The decision maker can choose from six types of preference functions suggested by the developers of the PROMETHEE II methodology [28].

- Type I (Usual preference function): the very simple case without any threshold.
 - Type II (U-shape preference function): always used for qualitative criteria and it uses a single indifference threshold which should be fixed.
 - Type III (Linear preference function): it is appropriate for quantitative criteria. The choice will depend on whether an indifference threshold is introduced or not.
 - Type IV (Level preference function): used in the case of an indifference and a preference threshold which must be fixed.
 - Type V: (V-shape preference function): a special case of the linear preference function where the indifference threshold is equal to 0.
 - Type VI (Gaussian preference function): an alternative to the linear version with a smoother shape; preference increases and it follows normal distribution, of which the standard deviation must be fixed.
- Stage 2: definition of preference parameters

Depending on the chosen preference function, each stakeholder must set his preference parameters, which can have the following meanings:

- Indifference Threshold (q_j): indicates the gap in which no preference can be established between two alternatives according to a given criterion.
- Preference Threshold (p_j): indicates the deviation from which a clear preference can be established between two alternatives according to a given criterion. It is thus significantly larger than the indifference threshold.

- Gaussian Threshold (s_j): corresponds to an average degree preference; it is between the thresholds of preference q and a threshold of strict preference p .
- Stage 3: assignment of weights

The weight of criteria represents the level of importance that the decision maker is willing to assign to each criterion. Each decision maker assigns numerical weights to the criteria to reflect their priorities; more important criteria receive larger weights.

5.2.2. Step 2: individual PROMETHEE II analysis

Each DM develops his own PROMETHEE II analysis. The scores of alternatives (strategies) and the DM's preference information are combined to provide the individual rankings. The main steps to obtain PROMETHEE II rankings are described as follows:

- Stage 1: determination of deviations based on pair-wise comparisons

Let $g_j(a)$ be the value of a criterion j for an alternative a .

$$d_j(a, b) = g_j(a) - g_j(b) \quad (1)$$

$d_j(a, b)$: the difference of value of a criterion j for two alternatives a and b .

- Stage 2: applications of the preference functions

Values of preference index are calculated for each pair of compared alternatives (a, b) on the basis of certain preference functions and parameters (Table 2)

$$P_j(a, b) = F_j(d_j(a, b)) \quad (2)$$

$P_j(a, b)$: preference degree of a criterion for two alternatives a and b .

Table 2. PROMETHEE preference functions

Preference function	Definition	Parameters
Type I: Usual Criterion	$P(d) = \begin{cases} 0 & \text{if } d \leq 0 \\ 1 & \text{if } d > 0 \end{cases}$	-
Type II: U-shape criterion	$P(d) = \begin{cases} 0 & \text{if } d \leq q \\ 1 & \text{if } d > q \end{cases}$	Indifference threshold
Type III: V-shape criterion	$P(d) = \begin{cases} 0 & \text{if } d \leq 0 \\ d/p & \text{if } 0 < d \leq p \\ 1 & \text{if } d > p \end{cases}$	Preference threshold
Type IV: Level criterion	$P(d) = \begin{cases} 0 & \text{if } d \leq q \\ 1/2 & \text{if } q < d \leq p \\ 1 & \text{if } d > p \end{cases}$	Indifference and preference thresholds
Type V: V-shape with indifference preference	$P(d) = \begin{cases} 0 & \text{if } d \leq q \\ \frac{(d-q)}{(p-q)} & \text{if } q < d \leq p \\ 1 & \text{if } d > p \end{cases}$	Indifference and preference thresholds
Type VI: Gaussian criterion	$P(d) = \begin{cases} 0 & \text{if } d \leq 0 \\ 1 - e^{-d^2/2\sigma^2} & \text{if } d \geq 0 \end{cases}$	Gaussian threshold

- Stage 3: calculation of an overall or global preference index

The global preference index is computed as follows:

$$\Pi(a, b) = \sum_{j \in C} W_j P_j(a, b) \quad (3)$$

C : set of considered criteria

W_j : weight associated to the criterion j .

$\Pi(a, b)$: global preference index for a pair of possible alternative a and b with respect to all of the considered criteria.

- *Stage 4: calculation of outranking flows*

Positive and negative outranking flows are determined for the alternatives as follows:

$$\Phi^+(a) = \frac{1}{n-1} \sum_{x \in a} \Pi(a, x) \quad (4)$$

$$\Phi^-(a) = \frac{1}{n-1} \sum_{x \in a} \Pi(x, a) \quad (5)$$

Here, x represents the alternatives other than a and outranking values for n alternatives are obtained by adding $(n-1)$ value.

- *Stage 5: calculation of the net outranking flow*

The net outranking flow is computed from the positive and negative outranking flows for each possible alternative [11]. The ranking of alternatives is arranged in descending order of net flow value.

The net outranking flow $\Phi(a)$ of a possible alternative a is computed as follows:

$$\Phi(a) = \Phi^+(a) - \Phi^-(a) \quad (6)$$

At the end of that stage, each stakeholder establishes a list in which potential strategies are ordered (individual ranking).

5.3. PHASE 3: collective maintenance strategy selection

The aim of this last stage is to help stakeholders collectively select the most suitable maintenance strategy among several potential strategies.

The selection of maintenance strategy can be formalized as a group decision making problem characterized by:

- A limited number of stakeholders (voters): $\{\text{Stakeholder 1, Stakeholder 2, ..., Stakeholder } m\}$
- A set of strategies (candidates): $\{S1, S2, S3, ..., Sn\}$.
- A collection of individual ranking preorder denoting a preference relation between n strategies: $\{>_1, >_2, \dots, >_j, \dots, >_m\}$.

The virtues of the Borda procedure are exploited to extract from all the individual rankings the best decision (strategy) reflecting the preferences of the group of voters (stakeholders) as much as possible.

5.3.1. Step 1: building the global preference table

A global table regrouping the individual preferences of each stakeholder is built. The size of the collective preference table is $m \times n$, where m is the number of stakeholders (voters) and n is the number of possible strategies (candidates), while the cells of the table indicate the rank associated with the strategy i by the stakeholder j , as illustrated by Table 3.

Table 3. Global preference table

	Stakeholder 1	Stakeholder j	Stakeholder m
Strategy 1 ($S1$)	$Rank(S1, Stakeholder 1)$	$Rank(S1, Stakeholder j)$	$Rank(S1, Stakeholder m)$
Strategy2 ($S2$)	$Rank(S2, Stakeholder 1)$	$Rank(S2, Stakeholder j)$	$Rank(S2, Stakeholder m)$
Strategy i (Si)	$Rank(Si, Stakeholder 1)$	$Rank(Si, Stakeholder j)$	$Rank(Si, Stakeholder m)$
Strategy n (Sn)	$Rank(Sn, Stakeholder 1)$	$Rank(Sn, Stakeholder j)$	$Rank(Sn, Stakeholder m)$

- If the Strategy (Si) is the best candidate for stakeholder j then the rank number $Rank(Si, Stakeholder j) = 1$.
- If the Strategy (Si) is the second best candidate for stakeholder j then the rank number $Rank(Si, Stakeholder j) = 2$.
- and so on, if the Strategy (Si) is the worst one, then rank number $Rank(Si, Stakeholder j) = n$.

5.3.2. Step 2: computation of group consensus

This step allows determining the winner candidate (strategy) according to Borda procedure. Each strategy is given a score based on its ranking in the global preference table, as follows:

$$Score(Si, Stakeholder j) = n - (Rank(Si, Stakeholder j)) + 1 \quad (7)$$

n : Number of strategies (candidates).

$Rank(Si, Stakeholder j)$: Rank of the strategy i , according to the Stakeholder j , in the global preference table.

The different scores obtained by each strategy are summed, as follows

$$Total\ Score(Si) = \sum_{j=1}^m (Score(Si, Stakeholder j)) \quad (8)$$

The candidate (strategy) with the highest total score is elected and represents the Borda count winner. This candidate is seen as the collective or compromise maintenance strategy.

6. Case study

The maintenance system plays a key role in achieving organisational goals and objectives. To demonstrate the efficacy of the proposed decision making model, we consider the case of a textile company interested in choosing the most adequate maintenance strategy for its equipment.

6.1. The problem addressed

Textile refers to any filament, fiber, or yarn that can be made into fabric, cloth, and the finished product.

The problem presented in this case study is based on an Algerian textile company that specialises in producing various fabrics and yarns and has as its main goal promoting the quality and excellence of its products. Because of poor maintenance and unskilled labour, the company must select the most appropriate maintenance strategy to ensure machine availability, reduce system failures, and allow for cost effective production.

6.1.1. Identification of decision makers

The selection of an appropriate maintenance strategy impacts the company's various functional departments. Therefore, the experts and managers affected by this strategic decision are encouraged to participate in evaluating and selecting the strategy that best meets the company's needs.

For this study, the finance responsible (stakeholder 1), maintenance manager (stakeholder 2), company manager (stakeholder 3), and production manager (stakeholder 4) will constitute the decision making committee in charge of selecting the best maintenance strategy.

6.1.2. Identifying potential strategies

Stakeholders s have identified four maintenance strategies that are potentially suitable for the needs of the company.

- Corrective maintenance (CM): the main feature of corrective maintenance is that actions are only performed when a machine breaks down. There are no interventions until a failure has occurred.
- Time based maintenance (TBM): allows to plan a series of checks, replacements, and/or component revisions with a frequency based to the failure rate.
- A condition based maintenance (CBM): is best suited for high capital cost equipment. The availability of a set of measurements and data acquisition systems to monitor machine performance in real time is required for the application of condition-based maintenance.

- Reliability centered maintenance (RCM): is a structured maintenance strategy that aims to boost productivity while lowering maintenance costs. This approach focuses on identifying the failures that pose the greatest risk to the system and implementing the best strategy for each critical asset.

6.1.3. Identifying criteria

After discussion, the decision makers have chosen to consider the following decision criteria.

- Cost (C1): each type of maintenance has a particular cost range that differs from others and includes basically all the costs that might incur, crew cost, spare part cost, etc.
- Safety (C2): sums safety for personnel, equipment, facilities, and environment.
- Value added (C3): represents the additional value brought to the company by the application of the maintenance strategy. Indeed, the less the failure frequency, the more stable the equipment performance, the better the quality of the processed products, and the higher the added value of the corresponding maintenance strategy.
- Feasibility (C4): it is applied to determine whether the maintenance strategy is suitable for the system.

6.1.4. Evaluation of performances

The assessments of the different alternatives (strategies) according to the identified criteria are presented in the evaluation table, as illustrated in Table 4.

Table 4. Matrix of performance

	Cost	Safety	Added value	Feasibility
CM	634300	Medium	9.4	8.3
TBM	4074400,70	Very high	2	3.6
CBM	3805800,50	Medium	3.15	4.2
RCM	2537200,00	high	7.75	7

6.2. Elicitation of individual preferences

Decision makers are invited to define their preference functions and subjective parameters necessary for the execution of the PROMETHEE II method, as illustrated in Tables 5, 6, 7, and 8.

Table 5. Subjective parameters expressed by stakeholder 1

Weight	Preference function	Indifference threshold	Preference threshold
40.5	Linear	100000	200000
24.10	Linear	3	6
30.80	Linear	0.5	1
4.6	Linear	1	2

Table 6. Subjective parameters expressed by stakeholder 2

Weight	Preference function	Indifference threshold	Preference threshold	Gaussian threshold
17.07	Linear	150000	300000	-
20.12	Linear	2	4	-
32.67	Gaussian	-	-	10
30.14	Linear	1	2	-

Table 7. Subjective parameters expressed by stakeholder 3

Weight	Preference function	Indifference threshold	Preference threshold
16.66	Linear	350000	700000
50	Level	2.5	5
16.66	Level	3	6
16.66	Linear	0.5	1

Table 8. Subjective parameters expressed by stakeholder 4

Weight	Preference function	Indifference threshold	Preference threshold
22.20	Linear	400000	800000
12.35	Level	5	10
45.25	Linear	4	8
20.20	Level	1	2

Each DM conducts his own multi criteria analysis and establishes a list of potential maintenance strategies (total ranking), as shown in Tables 9, 10, 11, and 12.

Table 9. Ranking of strategies according to stakeholder 1

Strategies (Alternatives)	Net Flows	Positive flows	Negative flows
CM	0.5876	0.7483	0.1607
RCM	0.3441	0.6667	0.3226
CBM	-0.4290	0.2377	0.6667
TBM	-0.5027	0.2410	0.7437

Table 10. Ranking of strategies according to stakeholder 2

Strategies (Alternatives)	Net Flows	Positive flows	Negative flows
RCM	0.3208	0.4764	0.1556
CM	0.3145	0.4487	0.1341
TBM	-0.2219	0.2012	0.4031
CBM	-0.4334	0.0457	0.4791

Table 11. Ranking of strategies according to stakeholder 3

Strategies (Alternatives)	Net Flows	Positive flows	Negative flows
RCM	0.33333	0.6111	0.2778
TBM	0.1835	0.5001	0.3166
CM	0.111	0.4444	0.3334
CBM	-0.6278	0.0111	0.6389

Table 12. Ranking of strategies according to stakeholder 4

Strategies (Alternatives)	Net Flows	Positive flows	Negative flows
CM	0.5211	0.6034	0.0823
RCM	0.2842	0.4330	0.1488
TBM	-0.3534	0.1235	0.4769
CBM	-0.4519	0.00	0.4519

6.3. Group selection of maintenance strategy

Through a voting phase, the decision making committee (voters) attempts to select the most appropriate strategy (candidate) collectively. A set of points is assigned to candidates (maintenance strategy) based on their ranking, as illustrated in Table 13.

Table 13. Collective preference matrix

	Stakeholder 1	Stakeholder 2	Stakeholder 3	Stakeholder 4
CM	Rank=1	Rank=2	Rank=3	Rank=1
TBM	Rank=4	Rank=3	Rank=2	Rank=3
CBM	Rank=3	Rank=4	Rank=4	Rank=4
RCM	Rank=2	Rank=1	Rank=1	Rank=2

The RCM strategy has obtained the most significant score (Table 14); it represents the Borda winner and corresponds to the group's collective decision.

Table 14. Winner candidate strategy

Strategy	Score
CM	13
TBM	8
CBM	5
RCM	14

According to the various stakeholders, the RCM strategy is the best maintenance policy for this textile company; its successful implementation can reduce unnecessary costs, reduce asset downtime, improve safety, and increase the viability of textile equipment.

7. Conclusion

Which maintenance technique is best for maintaining equipment? This is one of the most common questions that maintenance managers are facing.

For achievement long-term success, organizations and manufacturing companies must exploit the potential strengths of collective decision making to improve maintenance management. The current research describes a group decision making model that values stakeholder involvement in selecting an appropriate maintenance approach based on a set of criteria.

One of the key challenges in group decisions including several stakeholders each with their own objectives and preferences, is the attainment of an acceptable consensus [36]. Based on the analysis of the preferences of stakeholders expressed as individual rankings, the suggested model seeks to reach an appropriate alternative representing the group compromise from the standpoints of stakeholders involved in the selection process. The Borda count, a consensus-based voting system was used to collectively select the best maintenance strategy taking as a starting point stakeholder's preferences that were individually established thanks to PROMETHEE II; an outranking class of multi criteria decision analysis method.

The maintenance strategy selection model was tested in a real-world setting: a textile company which machines must be maintained in order to properly and efficiently function. The case of study consisted of four maintenance strategies including corrective maintenance (CM), time based maintenance (TBM), condition based maintenance (CBM) and reliability centered maintenance (RCM) evaluated according to four comparison criteria cost, safety, added value, and feasibility. Nonetheless, reliability centered maintenance was found to be the best compromise from the points of view of stakeholders involved in the decision problem and its implementation was advised to increase productivity, safety, and efficiency other hand decrease manufacturing cost of company.

The participatory decision model can be easily replicated in other industries and can be adopted by managers and companies as a practical tool to select the most appropriate maintenance strategy for their machines. However, the suggested model suffers from some limitations, most notably:

- The difficulty that decision makers can encounter in selecting the appropriate preference function and the associated threshold values.
- The decision maker's 'imprecise nature of preferences is not taken into account by the proposed model. Indeed, the information concerning the parameter values provided by the decision maker is usually imperfect and subjectivity; since it is based only on his experience and intuition. Therefore, integrating the fuzzy set theory with PROMETHEE method may help to make the model more flexible and suitable for decision makers 'imprecise nature of preferences.

For future work, the maintenance strategy selection model will be applied in other industry sectors such as renewable energy. Likewise, other well known voting systems can be used to compare the results of this work.

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