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Research Article

Group decision model to support public managers in landfill site selection

Elton César dos Santos Silva[a*], Danielle Costa Morais[a]
[a]Universidade Federal de Pernambuco, Recife, PE, Brasil
*elton-ceesar@hotmail.com

Abstract

Paper aims: The objective of this work is to develop a comprehensive group decision model to support public managers in choosing the best location for the construction of landfills based on a strategy known as "regionalization" (collaborative construction of landfills).

Originality: The proposed group decision model innovates when considering the regionalization strategy in a multi-DM environment based on a framework for choosing a voting procedure.

Research method: The model is divided into three stages: (i) individual assessment of preferences; (ii) choosing a voting procedure; and, (iii) group aggregation and recommendation. First, it uses MCDA/M to elicit DMs' preferences and obtain individual rankings; then, a framework for choosing a voting procedure (VP) to aggregate individual preferences and obtain a collective choice.

Main findings: The main findings indicate that the proposed model that uses PHOMETHEE-ROC and a VP proposes a recommendation that is of everyone's interest in the presented multi-DM landfill site selection problem presenting its feasibility and applicability.

Implications for theory and practice: It encourages public managers to use a formal approach to make a comprehensive analysis of solid waste management practices. Furthermore, the proposition of an integrative framework to support group decision analysis by using MCDA/M and VP.

Keywords

Group decision making. Multi-criteria decision analysis. Choosing a voting procedure. Solid waste management. PROMETHEE-ROC.

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1. Introduction

Managing Municipal Solid Waste (MSW) is a universal issue affecting society. People and governments make decisions about consumption and waste management that affect the daily health, productivity, and cleanliness of communities. Poorly managed waste causes many problems, such as ocean contamination, drain clogging, disease transmission via the breeding of vectors, increasing respiratory problems through airborne particles from burning of waste, etc. Unmanaged and improperly managed waste requires urgent actions at all levels of society (World Bank Group, 2018). According to International Solid Waste Association (2021), it is estimated that, in the current scenario of consumer goods production, the generation of MSW will increase worldwide, going from 2 billion tons/year in 2021 to 3.4 billion tons in 2050, with most of this increase being observed in developing countries, where generation is expected to triple.

With that in mind, many developing economies have been seeking ways to improve their MSW practices, as happens in Brazil (Guedes et al., 2021). According to Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais (2022), 39% of MSW collected in Brazil still goes to inappropriate units (dumpsites or controlled landfills), which represents about 29,7 million tons of waste per year. Decisions regarding the appropriate location for disposal facilities are of a strategic layer and require deep investigation (Vargas et al., 2022).

In recent years, Brazil's National Congress has approved a new deadline for the shutdown of dumpsites established by its National Solid Waste Policy (NSWP). This new deadline was then defined based on cities population, and August 2024 is the deadline for those with less than 50,000 inhabitants (Brasil, 2020). Cities of that size represent the majority of municipalities in this country that still operate dumpsites and must urgently adapt to the new law. Otherwise, their municipal managers may suffer fines for misconduct in MSW management or even be criminally prosecuted.

These smaller cities face specific challenges given their budgetary limitations and population size. It turns out to be unfeasible to build and operate landfills independently, once they do not have economies of scale, which makes the construction and maintenance of landfills very costly for the population (Associação Brasileira de Empresas de Tratamento de Resíduos e Efluentes, 2020). Therefore, it is common for smaller cities to cooperate in building a joint landfill, a strategy known as "regionalization of landfills" when a single unit serves several cities. This action is commonly feasible and widely used, once it provides cost savings for all cities, with no loss to environmental quality (International Solid Waste Association, 2021). Moreover, there is a scale gain in investment and operating costs when several cities jointly build and operate a landfill.

The landfill regionalization strategy is characterized as a group decision problem where several Decision Makers (DMs) will work to possibly find a solution that benefits all. In this case, a region where the joint landfill will be located. One way to solve such decision-making processes is through voting procedures (VPs). Several existing VPs can be used to support social choice, the challenge, however, lies in choosing the procedure that best suits the features of the decision context. Therefore, Almeida et al. (2019b) propose a framework for choosing a voting procedure to support multiple DMs in the decision-making process by using multi-criteria approaches.

Thus, this work aims to apply the framework for choosing a VP proposed by Almeida et al. (2019b) to better structure the elements to be considered in this decision-making process. The comprehensive group decision model developed is based on MCDA/M to elicitate the preferences of DMs and obtain individual rankings and on the framework for choosing a VP to aggregate individual preferences and obtain a recommendation in a multi-DM environment for the landfill site selection problem. To illustrate the proposed model, a numerical application is run in Pernambuco State, Brazil.

2. Group decision and voting procedures

Applications based on group decision approaches are present in many contexts, such as supplier selection (Causil & Morais, 2023), water resources management (Fontana & Morais, 2017), maintenance policies (Zanazzi et al., 2022), among others. In each situation, DMs can share the same goals or have conflicting ones (Sabino et al., 2021).

There are two general types of procedures to aggregate DMs' preferences into group decisions: (i) aggregation based on DMs' initial preferences; and (ii) aggregation based on the DMs' final choices (Almeida et al., 2019a). Procedure (i) occurs when individuals are willing to give up their preferences to achieve the group's ultimate goal. In this case, it is assumed that DMs act together and group their judgments in such a way that the group becomes a "new" individual and behaves as one. In procedure (ii), the aggregation process focuses on the outcome of each participant's alternative priorities. In this case, each of the individuals acts according to their preference, using their own value systems. VPs are commonly used in procedure (ii).

Hence, VPs can play an important role in supporting multi-objective decisions for a group of DMs. Where each participant must indicate their preferences whatever the criteria considered or the method used to obtain their results (Almeida-Filho et al., 2017). There are several existing VPs, such as Plurality, Borda, Condorcet, Approval Voting, Copeland, among others (Almeida et al., 2019a). The key point is how to choose an appropriate VP for a decision context (Almeida & Nurmi, 2015). Given the existence of paradoxes and the different properties that voting procedures satisfy or not (Bisquert et al., 2019). Thus, the framework proposed by Almeida et al. (2019b) can be used to guide the process of choosing a VP.

In the first step of the framework, VPs, including those that are technically appropriate for the decision process, are pre-selected and grouped. Most of the known VPs can be included in this step, while the excluded ones are mostly those that might be inconsistent in some way with the decision process. For example, a VP may require the input of data that is not feasible to provide for such a decision process (Almeida et al., 2019b).

The second step is to establish the criteria, which are associated with the DMs' goals in choosing a VP, including the paradoxes and desirable properties of the VPs. Then, the consequence matrix and the decision matrix are built once the alternatives (VPs) and criteria are given. The next step consists of choosing the multi-criteria method to be applied for the analysis of these VPs according to the given criteria. Which multi-criteria method to choose is an important issue to be considered (Almeida, 2013). Completion is achieved with the steps of parameterization and application of the multi-criteria model (Almeida et al., 2019b).

2.1. Aggregating DMs' preferences using MCDA/M and VPs

In particular, the joint application of VPs and Multi-Criteria Decision Analysis (MCDA/M) have been used in the literature to support individuals in group decision contexts.

Lakicevic et al. (2014) proposed a model for evaluating management policies in urban forestry planning. Two voting techniques are applied, approval voting and the multi-criteria approval method, to select the most appropriate management policy for an urban forest located in Belgrade, Serbia. The main strength of the approach is a high tendency to provide a decision that will satisfy all the participants included in the research.

Almeida-Filho et al. (2017) developed an approach to analyzing the preferences of water supply maintenance managers including customer perspectives in the decision process, through the use of MCDA/M methods and the voting procedure by quartiles. Evaluation criteria are defined in terms of seeking to establish the optimal interval for preventive maintenance. The proposed approach to aggregate DMs' preferences was considered adequate to the context of maintenance management of such water supply system.

Palha et al. (2017) presented an application of the framework proposed by Almeida & Nurmi (2015) for choosing a VP in the business context to decide which voting rule is best suited for aiding a facilitator using a Group Decision Support System called GRUS. Since the DMs are not directly involved in this choice, it is more difficult for any of them to introduce biases into the process which allowed the framework to lead the process towards a social choice compatible with the group of DMs. Urtiga et al. (2017) proposed a model to support group decision-making that allows each member of a group to declare their preferences in a water resources management context. Possible combinations of alternatives are generated systematically using an option form approach (by GMCR+ software). The group's recommendation is obtained after aggregating the final individual rankings through a voting procedure and a voting support system, based on classification by quartiles. To illustrate its applicability, the proposed methodology is applied to a realistic decision problem faced by a river basin committee in Brazil. Loc et al. (2017) used the AHP method with three VPs to assess the applicability of sustainable urban drainage systems (SUDS), a flood control measure, in central Ho Chi Minh City, Vietnam. A set of four alternative urban drainage systems was evaluated through interviews with residents and the results were then compared with those obtained through the application of formal approaches. The use of the methods proved to be very useful in obtaining recommendations based on formal procedures, supporting DMs to make more assertive decisions.

Gonçalo & Morais (2018) sought to investigate how the selection of suppliers in a Brazilian oil company occurs through a multi-criteria group decision model to support this process. Thus, it proposes the use of the PROMETHEE II method to obtain the individual evaluations of the DMs and the voting procedure by quartiles, to convert the individual positions into a decision for the group. This work also brings as a contribution the unprecedented application of such integration in the context of supplier selection.

Sabino et al. (2021) proposed a group decision model to classify sustainable cities. The application is based on a MCDA/M method to support DMs in the construction of individual rankings and the framework for choosing a VP (Almeida et al., 2019b) to aggregate individual priorities into a collective ranking of sustainable cities. The applicability of the model is illustrated with a real environmental problem in a hydrographic basin in Brazil.

As previously discussed, and as can be seen in Table 1, although there have been increasing applications of MCDA/M and VPs to aid group decision processes, the literature lacks applications in the solid waste context, especially when it comes to landfill site selection. Tot et al. (2017), for instance, apply MCDA/M and a VP (the Borda method) to evaluate key indicators and their related sub-indicators in a group decision-making environment to improve sustainable waste management in developing countries. This approach, however, does not formally clarify how the Borda method was chosen. Most approaches found in the literature do not technically justify how a specific VP is chosen, given the existence of paradoxes and the different properties that VPs may or may not satisfy, that must be considered for its successful application.

Moreover, the literature shows a large number of scientific research using MCDA/M for landfill site selection in a single-DM environment (Rueda-Avellaneda et al., 2023; Ali et al., 2023), many of them combined with GIS (Geographic Information System (Donevska et al., 2021). However, it lacks applications considering multi-DM contexts, which is very common in the regionalization strategy. Thus, this research, seeks to explore landfill site selection considering the regionalization strategy in a multi-DM context, presenting the opportunity to develop a comprehensive group decision model in solid waste management by integrating MCDA/M and a framework for choosing a VP, showing its innovative proposal.

Table 1. Applying MCDA/M and VPs.

References	Paper title	Application area	Methodological intervention
Lakicevic et al. (2014)	*Decision making in urban forestry by using approval voting and multicriteria approval method (case study: Zvezdarska forest, Belgrade, Serbia)*	Urban forestry planning	Approval voting and the multi-criteria approval method
Almeida-Filho et al. (2017)	*A Voting Approach Applied to Preventive Maintenance Management of a Water Supply System*	Water supply maintenance	MAUT, PROMETHEE and the voting procedure by quartiles
Urtiga et al. (2017)	*Group Decision Methodology to Support Watershed Committees in Choosing Among Combinations of Alternatives*	Water resources management	GMCR and the voting procedure by quartiles
Palha et al. (2017)	*Choosing a Voting Procedure for the GDSS GRUS*	Business	PROMETHEE I, ELECTRE III and GDSS GRUS
Loc et al. (2017)	*Applicability of sustainable urban drainage systems: an evaluation by multi-criteria analysis*	Urban flooding	AHP and the VPs, Borda count, pair-wise voting, and range of value
Tot et al. (2017)	*Group assessment of key indicators of sustainable waste management in developing countries*	Waste management	AHP and Borda Count
Gonçalo & Morais (2018)	*Supplier selection model for a Brazilian oil company based on a multi-criteria group decision approach*	Supplier selection	PROMETHEE II and the voting procedure by quartiles
Sabino et al. (2021)	*A Group Multicriteria Decision Model for Ranking Sustainable Cities*	Sustainable cities	MCDA and the Copeland method

Source: The authors (2024).

3. Proposed decision model

In this session, we describe the group decision model developed to rank the locations in which a new landfill can be built through the regionalization strategy (co-participation). The model is divided into three stages (Figure 1): (i) individual assessment of preferences; (ii) choosing a voting procedure; (iii) group aggregation and recommendation.

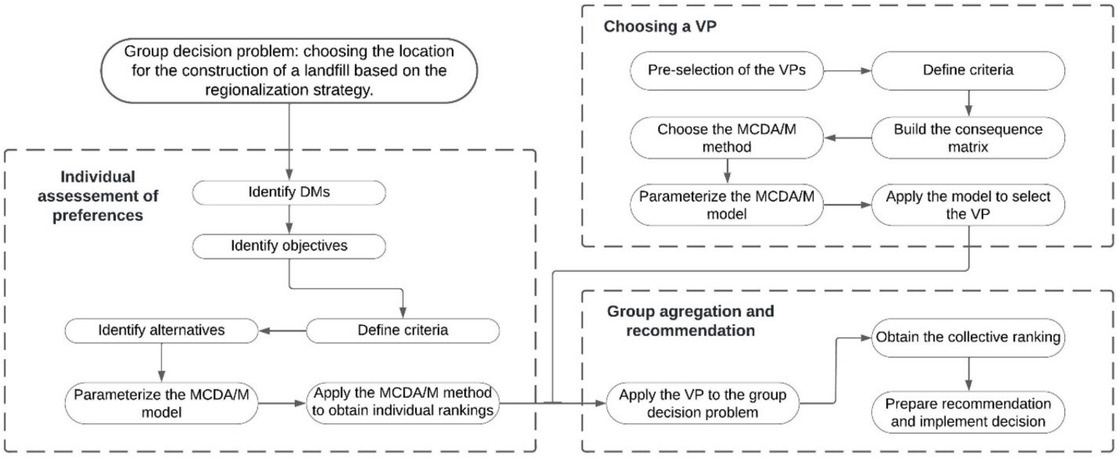

Figure 1. Flowchart of the proposed model.
Source: Adapted from Almeida et al. (2019b).

Initially, the group decision problem is defined; in this case, it is about understanding the aspects related to choosing the location of a landfill in a certain region that is composed of several cities that intend to cooperate in building a joint landfill. Problem identification requires an exploration of the environment to characterize the decision problem in details.

In the stage of individual assessment of preferences, DMs must be clearly identified. The DMs in this context are the municipal managers who are responsible for managing the municipal solid waste generated by the cities. In addition, this stage seeks to identify the goals of each DM, which are determined based on the values of each individual. From this, the criteria that will make it possible to measure the objectives previously identified are determined. Next, the action space (alternatives) that will allow evaluating their performance related to the criteria is established.

After the steps of structuring the model, we go to the parameterization step, which is crucial for the correct application of the MCDA/M method. At this stage, the rationality of each DM (compensatory or non-compensatory), the preference structure, as well as the entire process of eliciting preferences, value functions, and weights, according to the type of method to be used, must be identified. As an output from this stage, we will have the individual rankings of each DM related to their preferences; these rankings will serve as input to stage (iii) when the group aggregation will be done to obtain the final result.

The stage of choosing the VP is based on the framework proposed by (Almeida et al., 2019b). The purpose of this stage is to find a suitable VP to aggregate individual rankings into a collective group ranking. Initially, a pre-selection of VPs that are technically appropriate for the decision process is made; the excluded VPs are mainly those that may be incompatible in some way. For example, a VP may require inputting data that it is not possible to provide for such a decision process, as would be the case for VPs that do not input a ranking of alternatives, in which case these VPs are not appropriate for the decision problem discussed in this paper. Next, the criteria that represent the properties and paradoxes used to assess the performance of VPs are established. The literature presents several properties of VPs (Almeida et al., 2019a). According to Almeida et al. (2019b), the analyst must decide which properties are important for the decision context according to the DMs requirements.

Following, the consequence matrix is built, considering a discrete binary outcome, so that, if the VP satisfies a property it gets “1” in the consequence matrix, otherwise it gets “0”. Therefore, the result “1” is preferable to the result “0”. In this stage, for a “discrete binary outcome”, it does not matter the DMs’ rationality for the methods choice (Almeida et al., 2019b). Thus, any MCDA/M could be used once the VPs have already been preselected. Then, a MCDA/M method is chosen and the model parameterization is performed. Finally, the model is applied and as a result of this stage, the most appropriate VP is defined, which will be used for group aggregation in the subsequent stage, also a sensitivity analysis can be performed in this step.

In the final stage, the chosen VP will be used to perform the aggregation of the individual rankings of the DMs so that, finally, the global ranking of the group is obtained. After that, we prepare a recommendation and the necessary aspects are planned for the correct implementation of the decision. It is worth mentioning that a facilitator/analyst is needed in the whole process, which is the individual responsible for organizing the process from the technical viewpoint and setting up the decision support model.

4. Case application in Brazil

The proposed model was used to support municipal managers of cities that are part of the Microregion of Araripina, located in the Sertão Region of Pernambuco State, Brazil. Even though this is a real problem faced by public managers as discussed in this section, the application of the model was performed as a numerical example due to time constrain and difficulties in contacting real DMs during the development of this research.

4.1. Problem characterization

The Microregion of Araripina (Figure 2) is formed by ten cities, and comprehends more than 11% of Pernambuco State territory, which represents 11,792 km^2. This microregion has an estimated population of 330,000 inhabitants, where Araripina and Ouricuri are the largest cities (Instituto Brasileiro de Geografia e Estatística, 2024).

All cities in this microregion perform the final disposal of their solid waste inappropriately through the use of dumpsites. The inspection and control Bodies of Pernambuco State have been pressuring cities in that region to adapt to the National Solid Waste Policy, demanding them to perform the final disposal of their solid waste in landfills. The region, however, lacks landfills, which turns out to be unfeasible to send waste to pre-existing landfills in cities in other microregions of the State because of the distance.

Therefore, it is more feasible for the cities in this region to cooperate in building a joint landfill, a strategy known as regionalization. Thus, it gives rise to a group decision problem, which deals with selecting the best location for the construction of this new landfill, in a way that satisfies all municipal managers. Figure 2 shows the location of the Arapirina microregion in Pernambuco State, which is part of the Northeast region of Brazil.

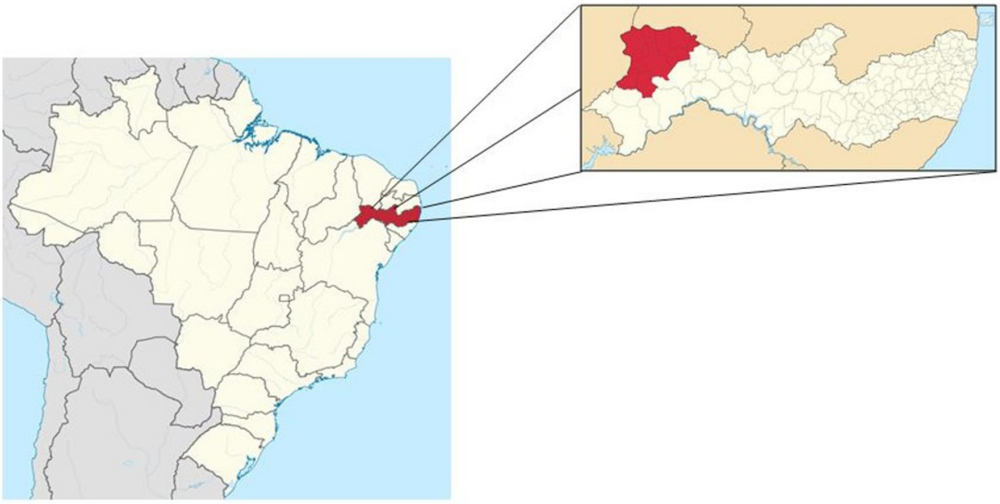

Figure 2. Location of the Araripina microregion.

4.2. Individual assessment of preferences stage

This group decision problem is composed of three DMs. As discussed above, the Araripina Microregion is made of ten cities, however, for simplification purposes it is assumed that some of them will work together, as they have very similar interests, in terms of preferences regarding the landfill site selection. Thus, DM1 will be represented by the municipalities of Araripina, Trindade and Ipubi; DM2 will be represented by Ouricuri, Santa Filomena and Santa Cruz; and DM3 will be represented by Bodocó, Exú, Granito, and Moreilândia. Normally, for landfill site selection problems, non-compensatory methods would be used, such as the PROMETHEE and ELECTRE family of methods (Achillas et al., 2013). Thus, the non-compensatory rationality was considered appropriate for this study, and the PROMETHEE-ROC method was applied to obtain the individual rankings.

The PROMETHEE-ROC structure allows ordinal information about the set of criteria to be treated in a coherent way for the application of the MCDA/M method. As only information about the order of priority of the criteria (surrogate weights) is requested, it is quite efficient to deal with complex decision problems in which only ordinal information about the weights is used to indicate the DMs' preferences. This method allows the opportunity to deal with ranking problems with non-compensatory rationality and partial information about the weights of the criteria involved in the problem (Almeida et al., 2014).

The PROMETHEE-ROC method, which has as its main feature (additional to PROMETHEE) the use of the ROC (Rank-Order Centroid) method (Barron, 1992) to establish weights to the criteria based on only from the preference ordering of the criteria by the DM (Morais et al., 2015). Thus, to determine the weights, PROMETHEE-ROC uses Equation 1, where *n* represents the number of objectives or criteria, is the weight for the *th* criteria in its position in the ranking. ROC identifies the extreme points in the weight space and determines the weights based on the centroid of this space.

$$w_j = \frac{1}{n}\sum_{k=j}^{n}\frac{1}{k}, j = 1, 2, \ldots, n \tag{1}$$

According to Morais et al. (2015) the use of ROC is considered in several contextual analyses due to its quality and simplicity in the process of assigning weights. Thus, in multi-criteria decision problems this method is widely recommended for dealing with imprecise information about the importance of criteria.

The cities that are part of the Araripina Microregion will be considered as alternatives to this problem. As discussed earlier, this region is made up of ten cities, so the landfill may be built in any one of them. Three of the cities (Santa Filomena, Granito, and Moreilândia), however, are considered unfeasible for the construction of the landfill, due to their small population and to the fact that they are located far away from the major cities. Thus, seven options remained, namely: A1 (Santa Cruz), A2 (Ouricuri), (A3) Trindade, (A4) Araripina, (A5) Ipubi, (A6) Bodocó, and (A7) Exú.

For this stage of the study, the MCDA/M model developed by (Silva & Morais, 2021) was considered, which is composed of six criteria, three of environmental nature and three of a socioeconomic nature. Table 2 presents the criteria and their main characteristics. And Table 3 shows the multi-criteria problem consequence matrix, which is based on a hypothetical application with fictitious numerical data.

Table 2. Criteria of the landfill location problem.

Criteria	Code	Excluded values	Preference direction
Distance from conservation areas	C1	Below 200 meters	↑Maximize
Distance from water bodies	C2	Below 200 meters	↑Maximize
Declivity	C3	Below 1% and above 30%	↓ Minimize
Distance from roads	C4	-	↓ Minimize
Distance from urban areas	C5	Below 500 meters	↑ Maximize
Landfill size	C6	Below 20.000 m^2	↑ Maximize

Table 3. Consequence matrix of the landfill location problem.

Alternatives	Criteria					
	C1 (m)	C2 (m)	C3 (%)	C4 (m)	C5 (m)	C6 (thou./m^2)
A1	6500	600	3	1200	600	80
A2	380	500	16	1700	2700	66
A3	500	2500	8	1000	1700	64
A4	1050	1750	8	350	900	75
A5	780	4000	5	1500	1200	42
A6	2400	700	24	800	1450	55
A7	1200	1800	18	900	1900	79

The DMs' preference functions were defined according to each criterion. The usual function was assigned to criteria C1, C2, and C5. This implies that any difference in the performance of two alternatives will reflect a strict preference for the superior performing alternative. A linear function (criterion with linear preference) was assigned for criteria C3, C4, and C6. This means that the intensity of preference of one alternative over the other increases linearly with the difference in performance between the alternatives until this difference reaches the preference threshold "p", where, after this value, the preference is strict (Almeida, 2013). The same preference functions were considered for all DMs, however, different preference thresholds were specified for each of them. Table 4 presents the preference functions, preference thresholds, and order of criteria used to obtain the individual rankings of DMs. Table 5 presents the individual rankings obtained after applying the multi-criteria method.

Table 4. Parameters used to obtain individual rankings.

DM1	Criteria					
	C1	C2	C3	C4	C5	C6
Preference function	Usual	usual	linear	linear	usual	linear
Order	4	5	3	1	6	2
p	-	-	4	100	-	22
DM2	**Criteria**					
	C1	C2	C3	C4	C5	C6
Preference function	Usual	usual	linear	linear	usual	linear
Order	6	1	5	4	3	2
p	-	-	4	80	-	30
DM3	**Criteria**					
	C1	C2	C3	C4	C5	C6
Preference function	Usual	usual	linear	linear	usual	linear
Order	1	4	5	6	2	3
p	-	-	5	75	-	20

Table 5. Individual rankings.

DMs	1º	2º	3º	4º	5º	6º	7º
DM1	A7	A3	A5	A4	A1	A6	A2
DM2	A1	A4	A7	A6	A3	A5	A2
DM3	A4	A7	A3	A1	A5	A6	A2

As can be seen in Table 5, each DM obtained a specific ranking based on their individual preferences previously established (Table 4). The next stage is to choose the most suitable VP to obtain a collective solution for the group.

4.3. Choosing a voting procedure stage

Initially, we must consider which VPs are potentially appropriate for the decision context. In this case, VPs that result in a ranking of alternatives are potential options. With that, the preselected VPs were: Amendment, Copeland, Dodgson, Maxmin, Borda, Nanson, and Hare. For further discussion about VPs the authors suggest (Almeida et al., 2019b).

The properties (criteria) that were considered for the problem can be seen in Table 6. Three properties that are commonly considered in the literature were not used in this problem: Independence of Irrelevant Alternatives (IIA), Chernoff, and invulnerability to the no-show paradox. The IIA and Chernoff properties were not considered because none of the pre-selected VPs satisfy them. The property of invulnerability to the no-show paradox is not relevant to this problem, once we assume that the abstention strategy to gain an advantage did not contribute to the decision context.

Table 6. Consequence matrix for choosing the voting procedure.

VPs	Criteria					
	Condorcet Winner	Condorcet Loser	Strong Condorcet	Monotonicity	Pareto	Consistency
Amendment	1	1	1	1	0	0
Copeland	1	1	1	1	1	0
Dodgson	1	0	1	0	1	0
Maxmin	1	0	1	1	1	0
Borda	0	1	0	1	1	1
Nanson	1	1	1	0	1	0
Hare	0	1	1	0	1	0
ROC-Weight	0.4083	0.0278	0.2417	0.1028	0.1583	0.0611

For the construction of the consequence matrix, “discrete binary outcome” was used, which consists of indicating whether a property is satisfied or not by the VP, so that, “1” means the VP satisfies the property and “0” otherwise. This outcome in the consequence matrix is preferably increasing; i.e., a score of “1” is preferable to a score of “0”.

It is noteworthy that, for a “discrete binary outcome”, it does not matter whether the DM’s rationality is compensatory or non-compensatory, from the point of view of the method choice (Almeida et al., 2019b). Thus, the application of any of the existing MCDA/M methods, such as those based on the unique criterion of synthesis (additive model) or outranking, would be analytically similar. Thus, to ease the process, the same MCDA/M method (PROMETHEE-ROC) used in the previous stage was also used for choosing the VP.

After applying the PROMETHEE-ROC method, the result presented in Figure 3 shows that the VP chosen for the stage of group aggregation of DMs’ preferences is the Copeland procedure. In order to verify the robustness of the model for the obtained results a sensitivity analysis was then performed. All criteria were considered in the analysis, the weights varied with a parameter range of 30% in 100,000 cases, as can be seen in Figure 4. After that, it can be noticed that the result remains the same once the Copeland procedure remains as the best alternative 100% of the time. Thus, we go to the final stage, where this procedure will be used to obtain the collective ranking that will define the location of the landfill that may be jointly built by the cities of the discussed problem.

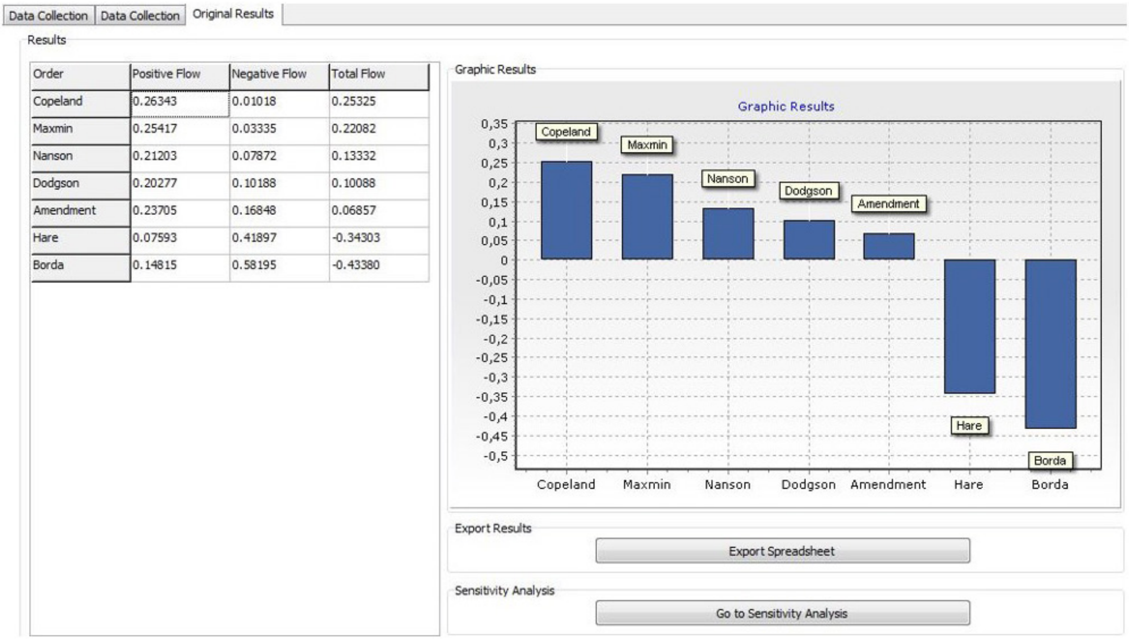

Figure 3. Result for choosing a voting procedure.

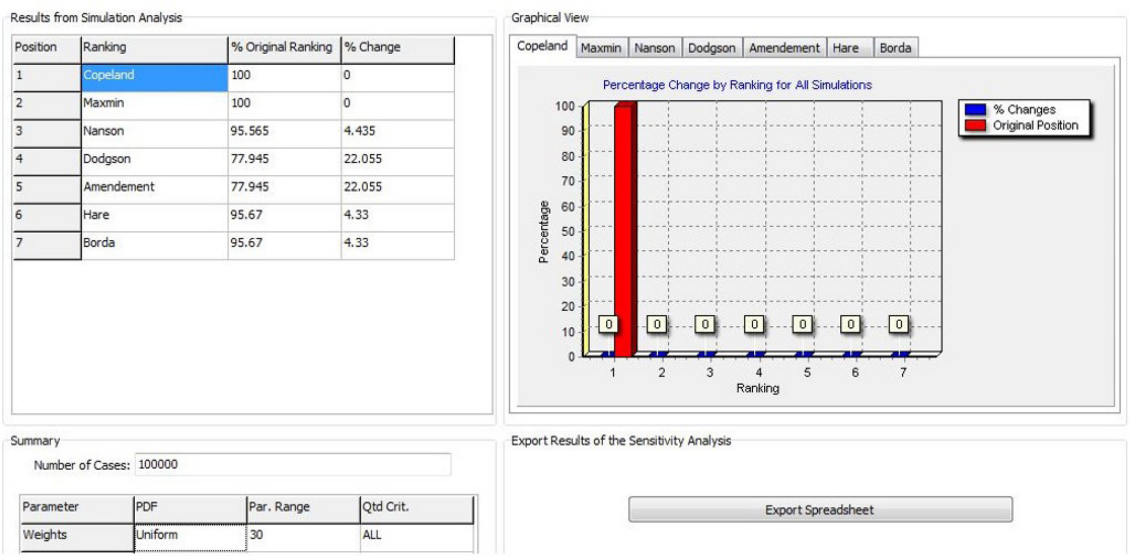

Figure 4. Sensitivity analysis.

4.4. Group aggregation and recommendation stage for managerial insights

As discussed in the previous section, the VP recommended as the most appropriate to perform group aggregation for the problem of choosing a landfill location was the Copeland procedure. This procedure is based on pairwise comparisons to determine the score of each alternative, selecting the alternative with the highest score. Thus, if one alternative wins (i.e., referencing to the majority of DMs considering one alternative to be better than the second one) one vote (+1) is given it, otherwise, it is discounted one vote (1) against it. Copeland's score is given by the difference between wins and losses. The highest score establishes which alternative must be chosen (Almeida et al., 2019a; Sabino et al., 2021).

Table 7 presents the final result of applying the Copeland procedure. Alternative 4 (A4) was the one with the highest score and is, therefore, the winner. This alternative represents the city of Araripina, which would be, according to the model, the city with the best location for the construction of the new landfill for the Microregion of Araripina, since it was the alternative that presented the best performance in the evaluated criteria. Next, the cities of Exú (A7) and Trindade (A3) can be seen in second and third positions, respectively, as the best options in the collective ranking. Santa Cruz (A1), Ipubi (A5), and Bodocó (A6) got the fourth, fifth and sixth positions, respectively. And finally, the city of Ouricuri (A2) presented the lowest performance, being in the last position of the ranking.

Table 7. Global ranking of alternatives.

Alternatives	A1	A2	A3	A4	A5	A6	A7	Wins	Total
A1	–	1	0	0	1	1	0	3	0
A2	0	–	0	0	0	0	0	0	–6
A3	1	1	–	0	1	1	0	4	2
A4	1	1	1	–	1	1	1	6	6
A5	0	1	0	0	–	1	0	2	–2
A6	0	1	0	0	0	–	0	1	–4
A7	1	1	1	0	1	1	–	5	4
Losses	–3	–6	–2	0	–4	–5	–1	–	–

Based on the results obtained, it is suggested that the group of DMs analyze the proposed recommendation and proceed to the final stage of decision implementation, which involves aspects related to planning, execution, and monitoring of the action implementation process.

5. Final remarks

A comprehensive group decision model was developed to support the analysis of landfill site selection based on the regionalization strategy. The proposed model uses MCDA/M to elicit DMs' preferences and obtain individual rankings, and a framework for choosing a voting procedure to aggregate individual preferences and obtain a collective choice. The model sook to find an impartial compromise solution that integrates the DM's different perspectives on the problem, considering social, economic, and environmental aspects.

A numerical application was performed to demonstrate the applicability of the proposed model in a group decision context for cities located in the Microregion of Araripina, Pernambuco State, Brazil. The results obtained recommended the region of Araripina as the most suitable for the construction of the landfill, in accordance with the hypothetical preferences established by the DMs.

The regionalization strategy for the construction of landfills is something very common in Brazil and other developing countries. For group decision issues of this nature, this model may be used as a way of how most cities adapt to the National Solid Waste Policy to perform the correct final disposal of the solid waste generated. As a large number of cities in this country still operate dumpsites and urgently need to adapt, the comprehensive model proposed in this research is potentially useful to support public bodies in group decision problems elsewhere. Thus, we highlight the importance of this research especially in the application layer, due to the need for public managers to find formal approaches to aid group decision processes in solid waste management, more specifically, related to landfill location.

This research presents an innovative proposal when considering landfill site selection in a group decision environment, as previously mentioned, most researches regarding landfill site selection take into consideration mono-DM contexts. In this work, we propose a comprehensive model in a group decision context, bringing light to a complicated scenario involving a diverse group of DMs with different needs and points of view to work along and search for solutions that benefit all, by using a formal approach. Furthermore, as advantages of the presented model compared to existing models in the literature, we highlight the innovative application in the landfill site selection scenario in a multi-DM environment and the usage of a formal approach to choose a VP and make collective choices, once most of the discussed models do not clarify how the VPs were chosen considering their properties and technical aspects, thus, avoiding manipulation on behalf of one or more parties.

As limitations of the study, we may consider the difficulty of obtaining real data for the application of the proposed model. This research ran a numerical example only, due to time constrain and limitations in contacting real DMs. Another point is the limited number of criteria established in the model to obtain the individual rankings of DMs. More comprehensive MCDA/M models that consider more aspects (criteria) to a problem of this nature may be used still considering the general aspects of the proposed model in this research.

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