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ARTICLES

PRIORITIZATION OF ALTERNATIVES IN WASTE MANAGEMENT: A CASE IN PERNAMBUCO STATE, BRAZIL

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ABSTRACT. Waste sorting is a core element for adding value to the recycling chain. Exploring and prioritizing alternatives regarding its expansion and improvement is very challenging. This study proposes a multi-methodological approach through the integration of a Problem Structuring Method (PSM) and a multicriteria method (MCDA/M) to support decision-making in the solid waste management context. The developed model uses Soft Systems Methodology (SSM) in the problem structuring stage to explore the problematic situation and identify alternatives. Preference modeling was conducted in a flexible and interactive manner, aided by FITradeoff method to rank the identified alternatives and obtain a recommendation. The proposed model was developed for a real case study in Brazil. In the elicitation process, the decision maker answered 9 questions to obtain the ordering of alternatives. This work seeks to enrich the literature proposing the successful application of an innovative model in the waste management context, especially regarding waste sorting.

Keywords: soft systems methodology, FITradeoff, solid waste management, waste sorting, multi-methodologies.

1 INTRODUCTION

Municipal Solid Waste Management (MSWM) is a worldwide challenge. Within the scope of a circular economy, the recycling chain seeks to keep materials and products in circulation for as long possible (EPA, 2023). Waste sorting is considered a key element in annihilating the challenges of solid waste generation, promoting a circular economy and environmental sustainability (Adu-Gyamfi et al., 2023). Developing effective waste sorting actions is the main issue, as it may involve community awareness and participation, government commitment, transportation costs, public and private sector integration, operations efficiency, waste pickers, the recycling industry,

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among others. How to relate all these aspects in a systemic manner is crucial to obtain successful waste sorting practices, which becomes even challenging when it comes to developing countries (Fernando & Zutshi, 2023).

In 2022, Brazil generated approximately 81.8 million tons of MSW which represents around 224,000 tons per day. As a result, each Brazilian generated, on average, 1.043 kg of waste per day. Of this amount, about 93% was collected, around 76.1 million tons (ABRELPE, 2023). A significant amount of this MSW generated is inappropriately disposed of in controlled landfills and dumpsites (about 39,5%). One way to reduce the volume of MSW disposed of in these areas or even in proper landfills is through waste sorting.

Waste sorting is a specific collection of dry solid waste (paper, plastic, metal, glass and organic). The recyclable material, separated at the generating source, is collected through a special (sorting) collection, which must be implemented by the service holder (municipal manager) according to the Brazilian law (BRAZIL, 2022). Collection can be performed door-to-door, at voluntary drop-off points, or in other ways (SNIS, 2021).

Separation of recyclable materials plays a strategic role in integrated solid waste management, providing several social, environmental, and economic benefits: it encourages the habit of separating waste at the source for its use; promotes environmental education aimed at reducing consumption; generates jobs and income for low-income people; reduces the need for raw material extracted from nature; improves the quality of organic material for composting; as well as extends the useful life of landfills.

According to the Brazilian National Solid Waste Policy (NSWP) (Law nº 12.305/10), responsibilities for MSWM are assigned to the municipalities. However, waste sorting services may be operated by the municipality itself or by outsourced companies or associations/cooperatives of waste pickers in partnership with the municipality. In 2022, the number of municipalities that presented some waste sorting practice was 4,183, representing 75.1% of the total municipalities in Brazil (ABRELPE, 2023).

It is important to note, however, that in most municipalities, waste sorting activities still do not cover the entire population, and may be one-off initiatives. Despite Brazil having a National Solid Waste Policy since 2010, this country recycles only 2.8% of the total collected waste (SNIS, 2021). The South and Southeast regions have the highest percentages of municipalities with waste sorting initiatives; both surpass 90% of municipalities with some waste sorting practices.

On the other hand, in the Northeast region, the second largest solid waste generator in this country, around 57,7% of the municipalities do not have any waste sorting practice. Recife, the capital and largest city of Pernambuco State, however, has a waste sorting program since 2016, known as “EcoRecife”. This project promotes the improvement and preservation of the environment and also generates jobs and income for waste pickers, who play a fundamental role in the process of correct waste disposal, as they separate all the material and provide what is useful to the recycling industry (Recife, 2023). Nevertheless, it is important to highlight that this waste sorting program does not cover the entirety of Recife’s urban area, nor the potential for achievable collected volume (in terms of what is produced). Thus, according to what was previously discussed, this project faces challenges in expanding and improving its operational practices to enlarge the waste sorting services due to lack of holistic comprehension of the problem, managerial limitations, and necessity of identifying alternative courses of action.

Problems of this nature are common in solid waste management, as they normally involve multiple stakeholders, who have different interests, perspectives and roles regarding the issue. The process of exploring and understanding this type of problematics can be supported by formal methodologies that guide them in a structured and systematic way. These approaches are known as Problem Structuring Methods (PSMs). One of the most prominent found in the literature is Soft Systems Methodology (SSM). It is an action-oriented process of inquiry into problematic situations in which users learn their way from finding out about the situation, to taking action to improve it (Checkland & Poulter, 2020).

On the other hand, the set of alternatives found should be explored and possibly taken according to the limited resources and different objectives faced (technical, economic, environmental or social) in the decision context, where some kind of prioritization is needed. MCDA/M can be very useful to carry out a rational ordering of these alternatives considering different attributes of the problem to ultimately support managers to make better decisions (Trojan & Morais, 2015). According to Garcia-Garcia (2022), MCDA/M has been widely used to support solid waste management.

Therefore, this paper proposes a multimethodological intervention to aid decision-making in MSWM. Firstly, a Problem Structuring Method known as Soft Systems Methodology (SSM) is applied to guide the process of structuring the problem associated with the expansion and improvement of waste sorting policies in one of the largest cities in Brazil. This stage aims to aid the decision maker (DM) to obtain a deeper understanding of the problem and for the identification of alternatives that will support in such decision-making process. Secondly, the multicriteria method FITradeoff (Flexible and Interactive Tradeoff) will be applied for the prioritization of alternatives obtained from the structuring stage in order to propose a recommendation.

This paper is organized as follows. Section 2 presents a literature review on the development of multimethodologies to support decision making specifying the use of Problem Structuring Methods and Multi-Criteria Decision Analysis (MCDA/M) in the solid waste management context; in section 3, we propose an integrated model to support municipal managers in MSWM; section 4 shows the application of such model in a real case study of waste sorting in one of the largest cities in Brazil; finally, section 5 presents the final remarks of this paper.

2 MULTIMETHODOLOGIES TO SUPPORT DECISION MAKING

A multimethodology is the combination of different techniques to assist in decision making, and it is something that has been widely studied in the field of Operations Research (OR) (Georgiou, 2012). A methodological intervention can be applied from several ways (Kotiadis & Mingers, 2014). For instance, multimethodologies can be developed through integrations between different Problem Structuring Methods (PSMs) (Georgiou, 2012); between PSMs and quantitative/hard approaches (Cambrainha & Fontana, 2018; Medeiros et al., 2017); or even between different quantitative/hard techniques (SILVA et al., 2019). In particular, the most common way of methodological interventions found in the literature is among PSMs and Multi-Criteria Decision Analysis (MCDA/M), which is also known as "Soft" and "Hard" OR integration. This is the type of intervention that we seek to delve further into in this research.

Structuring problems for MCDA/M has attracted increasing attention over the past 20 years from both a conceptual and a practical perspective. This is reflected in a significant growth in the number of published applications which use a formal approach to problem structuring combined with an analytic method for MCDA/M (Marttunen et al., 2017). According to Marttunem et al. (2017), there are different ways to combine PSMs and MCDA/M, as can be seen in Figure 1:

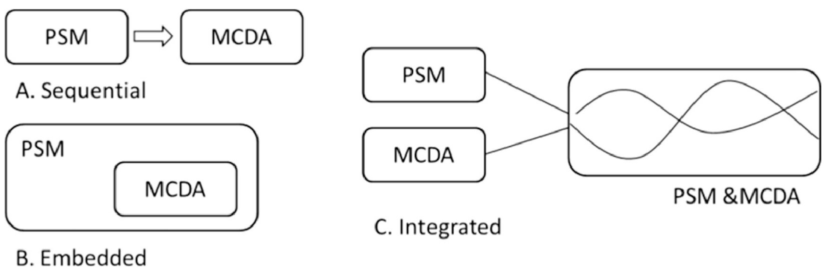

Figure 1 – Three different ways to combine PSMs with MCDA/M.

Source: Adapted from Marttunen et al. (2017).

A. Sequential: one or more PSMs inform the subsequent MCDA/M;

B. Embedded: MCDA/M is embedded within a generic problem structuring process;

C. Integrated implementation: the combination of PSMs and MCDA/M moves from a more independent consideration of the two perspectives to an integrated analysis.

PSMs have evolved within Operations Research (OR) over the last 30 years in order to better deal with messy, wicked and complex problems that are not amenable to the traditional, largely quantitative, OR techniques (Kotiadis & Mingers, 2014). The importance of PSMs is clearly recognized in the literature, as these approaches allow the evaluation of complex problems, paying special attention to the qualitative and subjective aspects of decision processes, seeking to learn and organize information about the problem (Mingers & Rosenhead, 2004; Cunha & Morais, 2017). Furthermore, PSMs allow stakeholders identification, specifying objectives, defining associated criteria, and suggesting resolution options for these complex problems, in environments of uncertainty and conflict. These aspects reduce the risk of "solving the wrong problem" or recommending an inappropriate solution (Marttunen et al., 2017).

The most prominent PSMs include Strategic Options Development and Analysis (SODA) (Ackermann & Eden, 2020); Strategic Choice Approach (SCA) (Friend & Hickling, 2004); Value-

Focused Thinking (VFT) (keeney, 1992); and Soft Systems Methodology (SSM) (Checkland & Poulter, 2020) and all these techniques have been successfully applied in a multimethodological context (Marttunen et al., 2017). According to Gomes Junior & Schramm (2022) and (Kotiadis & Mingers, 2014), SSM is one of the most frequently used PSMs in the literature (by itself or combined with other methods), showing its applicability in different situations.

Soft Systems Methodology is an approach for tackling problematical, messy situations of all kinds. It is an action-oriented process of inquiry into problematic situations in which users learn their way from finding out about the situation, to taking action to improve it (Checkland & Poulter, 2020). The learning emerges via an organized process in which the situation is explored using a set of models of purposeful action (each built to encapsulate a single worldview) as intellectual devices, or tools, to inform and structure discussion about a situation and how it might be improved.

As previously discussed, SSM has been used as part of multimethodological interventions in a large variety of problems, such as, water management (Gomes et al., 2015); aircraft manufacturing (Abuabara et al., 2017); environmental management (Marttunen et al., 2017); energy management (Bernardo et al., 2018); technology management (Small & Wainwright, 2014); Healthcare (Crowe et al., 2017; Lamé et al., 2019) among others (Marttunen et al., 2017). However, there is a lack of applications of this method when it comes to solid waste management.

In their work, for instance, Sridan & Surapolchai (2003) combined SSM and Critical Systems Heuristic (CSH) in a qualitative analysis, for structuring the process of collecting perspectives from all stakeholders, exploring the key problems, and finding out strategies to address the critical solid waste management issues of Tan-Dean, a district of Thailand. On the other hand, Adamides et al. (2009) present the combined application of SSM, system dynamics and multi-objective optimization in an action research project for the development of a Solid Waste Management (SWM) system for a specific region in Greece.

Even though SSM is commonly applied with MCDA/M methods in many contexts, to the best of the authors knowledge, there is no such intervention in solid waste management problems regarding waste sorting. Research about the implications and benefits of using PSMs to ease MDCA/M has become more and more common in the literature while the problem structuring phase receives increasingly attention in the decision-making process (Marttunen et al., 2017). Thus, this research aims to contribute to this gap in the literature presenting a multimethodological intervention in the context of solid waste management regarding waste sorting by using SSM and FITradeoff, an MDCA/M method that has been receiving increasingly attention in the literature due to its ease and applicability.

2.1 FITradeoff method

Among the large number of MCDA/M methods found in the literature, FITradeoff is a considerably new method which uses the flexible elicitation concept to improve the applicability of the traditional tradeoff elicitation procedure developed by Keeney (1992). FITradeoff offers two main benefits: the information required from the DM is reduced and he/she does not need to make adjustments for the indifference between two consequences (trade-off), which is a critical issue in the traditional tradeoff procedure. Furthermore, it is easier for the DM to make comparisons of consequences (or outcomes) based on strict preference than on indifference (De Almeida et al., 2016). Hence, the partial information used in FITradeoff reduces the cognitive effort of the DM and can result in fewer inconsistencies in the elicitation process (Freaj et al., 2017).

The flexibility of the FITradeoff Decision Support System (DSS) consists of systematically evaluating the possibility of finding a solution for the problem while the elicitation process is being conducted. This means that the elicitation procedure may be suspended as soon as a solution is found with the partial information obtained during this process. This partial information is based on preference (P) relations in order to find a solution, which in most cases can be achieved by using this partial information obtained from the DM up to that point, which is then applied to solve a linear programming problem (LPP) (De Almeida et al., 2016).

As previously discussed, the FITradeoff method is based on an interactive elicitation process, assuming partial information about the criteria weights representing the DM's preferences. Assume a set $S = (A_1, A_{2,} \dots, A_n)$ of N alternatives, which are evaluated with respect to M criteria. In this method, the alternatives are scored using a value function based on the additive model within the context of multi-attribute value theory (MAVT):

$$V(A_i) = \sum_{j=1}^{m} w_j v_j(A_i) \tag{1}$$

where w_j is the weight value of criterion j, and $v_j(A_i)$ is the value of the alternative A_i for criterion j (Correia et al., 2021). For further reading on how weights are calculated and the analytical process of FITradeoff we suggest (De Almeida et al., 2016).

This method allows a recommendation to be provided with fewer information from the DM if compared to other MCDA/M methods, once as previously said, it uses partial preferential information that act as input for mathematical programming models to find potentially optimal alternatives (POA), thus, reducing time and cognitive effort on the process for eliciting the DM's preferences (Fossile et al., 2020).

Even though FITradeoff is a considerably new method, it has been increasingly used in the literature, including multimethodological interventions with PSMs. Correia et al. (2021), for instance, considered the association of two PSMs (VFT and SODA), to structure a hierarchy of key objectives for evaluating the decision process of a foot industry. Preference modeling was conducted in a flexible and interactive manner, aided by FITradeoff. This intervention was considered successful for prioritizing workstations in ergonomic decision problems.

Silva et al. (2019), applied an integration of VFT and FITradeoff for the selection of World Class Manufacturing (WCM) projects. Their work showed the necessity and relevance of a PSM that follows a MCDA/M model to improve the decision-making for the choice of WCM projects. Monte & Morais also applied VFT and FITradeoff, in their case, in an urban water supply system. The model yielded a deep analysis of the manager's reasoning, which was transcribed through the objective's hierarchy, and reached a solution to the problems of the local water supply system. Other FITradeoff applications can be found in Information Technology (Poleto et al., 2020); Maintenance Outsourcing (Rodrigues et al., 2023); Social Sustainability (Passos Neto et al., 2021); Renewable Energy (Fossile et al., 2020); Management and Industry (De Oliveira et al., 2022; Zanazzi et al., 2023); Circular Food Economy (Lugo et al., 2023); Agriculture (Carrilo et al., 2018; Rodriguez et al., 2021), among others (De Almeida et al., 2023).

2.2 Waste sorting and MCDA/M

Municipal waste management problems have been analyzed and solved by utilizing various tools and techniques all through the past decades (Singh, 2022). From the MCDA/M perspective, the literature shows that studies using this type of techniques in solid waste management are predominantly addressed to problems related to MSW involving facility location or management strategy (Coelho et al., 2017). Moreover, one may find a limited amount of works about circular economy transition (Silva & Morais, 2021), assessment of solid waste treatment techniques (Omran et al., 2023; Toro et al, 2023), assessment and monitoring of MSWM services or facilities and research related to waste transportation and collection routing (Coelho et al, 2017), among others. When it comes to waste sorting programs, the literature presents innumerous research regarding general aspects of this topic, but there is no evidence of multicriteria methods used to support the improvement of waste sorting policies.

Rousta et al. (2020) on their work, conducted a meta-analysis of the factors that influence participation in household waste sorting in developing countries. Results of this meta-analysis indicate that knowledge, situational factors, such as physical conditions, and governmental incentives can influence participation in household waste sorting in developing countries. This study, however, does not present courses of actions which waste managers may take to improve their waste sorting practices. Dahlén & Lagerkvist (2010), propose the evaluation of recycling programs in household waste collection systems. The aim is to contribute to the understanding of how recycling programs affect the quantity of waste and sorting activities. Their research identified 43 factors influencing the output of source-sorting programs in household waste collection systems. Three indicators concerned with source sorting, mis-sorting and participation reflect the current ability of the inhabitants to sort waste for recycling. On the other hand, this study shows the need to further research to support policy development.

Knickmeyer (2019), on the other hand, presents a literature review to support waste manager practitioners and policy makers to design future strategies and interventions to motivate household waste separation behaviour. The research emphasizes the relevance and consideration of its underlying social factors when it comes to the successful implementation of MSWM Systems. Results show that targeted communication and educational programs that involve the community and present sorting wastes as a social norm are crucial for the establishment of a recycling culture. The work presents many approaches for the development of practicable solutions, but is supposed to serve solely as a basis for context-specific investigations. As previously discussed, research related to waste sorting normally focuses on general aspects of the issue, lacking on the identification of waste sorting policies or the exploration of such policies in order to improve waste sorting programs.

However, there are findings in the literature that are associated with multicriteria decision models to support waste management decisions (Coelho et al., 2017). Thus, more studies are necessary to evaluate the results of structuring and developing multicriteria decision models to find plausible recommendations when it comes to waste sorting. These gaps motivate the choice of the research question examined in this study. Hence, this research aims to contribute to the literature applying SSM and FITradeoff through a methodological intervention in solid waste management due to the gap in the applicability of such approaches in this context, especially regarding waste sorting. Moreover, it considers bringing the practical and feasible aspects of applying these approaches together, in the waste sorting context.

3 PROPOSED MODEL

This section proposes the development of a model based on a multimethodological intervention using SSM and FITradeoff to the prioritization of alternatives in order to improve and expand a waste sorting project. The model is divided into two stages (Figure 2): (i) problem structuring stage and (ii) problem evaluation stage.

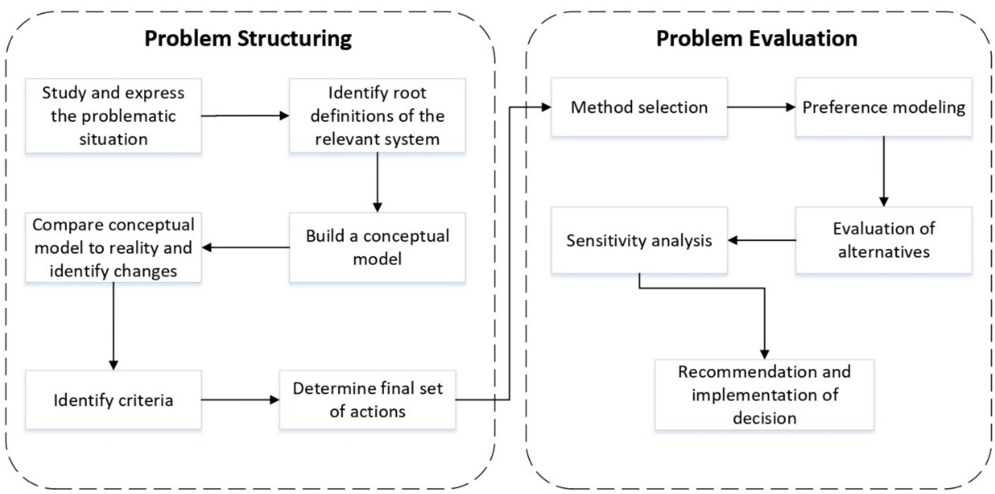

Figure 2 – Flowchart of the proposed model.

Source: the authors, 2024.

3.1 Problem structuring stage

In the first stage, the problematic situation is characterized. A problem of this nature commonly deals with different stakeholders who influence the context in many aspects. These stakeholders must be identified and their roles must be considered. At this stage, the DM thinks about how to expand and improve the waste sorting. From this perspective, the DM will be able to explore and express the problematic situation through interviews, brainstorming, and also data collection and observation of documents.

After the definition and exploration of the problematic situation, it will then be expressed through the Rich Picture, which is a visual tool that allows the inclusion of details for a better comprehension of the situation. Then, the root definitions of such a problem are created and discussed. These root definitions deal with the core competence of human activity, as well as its elements. According to Checkland & Poulter (2020), the elements of the root definition (CATWOE) are:

- Customer: Who are the victims or beneficiaries of the system?
- Actors: Who will perform the activities?
- Transformation: What transformations will the activities fulfil?
- Worldview: What point of view validates the root definition?
- Owner: Who can stop this activity?
- Environment: What are the external constrains?

Then, the conceptual models are developed, which are a structured set of activities necessary to achieve the expected objectives in the root definitions, as well as the existing relationships between these activities. After that, the conceptual models will then be compared to reality. The developed model works as a basis for comparison with reality and, based on the perceived differences, points will be raised for the discussion of the problem, as well as solutions and suggested changes (which is the main objective of this step).

Changes proposed in the previous step are then discussed, checking if they are feasible and desirable. These changes can be of three types, structural, procedural, and attitudinal. They also depend on acceptability, culture, and economic feasibility for implementation. With that, as a consequence of the problem structuring stage, the criteria of the problem will be identified, as well as the set of actions. The identification of actions is a step to which one can always return in the course of the process.

3.2 Problem evaluation stage

In the second stage, the analytical process of the model is performed, i.e., there will be considered the quantitative aspects of it. Thus, in the first and second steps - preference modeling and method selection, respectively - the aspects involved in multicriteria method selection are structured. Next, the alternatives will be evaluated to obtain the results; here the multicriteria method is finally applied. A sensitivity analysis is then performed to verify the robustness of the developed model.

Finally, one should prepare a recommendation and the necessary aspects are planned for the correct implementation of the decision. This phase ends when opportunities and recommendations are identified for the continuous improvement of model performance. It is worth mentioning that a facilitator/analyst is needed in the whole process (structuring and prioritization stages), which is the one responsible for organizing the process from the technical viewpoint and setting up the decision support model.

4 CASE STUDY IN PERNAMBUCO STATE

In this section, we will present the application of the proposed model in a case study of waste sorting located in Recife, capital and largest city of Pernambuco State, Brazil.

EcoRecife is a waste sorting service offered by Recife municipal management. It aims to make the recyclable material discarded domestically by Recife's population reach waste pickers' cooperatives. This action promotes the improvement and preservation of the environment and also generates jobs and income for waste pickers. They play a fundamental role in the process of correct waste disposal, as they separate all the material and provide what is useful to the recycling industry located in Recife Metropolitan Area, which is the largest industrial recycling complex in Northeastern Brazil. Considering the necessity of improving operational practices faced by municipal public management and cooperatives, and the potential for its expansion, this project was chosen for the application of the proposed multi-methodological intervention.

4.1 Problem structuring stage

At this stage, SSM was initially chosen to aid the process of structuring the problem in an AFT (Alternative-Focused Thinking) perspective. As previously mentioned SSM is an approach that works with the environment and the learning process to analyze complex problems. It emphasizes the evaluation of the real world, in which people live and with which they relate. Thus, the purpose of this stage is to assess the problem comprehensively, in order to build a conceptual model that may allow the identification of stakeholders, possible alternatives, objectives, criteria, and general aspects about the problem.

4.2 Study and express the problematic situation

The DM of this problem is the city municipal manager (mayor), once he is formally responsible for the USW management generated by the municipality according to Brazilian law, thus, his preferences will be considered in the model. Nowadays, only 2% of the USW is recycled compared to the recycling potential of the waste volume collected in Pernambuco State (SEMAS-PE, 2020). The percentage of recycled material is still low compared to waste production, but companies are beginning to realize that big business is not just receiving and burying it. The DM interacts with several stakeholders in the problem, these are: cooperatives and waste pickers that are part of the waste sorting program, the recycling industry that buys the scrap from the cooperatives, and the local community that participates in waste sorting actions.

First of all, the analyst encouraged the DM to think about the problem starting from the initial questioning of "which aspects hamper to expand and improve waste sorting services?" From this initial statement, in a brainstorming process, the DM's perspectives of the problem were expressed in a Rich Picture (Figure 3), which provides a better understanding of all the factors and stakeholders involved. The stakeholders identified and their roles in the process are described below.

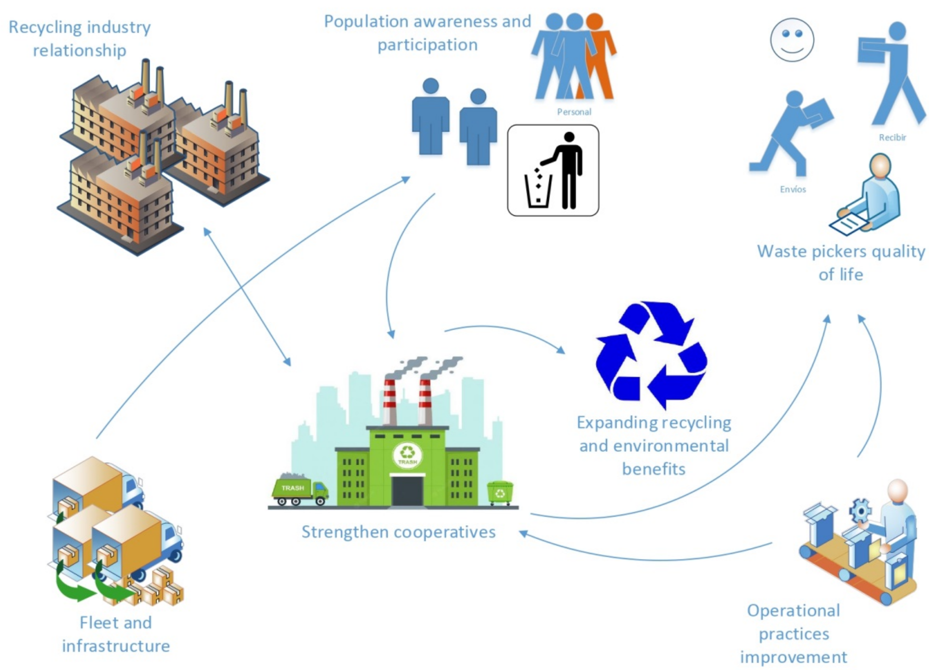

Figure 3 – Rich Picture of the problematic situation.

Source: the authors, 2024.

The purchasing (recycling) industry currently has no restrictions on the volume of scrap received due to the low volume sent by its direct suppliers (cooperatives). The purchasing industry wants to increase the volume of material received as long as it is within the specifications, and may even pay more attractive prices for better quality inputs.

On the other hand, there are recycling cooperatives that develop the process of treating recyclable materials and sending them to the recycling industry, through the collection, sorting, and sale of the material. These cooperatives, however, need to improve their operational practices to provide appropriate material to their purchasers to strengthen the relationship with the recycling industry by increasing the volume of material sold as well as the selling price. Furthermore, the waste pickers, who work for the cooperatives, need better work conditions and training to improve their activities and contribute to increase performance as well as their quality of life.

The local community is also a stakeholder in this problem as it is the generating source of USW. Furthermore, it is through the active participation of the community that the waste sorting process begins, through the separation of waste at source and its subsequent distribution, either through the residential collection, or at official collection points (eco-points and eco-stations located throughout the city). Thus, their awareness as well as their participation is essential for the success of the project.

4.3 Identify root definitions of the relevant system

During the discussions supported by the Rich Figure, the following considerations emerged:

1. Strengthen and expand infrastructure;
2. Improve the quality of life of waste pickers, in economic, training, and work environment terms;
3. Strengthen the relationship with the recycling industry;
4. Improve operational practices for solid waste collection, transport, and sorting.

For each of the statements identified above, the essential (root) definitions of the problem will be specified. Thus, the components of the root definitions (CATWOE) are determined as follows (Tables 1-4):

Table 1 – The elements of a CATWOE and their root definition 1.

	Element	**Root definition**
C	Clients	Population and cooperatives
A	Actors	Municipal management
T	Transformation	Expansion of waste sorting activities to more areas
W	World-view	It allows increasing the volume of collected waste and consequently recycled material, in addition to a greater participation of the population in waste collection
O	Owner	Municipal management
E	Environment	Areas of difficult access and lack of interest of the population

Table 2 – The elements of a CATWOE and their root definition 2.

	Element	Root definition
C	Clients	Waste pickers
A	Actors	Municipal management and cooperatives
T	Transformation	Waste pickers will be able to better perform their activities, increase their income, and have a less unhealthy work environment
W	World-view	Happier and more productive employees
O	Owner	Municipal management
E	Environment	Waste pickers resist to get trained or to use personal protective equipment (PPE)

Table 3 – The elements of a CATWOE and their root definition 3.

	Element	Root definition
C	Clients	Cooperatives and recycling industry
A	Actors	Municipal management, cooperatives, and recycling industry
T	Transformation	Strengthen relationship between cooperatives and recycling industry
W	World-view	Better quality inputs (solid waste) for the recycling industry and increase in the prices of inputs sold by cooperatives
O	Owner	Recycling industry
E	Environment	Non-attractive input sales price; market ignorance

Table 4 – The elements of a CATWOE and their root definition 4.

	Element	Root definition
C	Clients	Population, municipal management, cooperatives, and industry
A	Actors	Outsourced collection company, and cooperatives
T	Transformation	Increase efficiency in waste collection, transport, and sorting operations, and reduce operation costs
W	World-view	Strengthen the entire supply chain
O	Owner	Municipal management
E	Environment	Opposition to change (difficulties in adhering to new operational practices); lack of investment

4.4 Build a conceptual model

After identifying the root definitions for the problem, the conceptual model is developed. A conceptual model is a structured set of activities necessary to achieve the objectives expected in the root definitions and shows the relationships between these activities. Thus, modeling is based on the root definitions and the CATWOE elements; it is done by using verbs to describe activities and by assembling a handful of such activities structured in terms of logical dependence. Figure 4 presents the conceptual model of the problem.

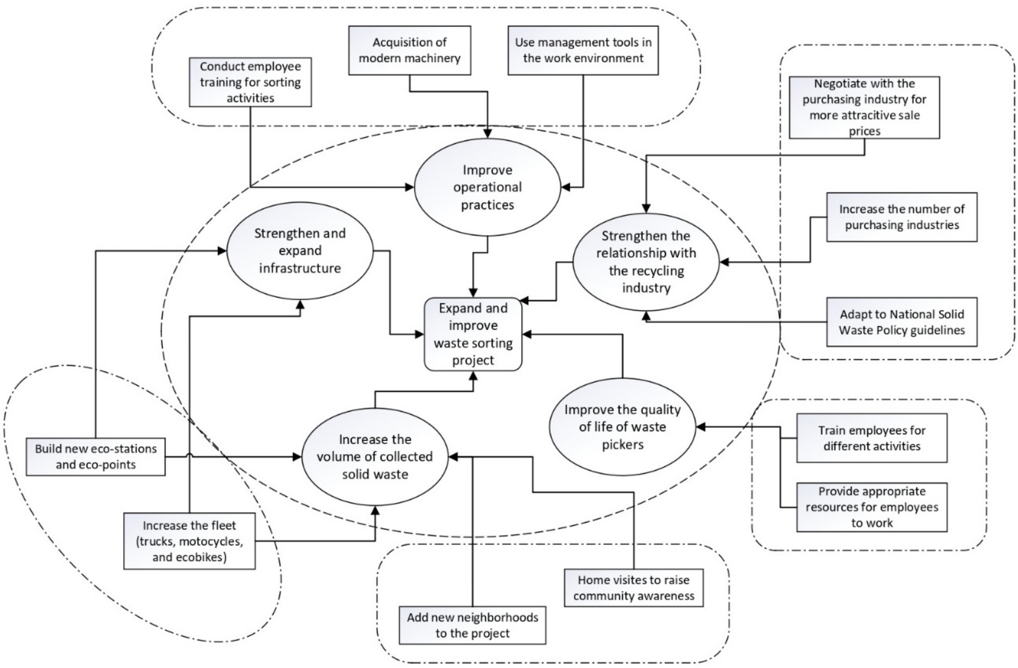

Figure 4 – Conceptual model.

Source: the authors, 2024.

Aiming to ease the understanding of the processes described in the conceptual model, Table 5 presents a description for each action.

Table 5 – Detailing the conceptual model actions.

Action	Code	Description
Increase the fleet (trucks, motorcycles, and ecobikes)	A1	Obtain new trucks that collect waste in homes and in eco-stations; obtain new ecobikes that travel along the bicycle paths on Sundays, collecting material from paper bins; and new motorcycles, which are tricycles equipped with buckets that collect household waste generated in an area of difficult access, where collection trucks cannot enter.
Build new eco-stations and eco-points	A2	Increase the number of eco-stations (waste collection stations, which offer the community an alternative for the disposal of old furniture, waste from small residential construction, and other materials); and eco-points (voluntary collection stations for recyclable USW).
Add new neighborhoods to the project	A3	Expand waste sorting to neighborhoods where these services do not exist.
Train employees for different activities	A4	Conduct courses so that employees may perform other material recovery activities such as fixing fans, refrigerators, electronic devices, etc., adding value to the waste received and increasing their income.
Provide appropriate resources for employees to work	A5	Provide PPE, general tools, uniforms, and all equipment necessary for employee protection and for the development of skills both in training activities and in professionalizing courses.
Use management tools in the work environment	A6	Apply management tools to make the organizational environment more appropriate, safe, and comfortable for employees, as well as enable the improvement of their operational activities.
Acquisition of modern machinery	A7	Invest in modern machinery to improve cooperatives' productive processes.
Conduct employee training for sorting activities	A8	Train employees for waste sorting activities so they may increase productivity and reduce waste and accidents in the operation.
Home visits to raise community awareness	A9	Perform systematic home visits to aware local community on the importance of participating in selective collection actions.
Increase the number of purchasing industries	A10	Seek to do business with more recycling companies in the region aiming to increase the volume of material sold, and to have more options of purchasers to negotiate with.
Negotiate with purchasing industry for more attractive prices	A11	Negotiate with the recycling industry to purchase scrap at more attractive prices, committing to supply better input, and meeting the purchaser's specifications.
Adapt to the guidelines of the NSWP	A12	Provide the necessary instruments to achieve the NSWP's objectives in the municipal level.

The conceptual model should incorporate the processes of monitoring and control, which establish measures of performance. Monitoring and control were described in terms of efficacy, efficiency, and effectiveness ("3Es") (Checkland & Poulter, 2020). *Efficacy* normally refers to verifying if the system works, in the sense of producing its intended outcome; *efficiency* is used to assess if the transformation is being achieved with minimum use of resources; and *effectiveness* is used to evaluate if the system is helping achieve some higher-level or longer-term aim. The definitions of the principles to evaluate the system, according to the root definition, in terms of "3Es" are:

- *Efficacy*: Recyclable material is delivered in good quality (within specifications) to the recycling industry;
- *Efficiency*: A balance is achieved when the amount of non-economic material collected is reduced to acceptable levels;
- *Effectiveness*: The system increases the waste collection area, and consequently the community's participation and the volume of recyclable material for sale; the cooperatives increase their revenue and reduce overall costs.

The 3Es enable the system to be continuously controlled, monitored, and reported. Thus, the DM will be able to verify what is being done and what can be done compared to what was established in the CATWOE and in the conceptual model.

4.5 Compare conceptual model to reality and identify changes

At this step, the model is compared to reality expressed in the Rich Picture from step 2. The constructed model serves as a basis for comparison to reality and, based on the perceived differences, points will be raised for the discussion of the problem, as well as suggested solutions and changes. These changes are also discussed in this step, checking whether they are feasible and desirable.

Changes may be of three types, these are changes to structures (structural), changing processes or procedures (procedural), and changing attitudes (attitudinal). They also depend on acceptability, culture, and economic feasibility for implementation. Hence, the desirability and feasibility of the identified actions are verified, and they are then classified according to their type, as can be seen in Table 6.

Table 6 – Comparison between conceptual model and real world.

Code	Conceptual model activities	Real world	What could we do	Type of change
A1	Increase the fleet (trucks, motorcycles, and ecobikes)	Insufficient fleet to expand collection actions in new neighborhoods; limited resources to buy new fleets.	Prioritize the allocation of resources to buy new vehicles; reprogram existing vehicle routes.	Structural
A2	Build new eco-stations and eco-points	The existing eco-stations and eco-points are not enough to serve the entire population.	Carry out gravimetric analysis (the study of waste composition by neighborhood) in potential neighborhoods for expansion.	Structural
A3	Add new neighborhoods to the project	Difficulty in expanding the project to hard-to-reach places.	Look for alternative ways to get to these places.	Structural

Table 6 – Continuation.

Code	Conceptual model activities	Real world	What could we do	Type of change
A4	Train employees for different activities	There is opposition from employees to qualify;	Provide professional qualification courses presenting employees the advantages to increase income and improve their quality of life.	Procedural/ Attitudinal
A5	Provide appropriate resources for employees to work	Opposition from employees to use PPE and use new tools.	Promote knowledge on the importance of using PPE; Provide new work tools that allow the restoration of materials, and sufficient PPE for safe activities.	Attitudinal
A6	Use management tools in the work environment	There is not a continuous improvement policy in the cooperatives; Opposition to changes in the work environment.	Provide lectures and courses to internalize the need and importance of improving internal processes.	Procedural/ Attitudinal
A7	Acquisition of modern machinery	Employees unable to operate modern machinery; resource limitation.	Prioritize resources for process modernization; Train employees to use the new machines.	Procedural/ Structural
A8	Conduct employee training for sorting activities	Opposition to change activities/processes they are used to do.	Promote knowledge on the advantages of improving internal processes in financial, ergonomic and operational terms.	Procedural/ Attitudinal
A9	Home visits to raise community awareness	The community does not recognize the value of household solid waste; The community lacks communication with the government sector about the participation in the systematic solid waste management.	Keep communication with the community presenting the advantages of sorting collection and their role in the systematic solid waste management.	Attitudinal
A10	Increase the number of purchasing industries	The volume of collected waste nowadays does not allow expanding the number of partners.	Increase the volume of collected waste to be able to supply more recycling industries.	Structural
A11	Negotiate with purchasing industry for more attractive prices	The quality of the sorting material collected nowadays does not enable to negotiate higher sale prices.	Improve the quality of the sorting material collected (within specifications) to be able to charge higher sales prices.	Attitudinal
A12	Adapt to the guidelines of the NSWP	The NSWP does not incorporate the social and economic characteristics of the different regions of the country, which hinders its application.	Seek an integrated relationship with stakeholders of the systematic solid waste management (manufacturers, retailers and traders, community, cooperatives, and the recycling industry) through a shared responsibility considering the regional aspects.	Attitudinal

4.6 Identify criteria

Considering the objectives identified in the initial stages of SSM, the analyst encouraged the DM to think about how these objectives could be measured through the criteria. Thus, seven criteria were determined that will enable quantifying the objectives and evaluating the performance of the previously identified alternatives. Table 7 presents each criterion followed by their description.

Table 7 – Criteria and their characteristics.

Criteria	Code	Description	Preference direction
Amount of collected waste	C_1	Amount of waste collected per month (tons)	Maximize ↑
Impact of community participation	C_2	It measures the impact of each action on the number of people participating in selective collection activities (Likert scale)	Maximize ↑
Impact on accident prevention	C_3	It measures how much (impact level) each action may contribute to decrease the number of workplace accidents (Likert scale)	Maximize ↑
Average income	C_4	Average monthly income (BRL$) of waste pickers	Maximize ↑
Efficiency	C_5	It is calculated using OEE (Overall Equipment Effectiveness) by Nakajima (1988) (Likert scale)	Maximize ↑
Revenue	C_6	All Cooperatives' average monthly revenue (BRL$)	Maximize ↑
Households with waste sorting activities	C_7	It measures the number of households that participate in waste sorting	Maximize ↑

Criteria C_1, C_4, C_6, and C_7 are classified as natural criteria, once they can be directly measured, therefore they have well-defined numerical evaluation scales. On the other hand, criteria, C_2 C_3, and C_5, are classified as constructed ones and will be scored on a semantic scale, as shown in Tables 8, 9 and 10, respectively.

Table 8 – Scale for criterion C_2.

Level	Description
0	There is no impact in community participation
1	Has the possibility of increasing up to 10% population participation
2	Has the possibility of increasing up to 20% population participation
3	Has the possibility of increasing 20% or more population participation

Table 9 – Scale for criterion C_3.

Level	Description
0	There is no impact on accident prevention
1	Has the possibility of reducing up to 5% of accidents in the workplace
2	Has the possibility of reducing up to 15% of accidents in the workplace
3	Has the possibility of reducing 15% or more accidents in the workplace

Table 10 – Scale for criterion C_5

Level	Description
1	There is no impact in efficiency
2	It will be possible to contribute up to 10% in efficiency increase for the operations
3	It will be possible to contribute up to 20% in efficiency increase for the operations
4	It will be possible to contribute to 30% or more in efficiency increase for the operations

4.7 Determine final set of actions

At this stage, a deeper analysis of the alternatives (from Table 5) will be carried out to determine which ones will be appropriate for the multicriteria model. Hence, after identifying the alternatives in the previous stages, it was noticed that some of them do not fit the analytical (multicriteria) model, as they are considered strategic alternatives and their performances cannot be measured according to the established criteria.

The DM should look at these alternatives from a more strategic and less operational perspective, as these alternatives are related to the objective of *strengthening the relationship with the recycling industry* (alternatives A10, A11, and A12), and require a perception at the medium and long term. These alternatives are: "Increase the number of purchasing industries", "Negotiate with purchasing industry for more attractive prices", and "Adapt to the guidelines of the NSWP". The remaining alternatives will be considered in the prioritization stage. Table 11 presents the consequence matrix with the alternatives and their performances in each criterion.

Table 11 – Consequence matrix.

Alternatives	Criteria						
	C_1 (tons)	C_2 (Likert)	C_3 (Likert)	C_4 (BRL$)	C_5 (Likert)	C_6 (BRL$)	C_7 (Units)
A1	20	2	0	1200	2	40000	6000
A2	18	2	0	1350	2	38000	5800
A3	25	3	0	1400	2	47000	5000
A4	6	0	1	1500	2	43500	0
A5	6	0	3	1100	3	36000	0
A6	15	0	2	1300	4	49000	0
A7	10	0	2	1350	4	44000	0
A8	4	0	3	1350	4	46500	0
A9	12	3	0	1150	1	42700	8000

4.8 Problem evaluation stage

In this stage is performed the analytical process of the model to obtain the final ordering of alternatives.

4.9 Method selection and preference modelling

In this step, the appropriate preference structure must be defined to represent the DM's preferences. It was identified that the structure (P, I) is adequate for this situation, where P represents strict preference and I, indifference. In such a way, its evaluation can be obtained through the analysis of the marginal value function in which an alternative is preferable to another if it exceeds the performance of that alternative, otherwise, if the value functions have the same performance, there is indifference. Furthermore, it was noticed that the DM's rationality for the problem is compensatory, once, there is compensation for a lower performance of an alternative in a given criterion, through better performance in another. In this way, compensatory rationality considers the existence of trade-offs between the criteria, while evaluating an alternative, as previously discussed.

Thus, the global evaluation of the alternatives can be carried out through the compensation of the consequences in all the criteria under consideration. Therefore, taking into account all these characteristics, the appropriate approach is the deterministic additive aggregation (MAVT) corresponding to the unique criterion of synthesis method, which allows obtaining a global score for each alternative. Hence, to support the preference modeling process, the analyst used FITradeoff's DSS for ranking problematic (available online at www.fitradeoff.org) to facilitate the DM in the preference elicitation process.

To perform the aggregation in the additive model, the global value function requires the intra-criteria evaluation to be carried out, so that, the values of the consequences in the criteria are on an interval scale, 0 to 1, where 1 represents the best performance and 0, the worst performance. This normalization is done automatically by the DSS since the consequence matrix (from Table 11) will be input into the system. Without this normalization, it would not be possible to resolve the LPP proposed by the method, since it would present different intervals in relation to the assessments.

The next step is ranking the criteria by overall evaluation. Initially, the criteria must be ranked according to the order of impact they will generate on the final result of the problem as a whole, according to the DM's preferences. Hence, the DM has to choose the criterion that he/she considers to have the highest scale constant value, assuming that it will have its performance optimized to the best possible value. It is done by considering that the DM may improve the performance of an alternative in just one criterion for its maximum value, with all others having a minimum value. This procedure allows ranking the scale constants of all criteria. The order established by the DM in the overall evaluation process is the following:

$$K_{C1} > K_{C6} > K_{C2} > K_{C4} > K_{C5} > K_{C7} > K_{C3} \tag{2}$$

After ordering the scale constants (weights), the DM continues the process through the elicitation by decomposition. In this step, two hypothetical consequences are presented to the DM. In the first scenario, an intermediate consequence value is displayed in a criterion (for which the associated weight appears better positioned in the ranking) and the worst consequence for the others; whereas the second scenario presents the best consequence for a subsequent criterion and the worst performance for the others (Figure 5).

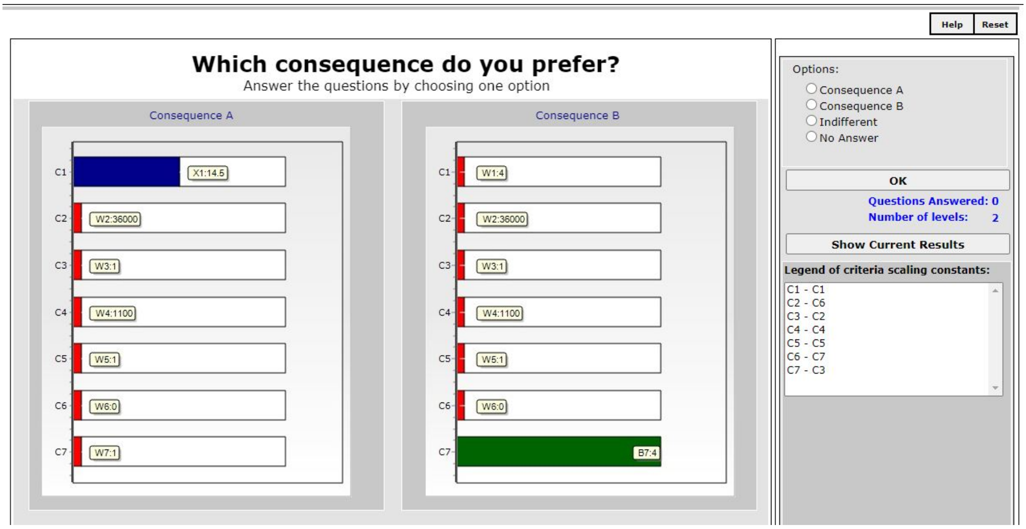

Figure 5 – Flexible elicitation of the scale constants.

Then, it is asked which consequence the DM prefers among the options presented, where he/she can answer: “consequence A”, “consequence B”, “indifference”, or even “no answer”. The preferences informed will be used for the construction and resolution of an LPP, allowing the establishment of relationships between alternatives based on the partial information obtained for each question. Thus, after the DM answered the first question, another question was asked, and the weight space was updated. The system also presented some information about the DM elicitation process, such as the number of questions answered, which is updated according to the number of responses, and the number of ordering levels.

The FITradeoff method does not seek to find exact values for the scale constants, but rather a space of feasible weight values, which will narrow the range within each criterion as the DM’s information is collected. With the ordering of the scale constants done previously and the elicitation process, after 9 questions, it was possible to establish a maximum and a minimum limit for each constant (Figure 6). The Hasse Diagram generated by the DSS with the recommended final ranking of alternatives can be seen in Figure 7.

4.10 Evaluation of alternatives

After the entire elicitation process of the DM’s preferences, the result obtained by applying FITradeoff shows the prioritization of actions in a complete ranking to support the improvement of the waste sorting, as can be seen in Table 12. According to the preference information given by the DM, A3 is considered the best alternative to improve the waste sorting program. In other words, some relations of dominance of the alternatives were found by the LPP model, while at

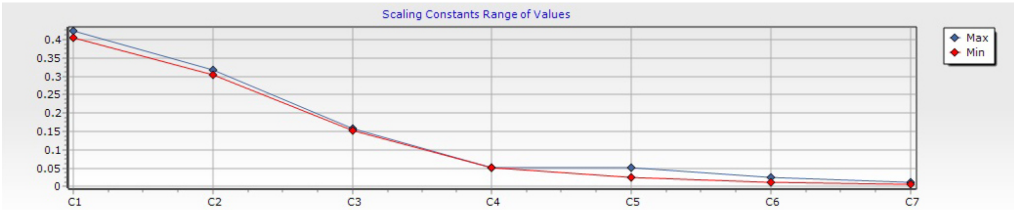

Figure 6 – Scaling constants boundaries graph.

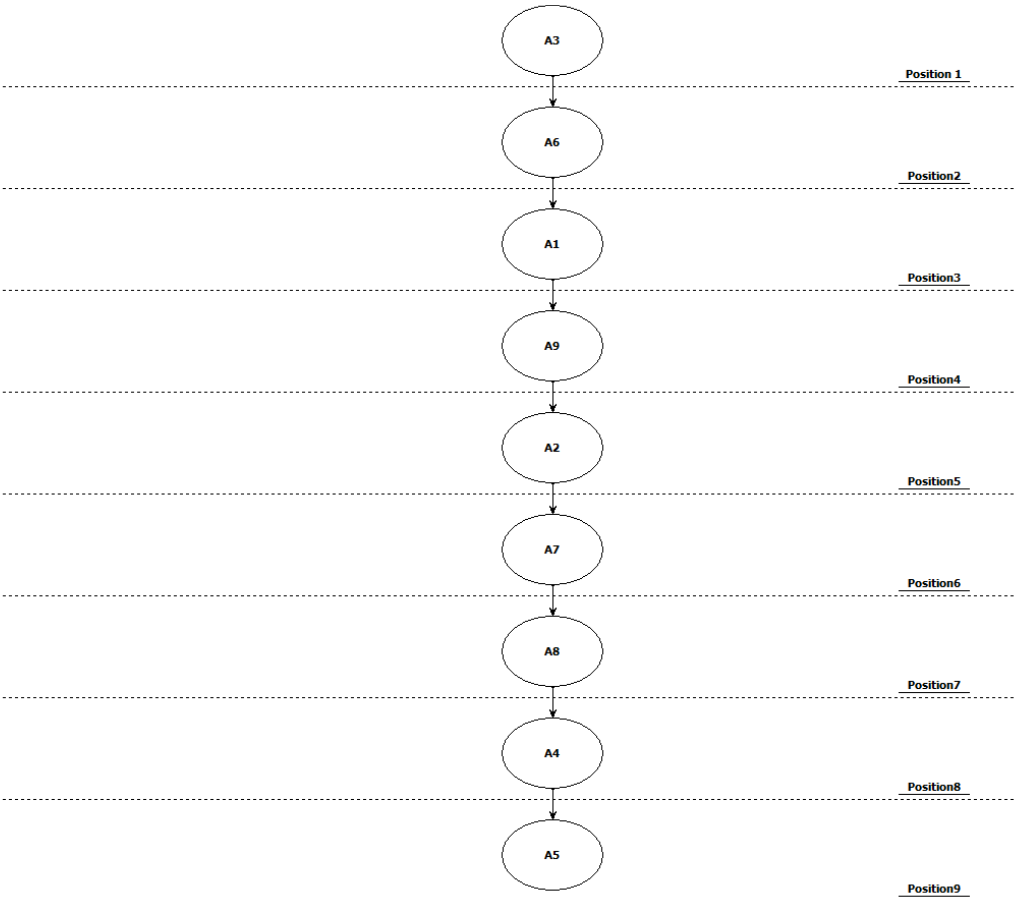

Figure 7 – Hasse diagram with the final ranking of alternatives.

level 1 there is A4, in which this alternative dominates the others. Thus, "expand the waste sorting to neighborhoods where these services do not exist" is considered the best alternative to be taken.

Following the evaluation, A6 and A1 are the next alternatives recommended by the ranking. Alternative A6 suggests the use of management tools in the work environment to improve cooperatives' operational practices as the second best option obtained by the model. A1, in turn, suggests increasing the waste collection and transport fleet as a way to expand the program, both alternatives dominate the other alternatives that follow the complete ranking obtained (Table 12).

It is worth mentioning alternative A5, which is in the last position of the ranking. This alternative presents the worst performance in criteria C2, C4, C6, and C7, and very low performance (the second worst) in C1, which, according to what was established by the DM's preferences, placed it as the least interesting option for the problem.

Table 12 – Recommendation.

Priority Ranking		Alternatives
1	[A3]	Add new neighborhoods to the project
2	[A6]	Use management tools in the work environment
3	[A1]	Increase the fleet (trucks, motorcycles, and ecobikes)
4	[A9]	Home visits to raise community awareness
5	[A2]	Build new eco-stations and eco-points
6	[A7]	Acquisition of modern machinery
7	[A8]	Conduct employee training for sorting activities
8	[A4]	Train employees for different activities
9	[A5]	Provide appropriate resources for employees to work

4.11 Sensitivity analysis

After the evaluation of the alternatives proposed by the FITradeoff recommendation, the next step is to perform a sensitivity analysis to verify the robustness of the model. The sensitivity analysis studies the impact that variations in the model's parameters may have on its output. This step is also performed by the FITradeoff DSS, where the parameters, in this case, the values of the consequences in most of the problem criteria varied in a ± 15% bound. The results obtained can be seen in Figure 8.

For this sensitivity analysis, the values of the consequences in criteria C1, C2, C3, and C5 simultaneously varied in a ± 15% bound. Thus, this analysis shows the percentage of simulation instances in which the alternatives remain in their original rank position or in which the alternatives' rank position changes. The obtained results present that almost all alternatives (except alternative A2) remain in the original rank position most of the time when comparing the percentage of times they were ordered in the original position with any other position in the rank. In particular, alternative A3, which appears in the first position in the original prioritization ranking and remains 100% of the time as the most preferable one.

Alternatives A4, A5, A6, A7, and A8 remain in their original position at least 74% of the time. The only alternative that changes its position most of the time compared to the original rank position is alternative A2. However, this change is not so alarming since this alternative moves from fifth to fourth position most of the time when it is not in its original rank position, thus not bringing discrepant changes from the original ranking. Hence, it can be affirmed that the model is robust for the sensitivity analysis performed. The percentage of times that each alternative changes its position regarding the original ranking can be verified in Table 13.

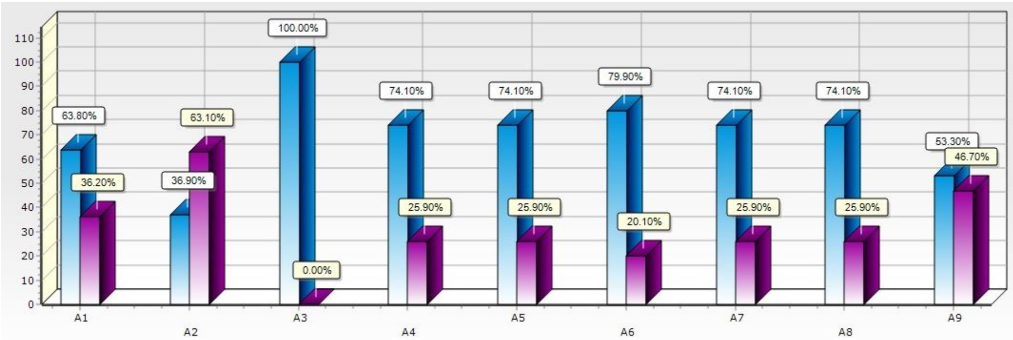

Figure 8 – Sensitivity analysis.

Table 13 – Percentage of times that each alternative was ordered in a given position.

	1	2	3	4	5	6	7	8	9
A1	0.00%	28.40%	63.80%	6.80%	1.00%	0.00%	0.00%	0.00%	0.00%
A2	0.00%	0.00%	16.00%	47.10%	36.90%	0.00%	0.00%	0.00%	0.00%
A3	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
A4	0.00%	0.00%	0.00%	0.00%	0.00%	1.80%	24.10%	74.10%	0.00%
A5	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.80%	24.10%	74.10%
A6	0.00%	79.90%	20.10%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
A7	0.00%	0.00%	0.00%	1.80%	24.10%	74.10%	0.00%	0.00%	0.00%
A8	0.00%	0.00%	0.00%	0.00%	1.80%	24.10%	74.10%	0.00%	0.00%
A9	0.00%	0.00%	10.10%	53.30%	36.60%	0.00%	0.00%	0.00%	0.00%

4.12 Recommendation and implementation of decision

In the final step, the DM and stakeholders should start the implementation of the decision, following the order of priority obtained by the model, selecting the necessary resources for implementation, whether these are financial, human or of other nature.

There are some critical points associated with this step. For example, situations in which the time spent in the process until the choice of actions is much less than the duration of time for their implementation. Decisions are assumed to be stable, at least until actions are implemented. However, when the time until implementation is too long, changes may occur that make the model not so compatible with reality, new problems may arise due to lack of actions, and the implementation process may not be as effective.

Thus, it is up to the DM to plan the process of implementing the actions suggested here by the developed model, seeking the necessary resources for their execution and adequate planning so that they can be implemented in the best possible way.

4.13 Managerial Implications

The obtained results show the importance of applying the proposed model to order alternatives for the expansion and improvement of waste sorting through the use of a multimethodological intervention. Using formal approaches to support decision-making allows a structured and guided decision-making process instead of only taking into account the DM's empirical knowledge about the problem. Thus, the proposed model that combines SSM and FITradeoff enables ranking the alternatives with more credibility and confidence.

Analyzing the use of SSM in the problem structuring stage, it should be noted that it enables to understand the various aspects that characterize the *status quo* of the problem. Furthermore, it allows determining the DM's objectives to improve the current situation and identifying the relevant systems and conceptual model of the problematic situation. Then, the conceptual (ideal) model is compared to the real world, verifying the feasibility and desirability of the identified alternatives. In addition, SSM permits to evaluate the system in terms of its efficiency, efficacy, and effectiveness, as well as, helps determine the criteria and the final set of alternatives to be considered in the prioritization stage. In sum, SSM proved to be very useful for the problem structuring stage, allowing a deep evaluation of the problem and a broad identification of alternatives.

In addition, results reveal the importance of considering a multicriteria approach to support decision-making in situations that involve prioritizing alternatives in waste sorting, once several options with different consequences in the criteria must be evaluated simultaneously. The FITradeoff method enables the evaluation of these alternatives analytically in an organized way allowing their final ranking. Having in mind that one of the most challenging aspects in a multicriteria decision problem is the elicitation of the scale constants (weights), the FITradeoff method eases this process as it reduces the cognitive effort required from the DM and also allows reducing errors by using partial information. Furthermore, the flexibility of the process means that elicitation can be changed to different conditions and circumstances as they occur interactively, with the aim of requiring less information from the DM.

From the DM's point of view, FITradeoff did not require much effort to solve the problem. This can be verified in the literature since the preference relation P requires less cognitive effort than the indifference relation I (DE ALMEIDA et al., 2016), once each question is answered by the DM, the range of scale constants decreases, thus not requiring that the indifference value of the criteria is informed by the DM, which differs from the traditional tradeoff procedure (Keeney and Raiffa, 1976). Therefore, at first, the DM ordered the scale constants of the criteria (overall evaluation). Then, the flexible elicitation was performed, where a range of values for the scale constants are calculated in a structured way based on a Linear Programming Problem (LPP). Lastly, the flexible elicitation process drew relevant conclusions for the decision after answering 9 questions, obtaining a final ranking of alternatives.

Furthermore, the use of such multimethodological intervention allowed the DM to obtain a deeper knowledge about the problem and a logical way for prioritize the alternatives to improve the waste sorting program. At first, there were difficulties by the DM in understanding many aspects of the problem in an integrated and holistic way. With the application of a formal approach such as the SSM, the process of understanding the problem takes place in a structured manner, which allows a systematized reflection for the DM. Some aspects of the problem that the DM not been taken into consideration, or were considered secondary to the problem such as, improve the quality of life of waste pickers or strengthen the relationship with the recycling industry, were recognized after the PSM use.

Moreover, some alternatives found after the SSM application were not very clear or even inexistent from the DM's perspective. SSM allowed the DM to think broader and consider unnoticeable aspects of the problem, which made possible to the DM identify new alternatives, specially those of procedural and attitudinal nature, such as "provide appropriate resources for employees to work", "use management tools in the work environment", and "conduct employee training for sorting activities". With the application of FITradeoff, the DM has a ranking of alternatives based on a rational analysis of their preferences. The proposed recommendation states that the DM's first alternative is "add new neighborhoods to the project", which corroborates the constrains found in the initial program, once the waste sorting services are not operating in the whole city. The need to improve the internal operations of cooperatives was also a core element discussed, which is strengthened by alternative A6 in second position in the ranking, as cooperatives need to optimize their internal processes in seeking to improve efficiency. Another central alternative that follows the proposed recommendation is also of structural nature, as it deals with the acquisition of new fleets for the expansion of waste sorting services, which is essential for increasing population participation and consequently increase the volume of collected material.

Finally, the methodological intervention of a PSM with an MCDA/M method carried out in the context of solid waste management proved to be successful, and the model developed in this research can be replicated in several similar situations faced by managers who aim to improve their waste sorting services. Therefore, it should be noted that the use of SSM to explore and structure the problem, as well as, to identify objectives and alternatives shows to be very appropriate in the solid waste management context. Furthermore, FITradeoff as a flexible interactive method allows a structured preference elicitation process, enabling for a more robust decision-making while promoting oriented recommendations. Thus, the methodological integration proved to be satisfactory, with outstanding results in this research.

5 FINAL REMARKS

The increase in the amount of solid waste generated annually around the world and the environmental, economic, and social implications that this has caused to society has increased the awareness of the population and public managers of solid waste management, especially regarding adequate disposal and recycling actions. In this paper, we reported a case study where we developed a model that combined SSM and FITradeoff to help improve and expand waste sorting services. SSM was applied in the structuring stage and helped explore and understand the problematic situation allowing the identification of alternatives. The Fitradeoff method was used in the prioritization stage to perform preference modeling to get a final ranking of alternatives.

The proposed model based on a multimethodological intervention provided a structured approach to aid better decision-making in the solid waste management context.

More precisely, SSM allowed for the identification of the fundamental and strategic aspects of the problem, creating a broad structure for the DM. Seven criteria were identified to represent the fundamental objectives related to this specific problem, and nine alternatives were evaluated against these criteria. The FITradeoff ranking method provided an adaptive cognitive structure to conduct the modeling of preferences considering the preferences of the DM within a compensatory approach. For this, the FITradeoff Decision Support System assisted the DM in the elicitation process, so that the DM would respond interactively to the proposed questions; the dominance relationships between the pairs of alternatives were sought through the solution of linear programming problems. The application of the FITradeoff method exhibited one of its main characteristics, namely, flexibility. Thus, with each response intention, the system computes the intention considering partial information, ensuring more consistency in the decision-making process.

This research contributes to the accumulating evidence on combining soft and hard OR approaches. By combining a softer learning-orientated and problem structuring method, SSM, with a hard approach such as FITradeoff, a multiparadigmatic multimethodology was developed and applied to waste sorting services in Brazil. The successful adoption of SSM and FItradeoff in this multimethodological intervention reveals its applicability in the solid waste management context and the possibility of its replication. Thus, this paper adds to the literature on OR hard and soft method's combination presenting the practical aspects of such intervention.

This study fills a gap in the literature on the assessment of subjective DM's perspectives in decision problems for prioritizing alternatives regarding waste sorting. Decisions made in solid waste management can encompass complex aspects, since this type of problematic situation commonly involves a considerable set of actors with countless objectives, criteria, and alternatives to be analyzed, making it difficult for managers to structure information and carry out a consistent evaluation of the process without the support of formal approaches. Therefore, as suggestions for future work, the proposed model addressed in this research can be applied to other situations in which it requires structuring and prioritizing complex problems in the solid waste management context. In addition, it is possible to adapt this model to support group decision situations; i.e., considering several DMs in the decision problem and developing preference modeling for the prioritization stage of alternatives based on existing group decision approaches.

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