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ARTICLES

DEVELOPING AND EVALUATING NEW ALTERNATIVES FOR URBAN MOBILITY: A CASE STUDY OF A BRAZILIAN CITY

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ABSTRACT. Mobility and urban planning are challenging tasks for public authorities, especially in densely populated cities. The city of Olinda, Pernambuco-Brazil, faces problems in traffic and access to places, making it necessary to identify new alternatives to improve urban mobility in Olinda. This study presents a decision support model to develop and evaluate new alternatives to do so. In the decision frontend, Value-Focused Thinking was applied to identify objectives and their respective attributes, and to create alternatives based on these objectives. As a result, 69 alternatives were generated, concatenated into 48, and categorized into four groups. Group 1 and Group 2 comprise 30 alternatives that serve the city's north side; however, they attend to the neighborhoods separately. Group 3 comprises 11 alternatives routes that serve the two areas together, this being the focus of this study, and Group four consists of 7 short-term alternatives. In the decision backend, the FITradeoff for ranking problematic method was applied to evaluate the 11 alternatives of Group 3. The study showed that it would be possible to improve mobility more urgently by making a few improvements to the itinerary on the existing routes. Therefore, the study discusses the possibility of starting to make progress in the urban system of the city by using fewer complex alternatives compared to setting up new routes.

Keywords: FITradeoff, urban mobility, ranking problematic, VFT (Value-Focused Thinking).

1 INTRODUCTION

Transport planning takes a broader view of urban mobility written by da Silva et al. (2008). The Brazilian Federal Law 12,587 stipulates that all municipalities with more than 20 thousand inhabitants must draw up and carry out an Urban Mobility Plan cited by O Brazil (2012). One of the goals of this Law is to implement sustainable urban development in cities since sustainability is fundamental to environmental, social, and economic issues by Assunção et al. (2020).

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Decision-making in the area of urban mobility involves issues, decision-makers, and stakeholders from different areas and is, therefore, a complex situation. Especially since it involves public finance. According to cited by de Almeida et al. (2019), applying soft approaches from Operations Research proves effective in tackling complex social problems because they effectively support how best to structure problems. The authors also comment on the advantages of combining different methodologies, called multi-methodology, to obtain more effective results in complex and unstructured contexts. One approach that has been used recently is the integration of Problem Structuring Methods (PSM) with Multi-Criteria Decision Analysis (MCDA) Methods cited by de Almeida et al. (2019).

These approaches are justified in the application of solving urban mobility problems because they allow the problem to be better understood and, therefore, the decision process becomes more accessible, due to its complexity. However, despite the importance and relevance of applicability, when searching the Web of Science and Scopus databases for the words "urban planning", "urban mobility", "urban transport", "public transport" and " Value-Focused Thinking (VFT)", " Soft Systems Methodology (SSM)", "PSM", "Strategic Options Development and Analysis (SODA)", "Strategic Choice Approach (SCA)", "MCDM/A", "Multicriteria" both separately and together, performing various combinations, it was found that there is very few publications, especially when the themes are used together with the integration of methods. According to Béhar and Dourado (2015), there are indications that State Urban Mobility Programs are being carried out in an impractical way, especially when compared to the policies previously used. Therefore, the authors believe that municipalities use outdated urban mobility plans with many non-innovative practices.

Thus, this article proposes a decision support model that integrates VFT cited by Keeney (1992) and the multi-criteria method FITradeoff (Flexible and Interactive Tradeoff) by Frej et al. (2019) to help decision-making in urban mobility problems in the cities. First, VFT is used on the decision frontend to structure the objectives and attributes and to create alternatives. Then, FITradeoff for the ranking problematic was applied in the decision backend to rank these alternatives, thus making it possible to obtain results that improve the situation.

This study is organized into six sections, including this introduction. Section 2 describes about urban mobility and its difficulties. Section 3 describes the decision model. Section 4 describes the object of research and the application of the proposed model. With the results and discussions, section 5 provides insights about the managerial implications, and, finally, section 6 lists make some final remarks, draws some conclusions, and makes suggestions for future lines of research.

2 URBAN MOBILITY

Urban Planning can positively stimulate job creation, the transportation system, economic activity, and consequently urban mobility by Forman and Wu (2016). These factors can contribute to the quality of life of the population, but also bring remarkable complexity to decision-making in urban systems. The rapid motorization and urbanization of urban areas has significantly impacted the transportation system, which has directly affected sustainable development by Pérez, Carrillo & Montoya-Torres (2015); Forman and Wu (2016).

Population mobility, traffic volume, and land use changes have a significant effect on environmental quality degradation; with a coefficient of determination of 94.1%, the direct impact of environmental quality decrease on air pollution index is 66.09% by Surya et al. (2020). In this case, these issues can severely disrupt a city's urban mobility and infrastructure, so that there is a more significant concern to adapt them, with greater rigidity, to achieve more consistent levels of urban planning decision-making.

These factors can contribute to the quality of life of the population, but they bring remarkable complexity to decision-making in urban systems. This involves multiple criteria related to economic, environmental, and sociopolitical issues: different spheres and actors with conflicting views by Diniz & Lins (2012); Pérez, Carrillo & Montoya-Towers (2015). Moreover, problems in this context involve dealing with planning and engineering elements and later integrating them by de Vasconcellos (2005). Therefore, appropriate methods must be used to address and coordinate political, social, and environmental issues, as they may conflict with each other.

To address the characteristics of mobility decision problems and urban planning, Khisty (1995) used SSM to aid transportation planning, and Alves et al. (2017) used SSM for urban mobility. While Pereira et al. (2019) used SCA to obtain results on mobility in the city of Recife, Pernambuco, Assunção et al. (2020) approached the soft methodology to develop a new holistic perspective on urban sustainability.

Stull (2019) argues that the 21st-century urban mobility system involves people moving physically and about their cities and surroundings and that optimizing this system requires a multidisciplinary effort, so the paper proposes the synthesis of a new language from three techniques that have proven useful: decision analysis with the support of VFT, design patterns, and iterative development. The VFT approach was also applied by Dell'Ovo & Oppio (2019) to preserve and improve the quality of life of the built environment. The authors used a multi-method analytical framework based on VFT to address the phases of the urban design process by defining goals and then defining strategies that lead to the design and evaluation of alternatives.

3 DECISION MODEL FOR IMPROVING URBAN MOBILITY IN OLINDA

The proposed model is presented in Figure 1, which integrates VFT and FITradeoff for the ranking problematic to obtain better compromise solutions in an urban mobility problem in the city of Olinda. In this context, the proposed model can be divided into two phases: Phase 1, the frontend, which concerns the structuring of problems with the application of VFT to identify the objectives, and attributes and generate alternatives, and Phase 2, the backend, which consists of evaluating the alternatives by applying FITradeoff to prioritize those to be implemented and to improve the urban mobility more urgently.

For Phase 1, we chose to apply VFT, since this approach allows us to work consistently with the objectives of the problem. Since the method has a robust methodology for identifying and understanding the objectives. In addition, the method makes the DM analyze the objectives over the nine properties, performing the rest of the problem with the only essential objectives. These had not yet been previously analyzed, not even in the city's Urban Mobility Plan, for example. In addition to which this enables hitherto unknown alternatives to be created. In the first phase of the decision-making process, the use of PSMs allows for incorporating subjective aspects or aligning the interaction of actors more quickly, according to cited by de Almeida et al. (2019). As a result, this will enable decision-makers (DMs) to develop better management policies (Assunção et al., 2020).

For Phase 2, the application of the FITradeoff for the ranking problematic was chosen since this method requires less cognitive effort from the DM. The DM is unprepared to list his preferences in detail and has compensatory rationality, which was established after asking the DM questions about the range of criteria used and the evaluation scale, then analyzing how the decision maker behaved, whether for the decision maker the values of the criteria in the alternatives offset each other or whether for the decision maker it is more important to have equal values in the alternative on all criteria. From this perspective, the ranking of alternatives that meet the defined and relevant criteria provides crucial insights, as it brings the possibility of starting implementation based on the greatest urgency. The use of MCDA methods in the second phase allows alternatives to be systematically and robustly evaluated, considering rational aspects. This procedure enables more efficient models that are needed for a specific decision situation to be designed and used.

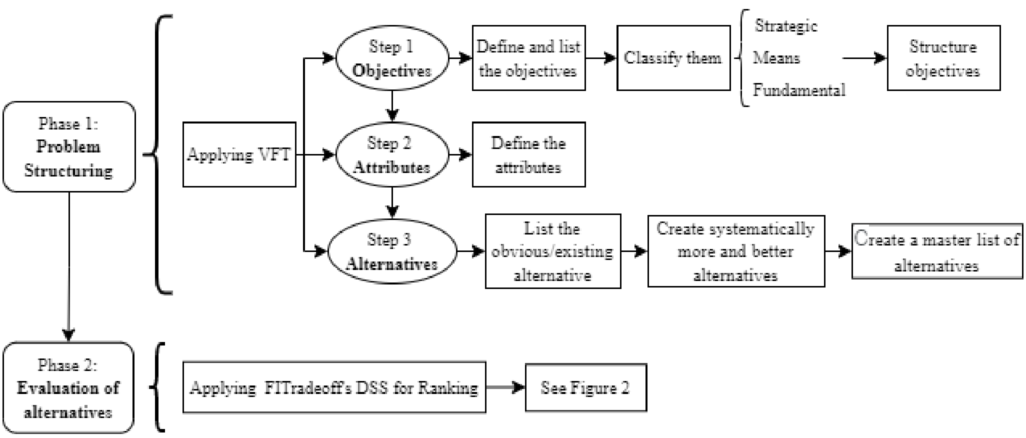

Figure 1 – Proposed decision model.

In the following subsections, the methods used are described in more detail so as, at a later point, to demonstrate how the urban mobility problem model was applied in Olinda.

3.1 Value-Focused Thinking (VFT)

VFT requires some procedures, as they were subdivided into the steps of the model, which make up the first phase. Cited by Keeney (2020) the stages of a decision-making process focused on value are divided into frontend and backend. The frontend stages consist of stating the decision problem, identifying the values and expressing them as objectives, clarifying what is to be achieved, and creating alternatives that contribute to achieving the objectives. The backend steps describe the possible consequences of each alternative to indicate how well each of them achieves the objectives, to identify the pros and cons of each alternative, to weight its importance, and to select an alternative using information and insights from its evaluation.

Keeney (1992) mentions that ten means can be carried out to identify these objectives. These are listed in Table 1.

Table 1 – Means to identify objectives. Source: Keeney (1992).

Devices for identifying objectives
A wish list
Alternatives
Problems and deficiencies
Consequences
Objectives, restrictions, and guidelines
Different perspectives
Strategic objectives
Generic objectives
Structuring objectives
Quantifying objectives

However, these objectives must be structured and worked to respect the nine properties of fundamental objectives: essential, controllable, complete, measurable, operational, decomposable, non-redundant, concise, and understandable.

Therefore, the objectives must be structured into means and those that are fundamental to the function of the strategic objective. Strategic objectives are a DM's ultimate objectives. All others must be objectives to achieve the strategic objective, so chains of means objectives link them together.

In step 1, the objectives must be identified and differentiated between fundamental, means, and strategic objectives. In this sense, the strategic objective is the desire in the general context, generating decision-making in several different contexts. On the other hand, achieving another objective is characterized as a means objective, as it directly affects another end. In comparison, fundamental objectives are the reasons for the interest in the situation by Keeney (2009); Siebert von Winterfeldt (2021). Thus, it is possible to establish a hierarchy between these objectives, to relate them to each other, and to create a network of means-end objectives.

Next, in step 2, it is necessary to establish how these fundamental objectives will be measured and then to identify their attributes. According to by Keeney (1996); Morais et al. (2013), these criteria can be classified as natural, constructed, and proxy. Natural attributes can be directly measured and have a common interpretation in any problem category. However, if the natural attribute does not exist, it is possible to construct it. It can, however, be measured directly by a constructed attribute or indirectly through a proxy attribute. Constructed attributes are developed explicitly for a decision context.

After defining how each objective will be measured and building the appropriate measurement scales, (Methling et al. forthcoming), it is now necessary, in step 3, to identify existing alternatives, to check if they can be improved, and to see whether it is possible to create alternatives that were not perceived or viable before. In this way, a wide range of high-quality alternatives can be identified. Furthermore, the previous objectives can be used as alerts to stimulate attractive alternatives according to by Siebert & Keeney (2015); Siebert (2016). Then, it is necessary to verify if the concatenation of the alternatives is feasible, to reduce the list and facilitate the next step of the decision-making process, the objective of which is to obtain a ranking of the alternatives.

3.2 FITradeoff

The FITradeoff method, which obtains the range of the scaling constants, had a significant evolution, including the types of problems it can tackle, so, currently, there are the FITradeoff for the choice problematic by de Almeida et al. (2016); Almeida, Frej & Roselli (2021); FITradeoff for the ranking problematic by Frej, de Almeida & Costa (2019); FITradeoff for the sorting problematic by Kang, Frej & de Almeida (2020); and FITradeoff for the portfolio problematic by Frej, Ekel & de Almeida (2021).

According to De Almeida et al. (2021), the FITradeoff method of choice and ranking uses two paradigms: elicitation by decomposition based on the classic Tradeoff procedure, concomitant with holistic evaluations, presented in the form of graphs. Holistic evaluation can be performed at any time during the decomposition elicitation process, rather than only at the end, and can even be performed at the criteria ranking stage.

It is a flexible process, but always analyst driven. Elicitation by decomposition is performed in consequence space, which means that the decision-maker performs the comparison of consequences in pairs, which can also be performed in the steps of the method. The holistic evaluation, on the other hand, brings the comparison of alternatives visually, through graphical visualizations, and can be performed, besides the classification step, whenever the analyst or the decision maker deems it necessary. This flexibility in the method can lead to fewer questions until a satisfactory result is obtained for the decision maker.

The way these consequences are presented is defined by the DSS, which uses the axiomatic structure behind the method to make the choices, always using all the information provided by the decision maker so far. Even if some of these consequences are unlikely, the way and mathematical programming problems are executed to present and structure them is always to facilitate preference elicitation modeling.

The DM with the analyst realized that the problem best fitted into a ranking issue. For this reason, FITradeoff for ranking was used in this model. The method proposed in by Frej et al. (2019) is based on obtaining a flexible and interactive Tradeoff by de Almeida et al. (2016); de Almeida et al. (2021), which allows partial information about the DM's preferences to be used and is developed based on the axiomatic structure of the Tradeoff procedure by Keeney and Raiffa (1993) since it has excellent robustness. Furthermore, the method carries the concept of pairwise dominance, thus allowing a partial or complete order of alternatives in each interaction with the DM. According to by da Silva and Costa (2020), these characteristics demand less cognitive effort by the DM and produce only minor inconsistencies.

To use the FITradeoff Decision Support System (DSS) for the ranking problematic, the DM must build a consequences matrix before inputting the data into the system. This acts as a constraint for the method's linear programming problem (LPP), which is thoroughly described in by Frej et al. (2019). These constraints form the dominance relationship between alternatives, and are updated at each iteration, thus generating new dominance relationships and up-to-date diagrams. The scale constants of criteria in non-compensatory multi-criteria methods, such as PROMETHEE by Brans & Vincke (1985), have the simple meaning of criteria weights. However, as FITradeoff is a compensatory multi-criteria method, criterion constants are used. In addition to the DMs analyzing the degree of importance of the criteria, they must explore the ranges (tradeoffs) of the scale constants of the criteria when they undertake the rankings.

The method by Frej et al. (2019) performs a two-step algorithm to generate the basis of the pairwise dominance relationship matrix of the alternatives obtained in each interaction cycle with the DM. The first is a visualization diagram of the ranking of alternatives, and the second is a further ranking obtained based on the diagram. In addition to performing a pairwise comparison of the criteria, the DM establishes the preference relationships between the alternatives, available through the analyst incorporated in the method's DSS, which is available at www.cdsid.org/fitradeoff. From this information, the Hasse diagram of the alternatives, can be obtained, thus allowing the ranking to be visualized. The modulation of the method, performed in DSS, is shown in Figure 2.

Figure 2 demonstrates the functionality of the FITradeoff DSS ranking, which was used to carry out phase 2 of the proposed model, showing that from the interaction with the DM, the LPP is updated, thus consistently generating a new configuration of the ranking of the alternatives for each cycle.

The alternative configuration can be visualized continuously in the decision-making process using the Hasse diagram or Table. The process can be terminated in three ways, namely, when the full ranking of alternatives is found; if the DM believes that the partial order is satisfactory; or if he has no further information to provide to the process.

4 RESULTS AND DISCUSSIONS

This section presents the results obtained by applying the proposed model in Olinda, a city located in the state of Pernambuco in the Northeast of Brazil. Olinda is considered the third-largest city in the state. However, the model was applied more precisely to two neighborhoods in the city, Jardim Atlântico and Jardim Fragoso, which contain more than 16% of the city's urban population. These neighboring neighborhoods have a significant inefficiency in urban mobility and

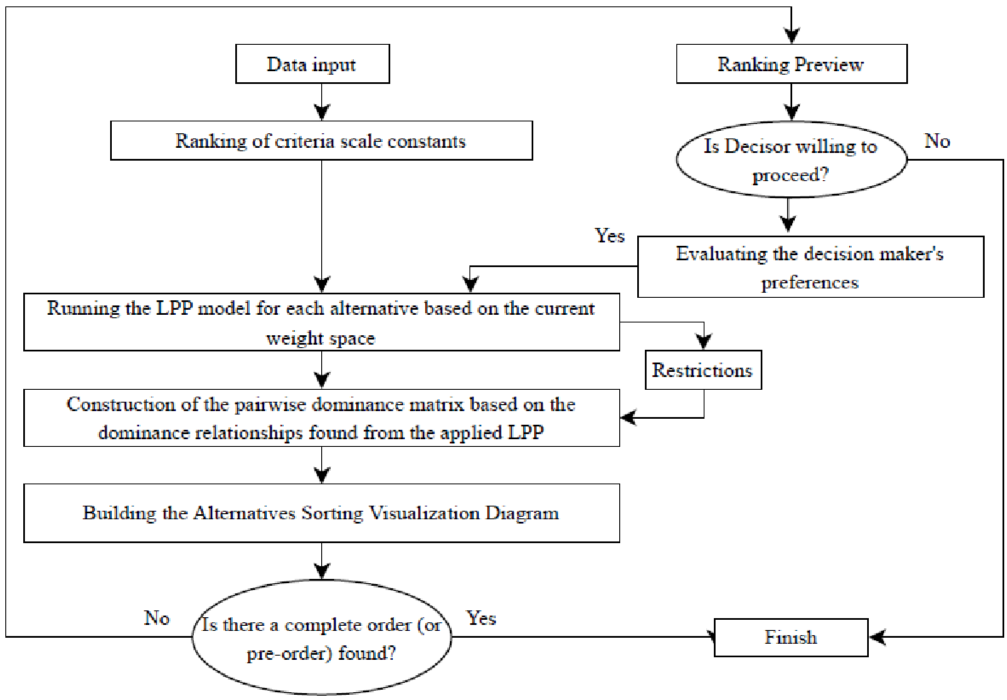

Figure 2 – FITradeoff DSS operation for ranking problematic. Source: Adapted from Frej et al. (2019).

public safety; a major highway is being built, mainly through these neighborhoods. This highway will ensure that other places in the RMR can be reached more quickly and efficiently from these neighbourhoods.

The study was applied with one expert, a Civil Engineer, a specialist in traffic engineering, a resident of Olinda, who is thoroughly familiar with the city's Mobility Plan (Plamob/Olinda). In addition, an analyst who knows multi-criteria methods and problem structuring acted as a facilitator to develop the process of the decision-making model.

4.1 Phase 1: Problem structuring with the VFT

In step 1 of the model, which consists of defining and listing the objectives, it was possible to obtain a network of means-ends, defining the strategic, fundamental, and means objectives.

The DM and analyst carried out structured approaches to promote systematic and in-depth thinking about the objectives to identify, structure, analyze, and understand the objectives by Siebert et. al. (2020). Thus, they were able to derive the values of concern for the situation. Since values are of concern in decision situations, these are then made explicit by identifying objectives cited by Keeney (1992).

Keeney (1992) points out that the most obvious way to identify objectives is to discuss the decision, such as starting iterative progress by asking, "What would you like to achieve in this situation?". In addition, at the beginning of the list of objectives, this was worked out as if there were no limitations or restrictions for objectives to be achieved or potential alternatives to be developed. Then, some questions and activities were carried out, as shown in Table 2.

Table 2 – Means used to identify objectives.

How was the list of objectives accomplished?
1 - Assuming you didn't have any limitations, what would your objectives be?
2 - What alternatives can improve urban mobility immediately?
3 - What alternatives can improve urban mobility in the long term?
4 - Which alternatives are successful and which are system failures? Why?
5 - What existing alternatives could be modified to improve urban mobility?
6 - Are there alternatives that can cause unacceptable consequences?
7 - The DM puts himself in the place of stakeholders, such as society and the transport secretary, and analyzes the possible objectives from another perspective.
8 - Use the city's Mobility Plan as a guideline to generate more objectives.

Thus, it was possible to establish the network of means-ends objectives, as shown in Figure 3. Then, in step 2, the attributes responsible for measuring each fundamental objective, exemplified in Figure 4, could be identified.

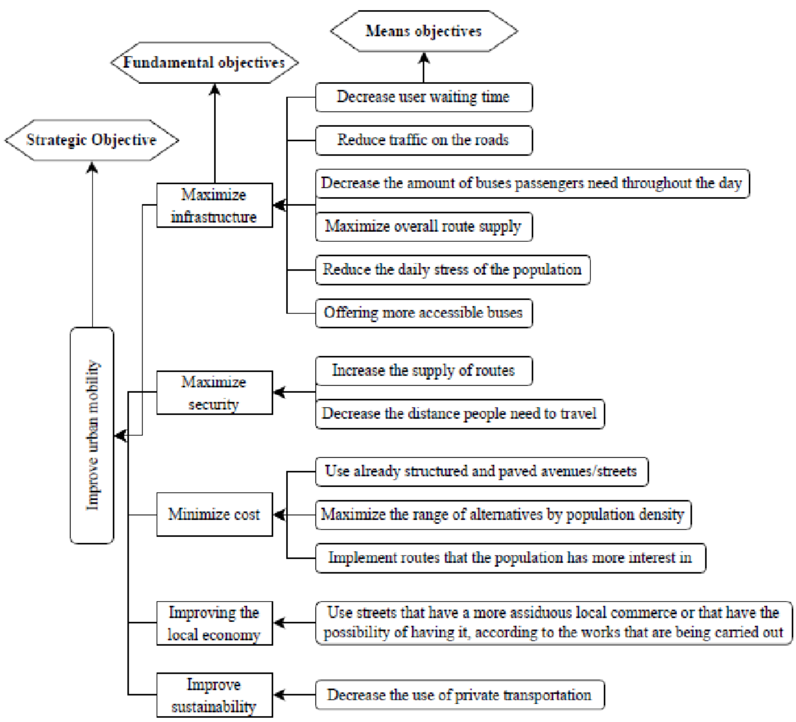

Figure 3 – Means-Ends Network.

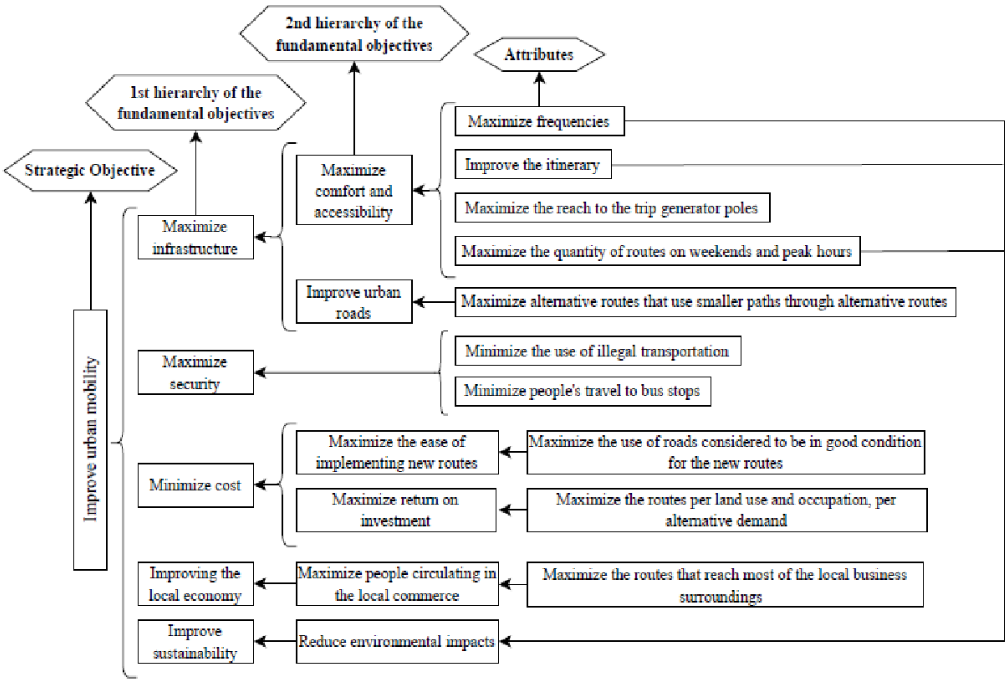

Figure 4 – Identification of the attributes.

In a structured way, this figure shows the strategic objective of the problem: to improve urban mobility, followed by the fundamental objectives, where the first and second hierarchy is demonstrated, and later the attributes. The scheme also shows that two attributes can measure two different but related fundamental objectives in a given decision context by Keeney (1992).

The strategic objective describes the general problem of the context to improve the urban mobility of the area analyzed. Then, the fundamental objectives of the problem are presented, which have as main concerns the issues of infrastructure, security, cost, local economy, and sustainability. In this perspective, the DM intends to find compromise solutions that effectively achieve these objectives, and thus aims to increase the use of public transport in the region, to make it more sustainable, and to improve safety and the availability of alternative routes for the population. Issues such as cost and local economy are posed as fundamental. Changes may become invalid for implementation, as they directly adversely affect the public and business coffers.

It is important to emphasize that, in this context, the VFT was applied to structure urban mobility, focusing mainly on creating routes to improve the current situation experienced by society, and then the FITradeoff was applied to prioritize the implementation of these alternative routes.

This step involves identifying attributes, building a value model, objectives, and specifying that attributes are interconnected processes, as these measures the degree to which various alternatives achieve an objective. Therefore, identifying an attribute makes it possible to understand the meaning of an objective better. But nothing prevents that, as the steps progress, other additional objectives can be added to the problem.

Ten criteria were defined to measure the objectives, making it possible to evaluate the performance of each alternative defined *a posteriori*. Its properties were expected in all attributes to be measurable, operational, and easy to understand. In this context, Table 3 presents the definition of the criteria, all of which were built for this problem, following their respective code, the preferred direction, and the number of scale levels. The construction of the criteria was necessary due to the complexity and lack of specific information for the use of natural criteria.

Table 3 – Criteria identification and characterization.

Code	Criteria	Preference	Scale
C_1	Frequency	Max	Likert (5 levels)
C_2	Itinerary	Max	Likert (5 levels)
C_3	Generator poles	Max	Likert (5 levels)
C_4	Quantity	Max	Likert (5 levels)
C_5	Alternatives routes	Max	Likert (5 levels)
C_6	Illegal transporation	Min	Likert (5 levels)
C_7	Path	Min	Likert (5 levels)
C_8	Viable roads	Max	Likert (6 levels)
C_9	Demand	Max	Likert (5 levels)
C_{10}	Commerce	Max	Likert (5 levels)

The DM aims to maximize and minimize the various criteria to be analyzed. Still, the analyst made it clear that as it is a multi-criteria problem, it is impossible to simultaneously reach the maximum or minimum of all criteria in applying them to an issue of this magnitude.

Thus, "C1 - Frequency" refers to maximizing the frequency of the lines, being measured by percentage; for example, if a line passed ten times a day and with the new planning, this would rise to twelve times a day, this percentage will be considered an increase, in this case. Then it will be placed in levels, how much that alternative would be able to increase the number of frequencies of the lines. This could achieve several objectives, such as not increasing the cost of implementing new routes, increasing demand for public transport users, etc. It was built on five levels, as shown in Table 4.

Table 4 – Description of criterion 1.

Level	Description
5	Possibility of increasing frequency by more than 50%
4	Possibility of increasing frequency by more than 40% and less than 50%
3	Possibility of increasing frequency by more than 30% and less than 40%
2	Possibility of increasing frequency by more than 20% and less than 30%
1	Possibility of increasing frequency by up to 20%

The “C2 - Itinerary” concerns the improvement of the route itinerary, and to measure this attribute, the issues considered were:

- It manages to reach a more significant number of people (demand), considered by the demographic density of the region.
- The cost would not significantly impact it; it +will be about how many more kilometers of the road this alternative will need.
- A time greater than 20% would not be added. This time will be counted in terms of average mileage, too, but how many kilometers of alternative routes could this alternative have, since it would be less congested; in this case, with a decrease in travel time.

In this context, combinations were made, and separate criteria were considered. However, more attributes would have to be placed, so this criterion was supposed to simplify the problem a little. It was built on five levels, as shown in Table 5.

Table 5 – Description of criterion 2.

Level	Description
5	It will be possible to reach more than 40% more people than the original route, the cost would not have much impact (also considering that fewer new routes would have to be implemented to reach the objectives more effectively), and the journey time would not be increased, since it would use some alternative, less congested routes.
4	It will be possible to reach 30% to 40% more of the population, the cost would be up to 5% more, and the journey time would not be increased.
3	It will be possible to reach more than 30% and less than 40% more of the population, the cost would impact up to 5%, and the journey time would be increased by up to 5%.
2	It will be possible to reach more than 20% and less than 30% of the population, the cost would not have much impact, and the journey time would be increased by more than 5% and less than 10%.
1	It will be possible to reach up to 10% more of the population, the cost would impact between 5% and 10%, and the journey time would be increased by more than 10%.

The “C3” measures the average number of generating poles that the alternative could reach. For example, how many trip-generating poles can the alternative reach with its route? It can be measured at five levels, as shown in Table 6.

The poles that generate trips are common points among citizens for which there is the greatest demand, like those considered in this research, as shown in Table 7. With these interconnections, it may be possible to facilitate the user’s life to the point that he can reach his final point more efficiently and more directly or quickly, such as terminals, which can reduce the locomotion of users, with thee being more route possibilities at that point to their desired destination. And in its place of origin, it would not fail to serve any alternative or only one, for example.

Table 6 – Description of criterion 3.

Level	Description
5	Reaches more than seven trip generating poles (TGPs)
4	Reaches more than five and less than seven TGPs
3	Reaches more than three and less than five TGPs
2	Reaches more than one and less than three TGPs
1	Reach at least one TGP

Table 7 – Description of the trip generator poles.

What are considered travel generating hubs?	
Casa Caiada (innermost roads and not the main roads)	Large Universities (UFPE, UPE, UFRPE, UNICAP, IFPE)
Bairro Novo (innermost roads and not the main roads)	Ouro Preto (innermost roads and not the main roads)
Cidade alta (innermost roads and not the main roads)	Peixinhos (Centro) – Avenida Presidente Kenedy
Boa Viagem – Shopping Rio Mar, Shopping Recife	Avenida principal de Olinda (Av. Dr. José Augusto Moreira)
Paulista (Centro) – Shopping North Way	Dantas Barreto
Casa Amarela	Derby
Terminal da Macaxeira (going via highway BR-101)	Metrô
PE-22	Av. Conde da Boa vista
Integration of PE-15	Camaragibe
Integration of Rio Doce	São Lourenço da Mata
Avenida Norte	Piedade
Encruzilhada	Candeias
Paulista (Janga)	Cabo de Santo Agostinho
Paulista (Maranguape)	Besides other colleges and universities
13 de Maio	Jaboatão

“C4” is measured in percentage terms. For example, is it possible to maximize by what percent of the routes at peak times with this alternative? It would be possible to increase from 10% to 15% or 10% to 22%. It can be measured at five levels, as shown in Table 8.

Table 8 – Description of criterion 4.

Level	Description
5	Possibility of increasing frequency by more than 40%
4	Possibility of increasing frequency by more than 30% and less than 40%
3	Possibility of increasing frequency by more than 20% and less than 30%
2	Possibility of increasing frequency by more than 10% and less than 20%
1	Possibility of increasing frequency by up to 10%

The "C5" is measured over the average of how many kilometers that the new route would use of main roads. Thus, the lower the mileage of the main road and the higher the alternative routes, the better it will be measured at five levels, as shown in Table 9.

Table 9 – Description of criterion 5.

Level	Description
5	Uses more than 25km of main roads
4	Uses more than 20km and less than 25km of main roads
3	Uses more than 15km and less than 20km of main roads
2	Uses more than 5km and less than 15km of main roads
1	Uses less than 5km of main roads

The "C6" measures the possibility of the action of the use of illegal transport, varying in five levels, according to Table 10.

Table 10 – Description of criterion 6.

Level	Description
5	Possibility of decreasing illegal transport by up to 30%
4	Possibility of decreasing illegal transport by more than 30% and less than 50%
3	Possibility of decreasing illegal transport by more than 50% and less than 70%
2	Possibility of decreasing illegal transport by more than 70% and less than 99%
1	Extinction of illegal transport (Because the alternative routes will be planned to cover the points from which these forms of transport operate, there will no longer be a need for illegal transport)

The "C7" measures the minimization of people's journey from their point of origin to the bus stop. This criterion intends to minimize the robberies that occur on this route. Therefore, a constructed attribute will be considered, considering whether the distance from the origin to the bus stop is decreased. For example, how much was the average distance traveled with just the previous routes? And with the alternative considered, will it be smaller? Yes, or no? According to Table 11.

The assault attribute was boiled down to this attribute. The attribute that would calculate the assault minimization is a complex attribute to measure. After deployment, a long-term analysis would be needed to produce more accurate numbers. However, the problem must consider the downside as it is of great importance to the user.

The "C8" is considered if the proposed alternatives only use roads that are already paved or that are about to be, if there is a mix of road types or if there are many roads that are not paved, or are yet to be paved, according to city mobility planning. Therefore, it was considered in nine levels, according to Table 12.

The "C9" is measured on reaching a more significant amount of the population, being related to the use, occupation, and demand of the land. However, as the measurement is uncertain, it was

Table 11 – Description of criterion 7.

Level	Description
5	Minimized from 0 meters to 5 meters
4	Minimized from 5 meters to 10 meters
3	Minimized from 10 meters to 15 meters
2	Minimized from 15 meters to 20 meters
1	Minimized above 20 meters

Table 12 – Description of criterion 8.

Level	Description
6	There are between 80% and 100% of roads already paved on the route, with the rest being roads that are to be paved soon
5	There are more than 70% and less than 80% of roads already paved, and the rest are roads that are to be paved soon
4	There are more than 50% and less than 70% of roads already paved, and the rest of the roads that are to be paved soon
3	There are more than 40% and less than 50% of roads already paved, and the rest are roads that are to be paved soon
2	There are more than 20% and less than 40%, and the rest is split between roads that are to be paved soon and roads that are not paved
1	There are less than 20% of roads already paved, and the rest is divided between roads that are to be paved soon and roads that are not paved

considered a constructed attribute. For the size of the percentages of the levels, some strategic points were considered; for example, a route that has the possibility of reaching a more significant amount of the population will be regarded as more relevant. And the difference in population density by neighborhoods through which that route passes will be considered. The “C9” is related to land use, occupation, and demand. It was measured at five levels, as shown in Table 13.

Table 13 – Description of criterion 9.

Level	Description
5	Has the possibility of reaching more than 80% of the population
4	Has the possibility of reaching more than 60% and less than 80% of the population
3	Has the possibility of reaching more than 40% and less than 60% of the population
2	Has the possibility of reaching more than 20% and less than 40% of the population
1	Has the possibility of reaching less than 20% of the population

The “C10” was measured for routes that reached avenues with a large number of commercial points. It would be difficult to pinpoint an exact number of how many trades would be hit, so it was considered built. It was classified into five levels, according to Table 14.

Table 14 – Description of criterion 10.

Level	Description
5	Possibility of reaching more than 70% of commercial points
4	Has the possibility of reaching more than 50% and less than 70% of commercial points
3	Has the possibility of reaching more than 30% and less than 50% of commercial points
2	Has the possibility of reaching more than 15% and less than 30% of commercial points
1	Has the possibility of reaching less than 15% of commercial points

After completing steps 1 and 2, it is possible to generate alternatives by performing step 3. The principle is that alternatives must be created to achieve the specified values for the decision situation (Keeney, 1992). So, we must first think about what is desired and then consider alternatives that meet the desire. When creating a list of alternatives, the ideal is to generate a set of promising alternatives. The intention is always to have the maximum number of alternatives made; this can never worsen. On the other hand, it would be wrong not to have anything to explore.

Some strategic procedures cited by Keeney (2009) were used, such as the generation of hypothetical alternatives that are the best possible, alternatives based on each objective, whether means or fundamental, and then working, in addition to working in pairs, by the set of objectives, one after the other.

From the map, Figure 5, it was possible to observe the main roads and alternatives, in addition to analyzing which areas could have more demand, when they had more houses or more apartments, for example. So, in this way, routes were created that reached each of the neighborhoods separately and the poles, as well as analyzing the routes that reached the poles and the two neighborhoods together.

Figure 5 – Demonstration of how the alternatives under analysis were obtained.

Thus, 69 alternatives were generated, but it was possible to unite them, obtaining forty-eight. As many alternatives were formed, these were separated into groups. The alternative routes were developed according to a study of the maps of the regions, as shown in Figure 5. The first group contains 15 alternatives that serve the neighborhoods of Jardim Atlântico. The second group includes 15 actions more focused on the Jardim Fragoso neighborhood; the third group consists of 11 alternatives, which reach both areas, located at the intersection of Figure 5. In addition, it was possible to verify another group of alternatives, group 4, which could be implemented in the short term, summarized in the seven alternatives, shown in Table 15.

Table 15 – Description of short-term alternatives.

	Alternatives
1	Creation of a channel for receiving complaints and feedback
2	Increase the frequencies of existing bus lines
3	Adequacy of paths for the existence of cycle paths
4	Integration of public and more sustainable transport (bicycle parking at bus terminals)
5	Implement the continuing education process
6	Improve communication and information with incentives and investment in specific applications
7	Install more bus stops

However, the DM understood that this set of alternatives is easier to perform, even with others. Furthermore, he understands that it is easier to order than the routes.

Therefore, it was more challenging to see, create, concatenate, and divide them into specific groups. In this perspective, only the makeup group three alternatives were considered because, on looking at the Table, they would be the ones that could benefit a more significant number of people together, as presented in Table 16.

Table 16 – Presentation of the alternatives.

Código	**Descrição das rotas**
R1	Jardim atlântico/Jardim Fragoso - BR-101 (Terminus of Macaxeira)
R2	Jardim atlântico/Jardim Fragoso - Camaragibe/São Lourenço da Mata
R3	Jardim atlântico/Jardim Fragoso - Boa Viagem/Piedade/Candeias/Jaboatão
R4	Jardim atlântico/Jardim Fragoso - Av. Norte (Casa Amarela/Encruzilhada)
R5	Jardim atlântico/Jardim Fragoso - Cidade Universitária
R6	Jardim atlântico/Jardim Fragoso - Derby/Boa Vista/Dantas Barreto
R7	Jardim atlântico/Jardim Fragoso - Dois Irmãos
R8	Jardim atlântico/Jardim Fragoso - 13 de maio /Dantas Barreto/Metrô
R9	Jardim atlântico/Jardim Fragoso - Paulista (center) /Shopping/Integration
R10	Jardim atlântico/Jardim Fragoso - Boa Vista/Derby
R11	Jardim atlântico/Jardim Fragoso - Paulista (PE-22) /Janga/Pau Amarelo /Maria Farinha

Existing ones can be modified or improved among the alternatives, and those are created based on the applied methodologies.

4.2 Phase 2: Evaluation of alternatives with the FITradeoff

Following the step of inputting the data to the DSS of the method, [Frej et al. 2019] requested the specification of the indifference threshold, which was set as 0.01, to slow down the elicitation process when the performance difference between two alternatives is not relevant. The indifference relationship between two alternatives will only exist if, for all weight vectors, the difference between the values of the two alternatives is equal or smaller than ε. Thus, the next step is the ranking of the criteria scale constants. Thus, the next step is to perform a pairwise comparison of the criteria.

Table 17 – Consequences matrix.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Preference	Max.	Max.	Max.	Max.	Max.	Min.	Min.	Max.	Max.	Max.
R_1	5	5	1	4	4	2	4	4	2	2
R_2	2	5	4	3	4	1	2	2	5	4
R_3	5	4	4	3	5	1	5	3	3	5
R_4	4	2	4	3	4	3	1	1	4	5
R_5	1	4	3	3	4	2	1	5	1	3
R_6	3	2	4	1	5	5	4	2	2	4
R_7	5	3	2	5	1	3	1	3	5	3
R_8	2	5	3	1	5	4	2	4	2	4
R_9	1	2	3	3	5	2	3	3	4	4
R_{10}	4	2	1	3	2	4	1	4	1	2
R_{11}	2	5	3	5	4	3	3	2	4	5

Next, the flexible elicitation was performed. The analyst embedded several hypothetical alternatives in the DSS presented and the DM stated his preferences. Table 18 summarizes how the elicitation process behaved in each round of questions, followed by the values of each consequence, which were compared by the DM, the preferences (A, B, indifference, or preferred not to answer), and the level of the ranking found.

The method is based on a heuristic that proposes to reduce inconsistencies, effort, and time demanded, besides having flexibility and iteration with the DM. Thus, it was possible to obtain a pre-order of alternatives, as shown in the Hasse Diagram in Figure 6, with the realization of only nine cycles, two of them being holistic evaluations that decreased the level of cycles when performed. It was possible to obtain the range of values for the scale constants in descending order, in maximum and minimum values.

It found a partial order of the alternatives, which satisfied the DM. The alternatives in incomparable positions did not interfere negatively with the results. The holistic assessments can be demonstrated in Figure 7. In the problem two were performed, one that increased by one level in the Hasse diagram and the other that led to the result. Holistic evaluations can be performed on bar, bubble, or radar charts.

Table 18 – Rounds and the DM's choices during the decision-making process.

Round	Consequence A		Consequence B		Preference	Ranking Level
	Crit.	Value	Crit.	Value		
1	C_1	3	C_{10}	5	A	1
2	C_1	3	C_2	1	A	1
3	C_2	3	C3	5	A	3
4	Avaliação holística: $R_7 > R_{10}$					4
5	C_3	3	C_4	1	A	5
6	C_4	3	C_5	5	A	6
7	C_5	3	C_6	5	B	6
8	C_6	3	C_7	5	A	7
9	Avaliação holística: $R_1 > R_6$					7

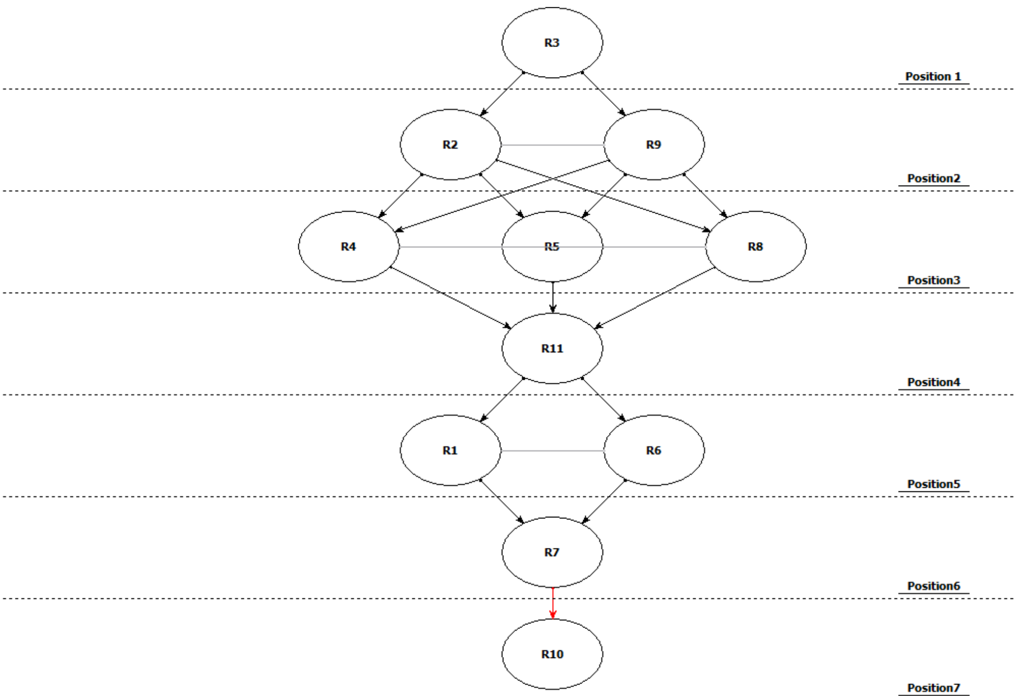

Figure 6 – Ranking of alternatives.

After the result, a sensitivity analysis was performed, Figure 8, in which a model with a specific sensitivity was verified; however, among several runs, it was observed that alternative R_2, R_3, and R_{10} remained several times in the original ranked position. In this perspective, even without filling the first position in the final ranking, R_{10} "Jardim Atlântico/Fragoso - Boa Vista/Derby" was the alternative to be advised implemented in first. This result was obtained and considered

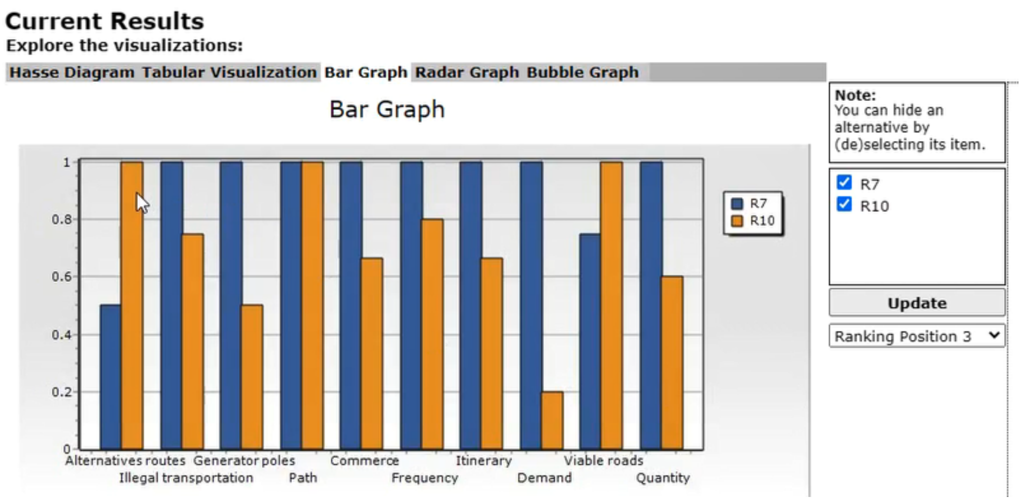

Figure 7 – Holistic assessment one.

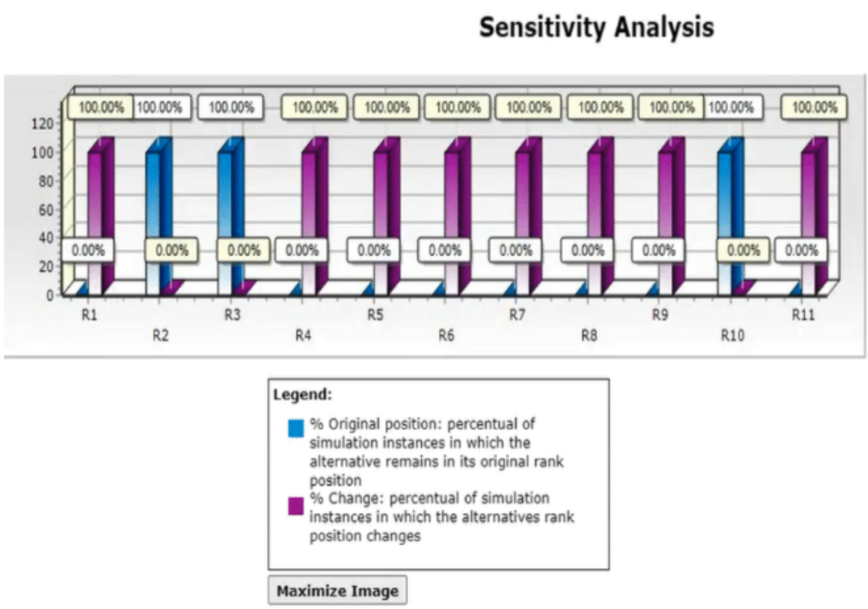

Figure 8 – Sensitivity Analysis.

more interesting because the alternative already exists, requiring only a few changes in the route to achieving the context objectives at a lower cost.

Three of the eleven alternatives analyzed, the R_6 “Jardim Atlantico/Fragoso - Derby/Boa Vista/Dantas Barreto”, R_8 “Jardim Atlantico/Fragoso - 13 de Maio/Dantas Barreto/Metro” and R_9 “Jardim Atlantico/Fragoso - Paulista (downtown)/Shopping/Integration”, exist and currently operate, but there are limitations, such as the localities they reach, which significantly limits their use. This observation is relevant since they occupied the first five positions. This brings the need for re-adaptation of the existing routing being of great worth, and an improvement in these itineraries, which, probably, would modify the ranking of urgencies.

The R_{10} "Jardim Atlantico/Fragoso - Boa Vista/Derby" has occupied the first position in the ranking, the problem since these trip generator poles are one of the most important in the RMR. Moreover, there are many companies in them, and much of the region's commerce. On the other hand, the R_5 position "Jardim Atlantico/Fragoso-University City" transposes the region's lack of locomotion for two central University and college centers in the state.

Although the characteristics of the problem and the context of urban mobility and routing integrate the urban planning of a city, this delineation was not discussed by Khisty (1995); Alves et al. (2017); Assunção et al. (2020). These were limited in presenting more generic urban planning or sustainability-specific issues. Pereira et al. (2019) despite applying Strategic Choice Approach presented solutions in the forms of improvements, such as implementing rotations, traffic readjustments, among other issues. Thus, these were the contribution of these studies to rethinking public transport routes, which could be readapted or created, to achieve the most important objectives of the context and complement the urban planning of a city.

5 MANAGERIAL IMPLICATIONS

Unlike what Plamob/Olinda presents, the methodology used in this research differs from the construction of strategic, means, and fundamental objectives. This makes the objectives be measured according to the reality of the city. Thus, the central differential is to integrate questions, which were elaborated robustly and carefully and applied in a decision support method, implemented in a DSS (Decision Support System) to verify the ordering of the urgencies of implementation of the routes. All this was done without a problem arising. The decision support method has an axiomatic and robust structure, so it can be said to recommend decisions more safely in highly complex problems.

Furthermore, overall, this study is also a means to rethink how public transport routes are used and what could be done to improve them. It could be read to achieve more context-critical objectives and complement the urban planning of a city. It is possible to verify the city that can be better developed; management always and knew how to prioritize urgencies. In addition, it is essential that the DM, governance, society, and all objectives are understood and that prioritizing more relevant objectives cannot consistently achieve secondary objectives.

This model can be applied in other cities since an adaptation for its peculiarities and objectives are done. So the systematic proposed for this model, using VFT to evaluate the objectives of the decision makers and the FITradeoff to rank the alternatives, it can used in different real cases. In addition, the routes can be added to and reduced for evaluation.

6 CONCLUSIONS

Decision problems, which involve political and social management, usually carry great complexity. For example, creating more efficient routes for the population, which offer more safety, convenience, and incentive to public transportation, requires much effort. However, it has become a real work, which besides conditioning an improvement in the city's sustainability and traffic, allows better public management in this area. It is even possible for the public authorities to obtain greater financial returns. The existence of multiple necessary but conflicting criteria to evaluate the various alternatives characterizes a multi-criteria decision problem.

However, any project or perspective that needs public power and money is liable to inconvenience for its implementation. In addition, in a direct and specific way, the model has been carried out as not being continuous and not having continuous variables, as this can improve it and make it more real. So, they are guaranteed to be for instructions, if possible, to perform in other cities.

Within this perspective, future analyses are proposed that capture the proposed methodology, the objectives, and criteria raised for the context and apply them with more alternatives, including the alternatives that were classified in the other two groups mentioned, analyzing them more consistently, each one of them, with the use of a more specialized team. It is also hoped to further substantiate the proposed model by applying it to other stakeholders, who could be included in the process and directly influence the context to bring greater robustness and stability.

It is concluded that the use of the VFT along with the FITradeoff is of great value, becoming a necessary tool to be applied in unstructured contexts since they enable more excellent knowledge, understanding, and a more solid survey of the crucial issues to be included in the process. From this perspective, the model proved viable for the context and can contribute to and reflect on what is being done based on the city's Mobility Plan.

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