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ARTICLES

BUILDING A MULTICRITERIA DECISION MODEL FOR SOLVING A TECHNICAL SCHOOL LOCATION PROBLEM WITH THE FITRADEOFF METHOD

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ABSTRACT. Facility location-related decision problems pose a significant challenge for managers due to the multiple and conflicting factors involved. Moreover, incorrect decisions can lead to substantial impacts on companies' long-term strategic planning, resulting in losses for the business. This paper deals with a facility location problem in the educational sector in the northeast region of Brazil, which concerns the definition of the best location to place a private sector technical school, considering multiple objectives throughout a multicriteria approach. The decision-making process is structured based on a 9-step multicriteria model, and the preference elicitation phase is aided by the Flexible and Interactive Tradeoff (FITradeoff) method, using partial information provided by the decision-maker (DM). In the application presented in this paper, preference modeling is conducted considering the combination of two preference elicitation paradigms in the FITradeoff decision process: elicitation by decomposition and holistic evaluations, throughout a flexible approach. The DM's preferences are elicited interactively, by means of a Decision Support System (DSS). At each interaction, the information given by the DM acts as constraints for a linear programming problem (LPP) model, which is computed in order to verify the potential optimality of each alternative. At the end of the elicitation process, a sensitivity analysis is performed so as to verify the robustness of the results obtained. Insights on the preference modeling paradigms combination with potential advantages for the decision process are also discussed in this paper.

Keywords: facility location, technical school location problem, multicriteria decision-making, preference modeling, FITradeoff method.

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1 INTRODUCTION

Over the last decade, the demand for technical courses in Brazil has grown greatly, especially from the private sector. This is explained by the economic difficulties that the country has been facing in recent last years: in times of economic crisis, when the unemployment rate grows, people look for complementary courses that add to their qualifications, and thus technical and professional courses are seen as good targets. According to UNESCO (2018), technical and professional education in Brazil needs to be expanded in order to prepare young people for entry into the labor market. In this context, the problem addressed here concerns the location of a branch of a technical school franchise, in a city in the northeast region of Brazil.

Decision-making concerning the location of facilities is not an easy task because wrong decisions can have severe impacts on the long-term strategic planning of the company and consequently may lead to incurring losses (Pizzolato et al., 2004). Besides that, decisions about the location of facilities have a high impact on the efficiency of the system in which the facility is involved (Pludow et al., 2022).

Studies applying Multicriteria Decision Making-Aiding techniques to solve facility location problems are commonly found in the literature, due to the inherent multifactorial nature of such problems. Farahani et al (2010) present a literature review on multicriteria facility location problems, highlighting those criteria that are most commonly used. The authors also draw attention to the main MCDM methods applied for solving facility location problems, including AHP, ELECTRE, MAUT, TOPSIS, and SMAA. Erkut et al (2008) present a multicriteria decision approach for addressing a solid waste management decision problem, using multiobjective linear programming (MOLP) and the Lexicographical minimax approach. Niyazi & Tavakkoli Mogghadam (2014) present three MCDM methods to solve a facility location problem: ARAS method, COPRAS method, and TOPSIS method; since the three methods recommend different rankings, the authors propose the REGIME method to find a final compromise solution. The FITradeoff multicriteria method has also been applied for solving facility location problems; Dell'Ovo et al (2017) present an application of this method in the healthcare sector, and Sousa Ribeiro et al (2021) address the location of a shopping mall in Brazil.

The use of multicriteria methods and their Decision Support Systems (DSS) to address facility location problems is extensively explored in the chapters of Oppio et al (2020), but specifically to healthcare facility location problems. In the education section specifically, the work of Mayerle et al (2022) presents a decision support methodology in the context of the public education sector, intending to improve the efficiency of the use of resources (including both human and infrastructure resources). This work, however, focuses on a specific real-life decision-making problem within the public sector. When it comes to education in the private sector, schools should be sited so that they attract the highest possible number of students. On the other hand, implementation costs should be as low as possible in order to maximize the profit margin of the unit. Therefore, this decision-making situation embraces several conflicting objectives that should be taken into consideration. Thus a multicriteria approach is developed here so as to structure and guide the decision-making process.

To the best of our knowledge, no previous work in the literature has addressed a private-sector technical school location problem through a multicriteria decision approach. The main contribution of this paper relies, therefore, on the construction of a structured multicriteria decision model to address a technical school location problem, considering a specific practical real-life case in the state of Piauí, in the Northeast region of Brazil.

A 9-step decision model is put forward to aid the process of making decisions on the location of a private-sector technical school, considering multiple and conflicting criteria. A crucial step in decision models involving multiple criteria is the preference modeling phase of the Decision Maker (DM), to obtain a measurement of prioritization on the multiple criteria involved in the process. To address such a challenge, the FITradeoff method (De Almeida et al., 2016; Frej et al., 2019; De Almeida et al., 2021) is applied in the preference modeling phase, in order to achieve the best solution for the problem with not much effort spent from the DM, since it works based on partial information about the DMs' preferences. This method has an innovative perspective, combining, in its structure, two paradigms of preference modeling: the classical elicitation by decomposition and holistic evaluations (De Almeida et al., 2021). This is a key flexibility feature of the method, which can fasten the decision process, saving time and effort from decision-makers.

The FITradeoff method has recently been applied in order to solve MCDM problems that have covered a wide variety of themes, including facility location (Dell'Ovo et al. 2017; Sousa Ribeiro et al., 2021). Table 1 presents an overview of some practical applications developed with the FITradeoff multicriteria method, demonstrating its high potential of use.

Table 1 – Applications of the FITradeoff method.

Application area	References
Logistics & Supply Chain	Frej et al. (2017); Cyreno et al. (2023), Rico Lugo et al (2023); Carvalho et al (2023)
Portfolio Selection	Frej et al (2021); Marques et al (2022); Cyreno & Roselli (2023)
Facility Location	Dell'Ovo et al. (2017); Sousa Ribeiro et al (2021)
Agricultural Sector	Rodriguez et al., (2023); Álvarez-Carrillo et al. (2018)
Energy Sector	Fossile et al., (2020); Kang et al., (2018)
Technology Information Sector	Gusmão & Medeiros (2016)
Production Management	Pergher et al. (2020)
Project Management	Santos & Costa (2023)
Industry 4.0	Ferreira et al. (2024)
Tourism Management	Czekajski et al. (2023)
Negotiation Analysis	Frej et al. (2022)

The list presented in Table 1 is not intended to be exhaustive; it aims to illustrate the applicability potential of the FITradeoff method and therefore to enhance the motivation for using this method to address the facility location problem presented in this paper. De Almeida et al (2023) present an overview of all practical applications and methodological developments made with the FITradeoff method. Neuroscience studies have also been applied to investigate issues about the behavior of decision-makers when applying the FITradeoff method (Da Silva et al., 2022a; Roselli & De Almeida, 2021).

The problem addressed in this paper emerges in the context of a well-established network of technical schools in Brazil, which is seeking to place a new unit in the state of Piauí, in the northeast region of the country. This is a branch of the largest franchise business of technical education in the private sector in Brazil. Choosing the best location to place the school is an important decision that leads to several consequences in the long term. Hence, a structured analysis should be conducted considering the multiple and conflicting factors inherently involved in the problem. Considering this, the central research question addressed in this research is how to choose the best location for placing a private sector technical school considering all short-term and long-term consequences and by taking into account all conflicting objectives involved.

The main contribution of the present paper, therefore, relies, on solving a practical real-life decision-making problem of the educational sector in a developing country, based on the construction of a well-structured 9-step methodology. In the proposed model, we deeply explore a new feature of a well-known MCDM method, the FITradeoff method, with a view to its benefits and implications for the decision process. We also show that improvements in the performance of the method are achieved based on the integration of preference modeling paradigms, leading to time and effort saving of DMs.

This paper is organized as follows. Section 2 introduces the main concepts and the mathematical model of the FITradeoff method. Section 3 presents the decision model proposed for structuring the decision-making process, which is divided into three main phases: the preliminary phase, in which the main elements of the MCDM problem are defined; the preference modeling phase, in which the FITradeoff method is applied for eliciting the DM's preferences; and the finalization phase, in which a sensitivity analysis is performed and the final recommendation is made. Finally, Section 4 discusses the results obtained and presents the main conclusions.

2 FITRADEOFF ELICITATION METHOD

Preference modeling is a critical issue in MCDM/A methods. This is because the elicitation of preferences can be a hard task for DMs, depending on the amount of preferential information required in the process to find a solution (Kirkwood and Sarin 1985; Kirkwood and Corner 1993; Athanassopoulos and Podinovki 1997). In order to reduce the cognitive effort demanded of DMs, several authors have proposed multicriteria decision-making (MCDM) methods for dealing with partial/incomplete/imprecise information about DMs' preferences (Park and Kim 1997; Malakooti 2000; Salo and Hamalainen 2001; Cook and Kress 2002; Mustajóki et al. 2005; Salo and Punkka 2005; Sarabando and Dias 2010; Danielson et al. 2014). The Flexible and Interactive Tradeoff (FITradeoff) method (de Almeida et al. 2016; De Almeida et al., 2021) was created in this context based on the entire axiomatic foundation of the traditional tradeoff procedure (Keeney and Raiffa 1976), but improving its applicability for the DM by using a flexible process which asks less cognitively demanding elicitation questions. The computation of potentially optimal alternatives is conducted by linear programming, and graphical visualization of partial results is available for the DM at any step during the elicitation process. According to a literature review of partial information methods conducted by Da Silva et al. (2022b), the FITradeoff method differs from other partial information methods in the literature due to the way in which the elicitation process is carried out: in a flexible manner, interactively, and with a structured protocol based on tradeoffs.

Solving multicriteria decision problems when the DM has a compensatory rationality leads to the use of unique criterion of synthesis methods (de Almeida et al. 2015), which work based on value/utility functions for aggregating criteria. Within the scope of Multiattribute Value Theory (MAVT – Keeney and Raiffa 1976), alternatives are scored straightforwardly according to an additive aggregation function of the criteria (1). Each alternative has a global value $v(A_j)$, which is computed by the weighted sum of the n criteria scaling constants – or weights – w_i and the consequence value of alternative A_j in criterion i, $v_i(x_{ij})$, normalized in a 0-1 scale. The values of the scaling constants w_i are also normalized, according to (2).

$$v(A_j) = \sum_{i=1}^{n} w_i v_i(x_{ij}) \tag{1}$$

$$\sum_{i=1}^{n} w_i = 1 \tag{2}$$

A critical issue related to additive aggregation models is the establishment of criteria scaling constants w_i. Traditional utility/value methods that work based on complete information usually ask DMs to provide precisely detailed information about their preferences, which is a hard, cognitively demanding task (Weber 1987). This leads to a tedious and time-consuming elicitation process, which DMs are not always willing to undergo (Salo and Hamalainen 1992; Belton and Stewart 2002). In this context, the Flexible and Interactive Tradeoff (FITradeoff) method (de Almeida et al. 2016) was developed so as to facilitate the decision-making process for DMs, while keeping the entire axiomatic structure of MAVT. The FITradeoff method is suitable for solving problems in the scope of the choice problematic (De Almeida et al., 2016), ranking problematic (Frej et al., 2019); sorting problematic (Kang et al., 2020) and portfolio problematic (Frej et al., 2021; Marques et al., 2022)

FITradeoff works with partial information about the DMs' preferences. The elicitation process is easier due to the amount and kind of information required. Throughout an interactive process, the two paradigms of preference modeling, elicitation by decomposition and holistic evaluations, are combined within the FITradeoff decision process (De Almeida et al., 2021). In the elicitation by decomposition, which is conducted based on the classical tradeoff procedure, the DMs are asked to state their preference regarding two consequences at each interaction, considering tradeoffs amongst criteria. This is an advantage if compared to the traditional tradeoff procedure (Keeney and Raiffa 1976), in which the DM has to identify the exact indifference point which makes two consequences indifferent to each other. Holistic evaluations, however, consist of comparisons between elements in the alternatives space, instead of the consequences space. In the choice problematic, the DM has two possibilities: select the best alternative among a subset of potentially optimal alternatives, or eliminate the worst alternative among a subset of them. This analysis is conducted with the help of graphical visualization tools provided in the FITradeoff Decision Support System. A key flexibility feature of this method is the possibility to alternate between these two types of preference modeling, in accordance with the DM's wishes and desires (De Almeida et al., 2021).

Another benefit of this method is that the DMs give as much information as they are willing to because the elicitation process can be interrupted at any time, namely, whenever the DM thinks that the partial result provided is already enough for his/her purposes.

The FITradeoff method is operated by means of an interactive Decision Support System (DSS). After an intracriteria evaluation is performed, the DM conducts the ranking criteria weights. The DM can choose to conduct this process through an overall evaluation of the criteria or by making pairwise comparisons between consequences. As a result of this preliminary step, the inequalities in (3) are obtained.

$$w_1 \geq w_2 \geq \ldots \geq w_i \geq w_{i+1} \geq \ldots \geq w_n \tag{3}$$

Thereafter, the DM chooses how he/she wants to continue the elicitation process: elicitation by decomposition or holistic evaluation. In the elicitation by decomposition, pairs of consequences are presented to the DM. He/she has to choose which one is more valuable for him/her, by considering tradeoffs amongst adjacent criteria. For instance, let us assume that consequences F_{1A} and F_2 are put to the DM (see Figure 1). F_{1A} presents the worst possible outcome W for all criteria, except for criterion i, which has an intermediate outcome ${X_i}^U$. F_2 presents the worst possible outcome W for all criteria, except for criterion $i+1$, which has the best possible outcome B_{i+1}.

If the DM prefers F_{1A} over F_2, then the global value of F_{1A} according to (1) is greater than the global value of F_2, and thus (4) is obtained. Now, let us assume that the DM is asked to compare F_{1B} and F_2. F_{1B} is similar to F_{1A}, but the outcome of criterion i is set to ${X_i}^L < {X_i}^U$, in such a way that now F_2 is preferred over F_{1B}, and (5) is obtained.

$$w_i v_i \left({X_i}^U\right) > w_{i+1} \tag{4}$$

$$w_i v_i \left({X_i}^L\right) < w_{i+1} \tag{5}$$

Inequalities (2 – 5) act as constraints for a linear programming problem model that runs for each alternative at each interaction cycle, in order to verify if this alternative is potentially optimal for the problem, i.e., if this alternative can be optimal for at least one vector of weights within

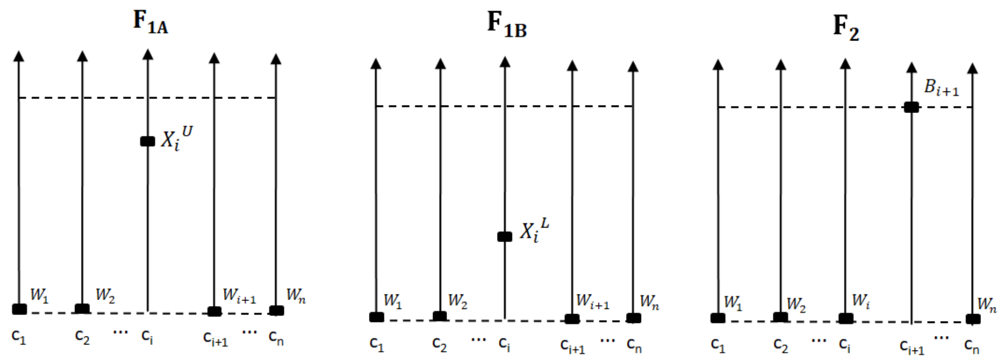

Figure 1 – Consequences compared in FITradeoff.

the weight space formed by inequalities (2 – 5). The objective function of the LPP model is to maximize the global value of alternative A_j in (1), and, in order to verify the possible potential optimality of A_j, the inequalities in (6) also act as constraints for this LPP model.

$$\sum_{i=1}^{n} w_i v_i(x_{ij}) \geq \sum_{i=1}^{n} w_i v_i(x_{ik}),\ k = 1, \ldots m; k \neq j \tag{6}$$

If the global value (1) of alternative A_j can be greater or equal to the global value of all other $m-1$ alternatives $A_k,\ \ k = 1, \ldots m; k \neq j$ for at least one vector of weights within the weight space (2 - 5), than A_j can be considered as a potentially optimal alternative for the problem.

As the DM gives additional preference information during the process with the comparison of more consequences, more inequalities of (4) and (5) are obtained, so that the weight space is updated. In addition to those inequalities, when a holistic evaluation is made by the DM, an inequality of type (7) is also included in the mathematical model, updating the weight space. Assuming that a holistic judgment is made by the DM, in which he/she declares preference for alternative a_p over alternative a_q; hence, the inequality in (7) aims to guarantee that the global value of a_p is greater than the global value of a_q (De Almeida et al., 2021).

$$\sum_{i=1}^{n} w_i v_i(x_{ip}) \geq \sum_{i=1}^{n} w_i v_i(x_{iq}) \tag{7}$$

Whenever there is an update in the weight space, the LPP models run again in order to find the refined set of potentially optimal alternatives. The process finishes if a unique alternative is found as potentially optimal; this is the optimal alternative to the problem. The DM, however, can stop the elicitation process before the end, if he/she thinks that the current subset of potentially optimal alternatives (POAs) is already sufficient for him/her to make a choice at that point, aided by the graphical visualization provided by the DSS. This will be illustrated in Section 3.2. The FITradeoff steps explained above are summarized in Figure 2 for a problem with an initial set of alternatives A_0.

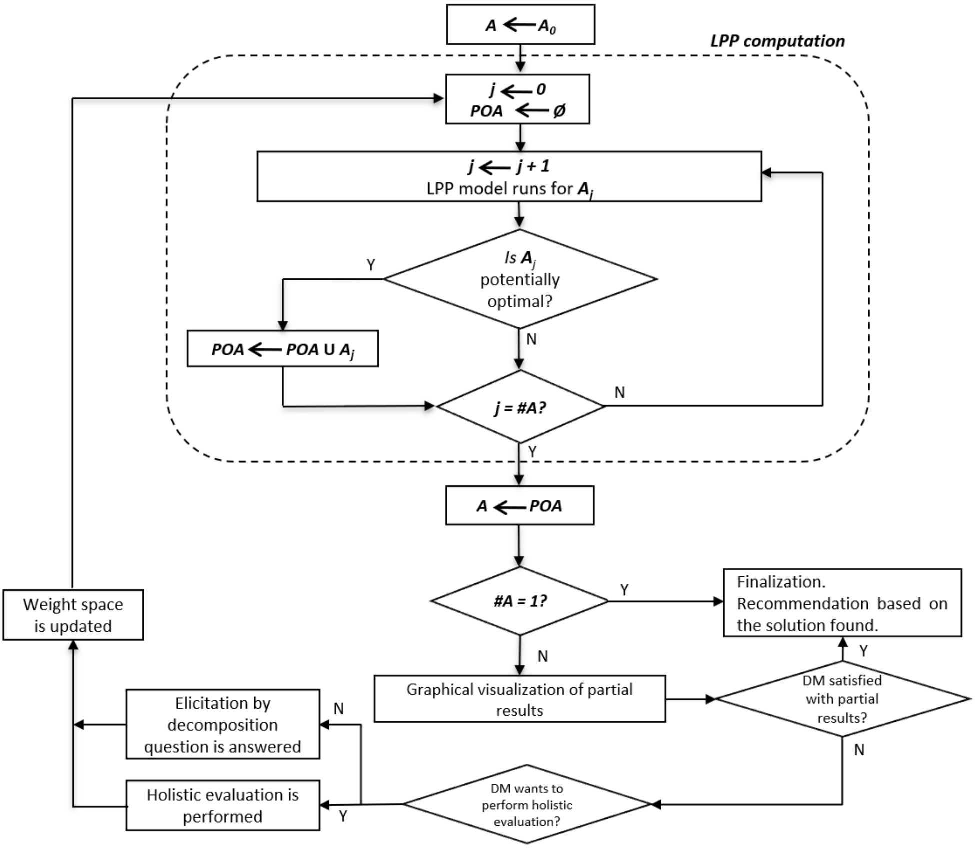

Figure 2 – FITradeoff process.

The application of this Multi-Criteria Decision-Aid (MCDA) method in order to help solve the problem of choosing the best location for a technical school is presented in the next section.

3 MCDA MODEL FOR A TECHNICAL SCHOOL LOCATION PROBLEM

The MCDA problem addressed in this paper concerns the location of a technical school in the city of Teresina, the capital of the state of Piauí, in the northeast region of Brazil. This school is a branch of the largest Brazilian franchise business of technical education in the private sector, founded in 2011. There are schools in all the five regions of Brazil. In total, there are 28 units in full operation around the country. Moreover, there are 17 new schools under construction. The schools offer more than 20 technical courses, including nursing, radiology, clinical analysis, management, construction skills, electro-technology, and health and safety at work. The aim of the brand is to attract young people between 18 and 35 years old, who have completed high school, and whose monthly income is up to R$2.000 (around 460 American dollars).

The state of Piauí is the only state in the northeast region of Brazil whose capital does not have a branch of this school. The capital of this state, the city of Teresina, has a population of over 850 thousand inhabitants, which makes it attractive for the brand to locate its next branch there. Therefore, the franchise team has designated a franchisee to start the processes that will lead to the opening of a technical school in Teresina. This person has collected data about possible buildings in the city to set up the school. In this context, the decision problem here is to choose one of these buildings in which to locate the branch, by considering several factors that must be borne in mind when making such a long-term strategic decision.

The steps for solving the technical school location problem were defined based on the framework for resolving MCDM problems proposed by de Almeida et al. (2015), which is illustrated in Figure 3. This model is divided into three main phases: the preliminary phase; the preference modeling phase and the finalization phase. Each of these phases is described in the following subsections for the context of the technical school location problem addressed here.

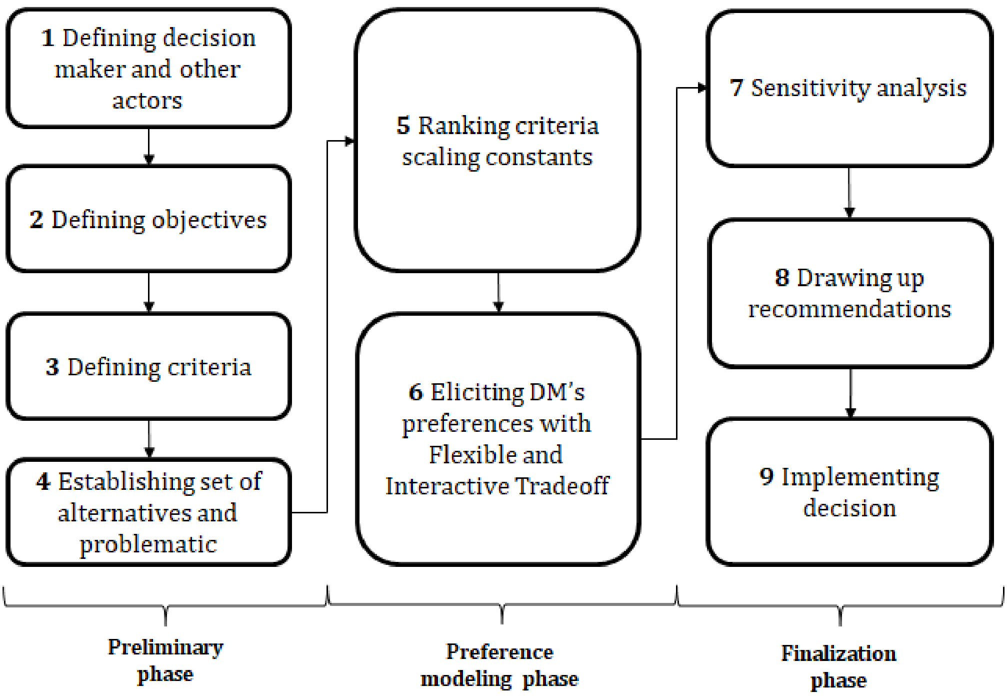

Figure 3 – MCDM model for addressing a technical school location problem.

3.1 Preliminary phase

This preliminary phase consists basically of defining the main elements of the MCDM problem, which are: the DM and other actors who may exert influence on how the decision-making problem is tackled; defining the main objectives that the DM wants to achieve by solving this problem; defining the set of criteria, which derive from the objectives defined; defining the set of alternatives that will be evaluated with respect to those criteria; and, finally, choosing the most appropriate type of problematic: choice, ranking or sorting (Roy 2005).

The DM is the franchisee who was designated by the franchise to be responsible for the branch of Teresina. There are also other actors who exert influence on this process, such as the owner of the franchise, who acts as a specialist in this case, since he has extensive experience in locating facilities of this franchise all over Brazil. The entire decision-making process was aided by an analyst with a strong background in MCDM.

The main objectives involved in this decision are to have a school with as many registered students as possible, which has high visibility in the street and which the students can reach easily. There should also be services nearby. The owners want to maximize their profit margin, and thus the costs of refurbishing should be as low as possible, and the monthly rent should be at an affordable price. Moreover, as it is a long-term strategic decision, possible expansions of the school in the future also have to be considered. Therefore, another objective of this decision is to locate the school in an area in which it can grow. Based on these objectives, a total of 7 criteria were defined. These are described in detail in Table 2.

Table 2 – Description of the Criteria.

Criteria	Description	Preference
Rental price	The monthly cost of renting a building (R$). This value is a fixed cost that will be paid every month. It has a direct impact on the profit margin of the branch.	Minimize
Cost of refurbishment	Cost of refurbishing the building to make it ready for the school's activities (R$). The lower this cost, the lower the payback time of this investment.	Minimize
Area	Total area of the property (m^2). The minimum desirable size for the area is 1000m^2; otherwise, further expansions would not be possible.	Maximize
Proximity to services	Related to the number of services nearby, such as hospitals and restaurants. These services are convenient for the students. This criterion is measured on a verbal scale from 1 to 3: 1- there are no services nearby; 2 - there are a few services nearby; 3 - there are many services nearby.	Maximize
Visibility	Related to the level of visibility of the location of the building. This is important because around 30% of the enrollments come from pedestrians passing by the school. This criterion is measured on a verbal scale from 1 to 5: 1- very low visibility; 2 - low visibility; 3 - medium visibility; 4 - high visibility; 5 - very high visibility.	Maximize
Grace period	This is the grace period on rental payment that the owners of some buildings offer the franchisee, measured in months. This criterion is important because the grace period directly impacts the total investment of the branch.	Maximize

Table 2 – Continuation.

Criteria	Description	Preference
Accessibility	Related to the facility of access for the students and teachers. Wide streets, bike paths, parking lots, and especially access by public transport are desirable. Around 90% of the students go to the school by public transport. This criterion is measured on a verbal scale from 1 to 5: 1- very low accessibility; 2 - low accessibility; 3 - medium accessibility; 4 - high accessibility; 5 - very high accessibility.	Maximize

With regard to the alternatives to the problem, the DM contacted three realtors and talked with them about what he was expecting as to the characteristics of the building, which took into consideration all the criteria mentioned above. The realtors initially presented the DM with a list of 15 buildings. Table 3 presents the consequences matrix and shows the performance of these 15 alternatives evaluated with respect to the criteria.

Table 3 – Consequence matrix with an initial set of alternatives.

Alternatives	Rental price (R$)	Cost of Refurbishment (R$)	Area (m^2)	Proximity to Services	Visibility	Grace period (months)	Accessibility
Building 1	22000	450000	1080	3	5	6	5
Building 2	60000	350000	1770	3	5	0	5
Building 3	10000	1000000	**936**	3	5	12	5
Building 4	14000	300000	1600	1	2	0	3
Building 5	40000	1000000	2000	2	3	3	2
Building 6	30000	800000	**938**	2	3	3	2
Building 7	20000	500000	**800**	2	3	0	3
Building 8	40000	500000	1500	3	4	3	4
Building 9	20000	700000	1075	2	3	0	3
Building 10	25000	350000	**600**	3	5	0	5
Building 11	25000	800000	**900**	2	3	0	3
Building 12	15000	450000	2500	2	4	12	4
Building 13	25000	100000	1000	1	1	0	3
Building 14	30000	200000	1600	3	5	0	5
Building 15	30000	100000	1000	2	2	0	3

The DM, however, noticed that, for 5 of these 15 alternatives, the value of the area is smaller than 1000m^2 (Buildings 3, 6, 7, 10, and 11). Therefore, these 5 alternatives are automatically eliminated from the decision process, because the criterion of area acts as a veto for this problem since buildings with an area below 1000m^2 do not allow for future expansions, as mentioned in Table 2. Hence, the refined consequence matrix with the final set of alternatives with 10 buildings is presented in Table 4.

Table 4 – Consequence matrix with a final set of alternatives.

Alternatives	Rental price (R$)	Cost of Refurbishment (R$)	Area (m^2)	Proximity to Services	Visibility	Grace period (months)	Accessibility
Building 1	22000	450000	1080	3	5	6	5
Building 2	60000	350000	1770	3	5	0	5
Building 4	14000	300000	1600	1	2	0	3
Building 5	40000	1000000	2000	2	3	3	2
Building 8	40000	500000	1500	3	4	3	4
Building 9	20000	700000	1075	2	3	0	3
Building 12	15000	450000	2500	2	4	12	4
Building 13	25000	100000	1000	1	1	0	3
Building 14	30000	200000	1600	3	5	0	5
Building 15	30000	100000	1000	2	2	0	3

By analyzing Table 4, it can be noticed that most buildings present a 0 on the ‘grace period’ criterion. One could wonder why not eliminate those buildings in a preliminary analysis, similar to what was conducted with buildings having less than $1000m^2$ area. However, in this case, the DM is willing to accept buildings without a grace period, as long as they have good performances in other criteria since the analysis is conducted under a compensatory rationality, in which the DM considers tradeoffs between criteria, allowing a lower performance in one criterion to be compensated by higher performance in other criteria.

With the consequences matrix established, the last task of this preliminary phase is to identify the problematic of this MCDM problem. Given that, for the time being, the franchise wants to build only one school in the city, the choice problematic is the most adequate one for dealing with this problem.

3.2 Preference modeling phase

The preference modeling phase was aided by the FITradeoff DSS. The first step of this phase is to rank the criteria scaling constants. The DSS gives the DM the option of making a holistic evaluation of the criteria or making a pairwise comparison. In this case, the DM chose to conduct a holistic evaluation. As a result, the following order was obtained:

$$w_{Rental\ price} \geq w_{Cost\ of\ Refurbishment} \geq w_{Visibility} \geq w_{Accessibility} \geq w_{Grace\ period} \geq w_{area} \geq w_{Proximity\ to\ services}$$

By following the steps in Figure 2, the LPP model is run in order to define the set of potentially optimal alternatives at this stage. According to the simulation studies performed by Mendes et al (2020), the information on the ranking of criteria weights is sufficient to significantly reduce the set of potentially optimal alternatives.

After the ranking of criteria weights performed by the DM, of the 10 buildings considered in this evaluation, only four of them have been found to be potentially optimal alternatives for the problem: Buildings 1, 4, 12, 14. The DSS provides the DM with a graphical visualization of the alternatives in the POA subset, as shown in Figure 4.

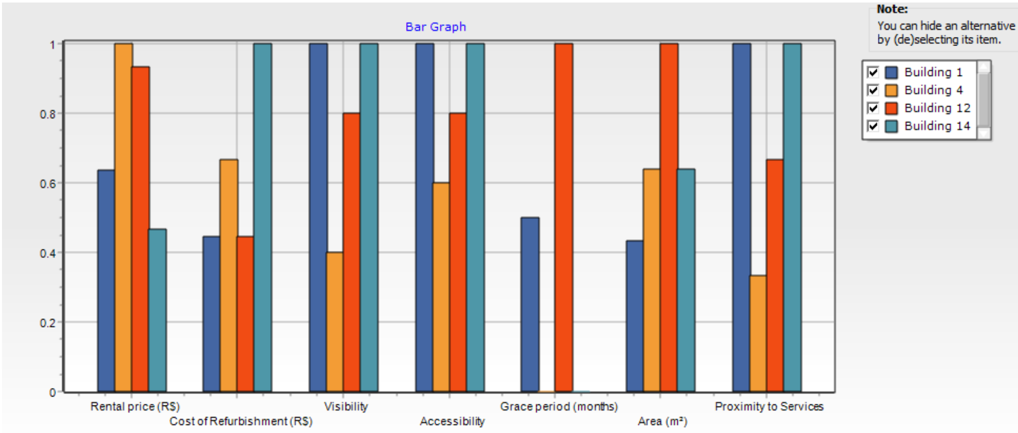

Figure 4 – Bar graphic of the POA subset after the ranking of criteria scaling constants.

The bar graphs in Figure 4 show the performance of the alternatives in each criterion, normalized on a ratio scale of 0-1. Each color represents one potentially optimal alternative, and the criteria are ordered from left to right. The DM has the possibility, at this stage, to make a holistic evaluation of the set of potentially optimal alternatives, performing a direct comparison of these alternatives. Anderson and Dror (2001) discussed the use of graphics when making decisions, and Kasanen and Ostermark (1991) make special mention of using these tools in a multicriteria decision-making/aiding process.

In this study, the DM's opinion was that the graph in Figure 4 still had too much information, and he was not able to perform a holistic evaluation at that point. Thus, he decided to continue the elicitation process, and therefore the question-and-answer procedure for comparing consequences in FITradeoff started. After the first and second questions had been answered, nothing had changed in the POA subset. After the third question, however, Building 4 was eliminated from the process, and therefore, only three alternatives remained in the POA set, namely, Buildings 1, 12, and 14. Figure 5 shows the graphical visualization provided by the DSS at this point.

By analyzing Figure 5, it can be seen that Buildings 1 and 14 are tied in three criteria with the best possible performance: visibility, accessibility, and proximity to services. However, Building 14 has 0 months of grace, which is a great disadvantage for this alternative. And Building 1 is worse than Building 12 in rental price – the most important criterion –, grace period and area, for both of which Building 12 has a great advantage. By following this point of view, the DM decided to perform a holistic evaluation at this point and chose to consider Building 12 as the best one. Hence, the elicitation process has finished with three elicitation questions being answered by the DM.

At this stage, however, the DM demonstrated curiosity about what would be the final result if he followed the elicitation by decomposition process until the end. Hence, the analyst continued the elicitation process with him, just to analyze how the results would be. After 10 more questions

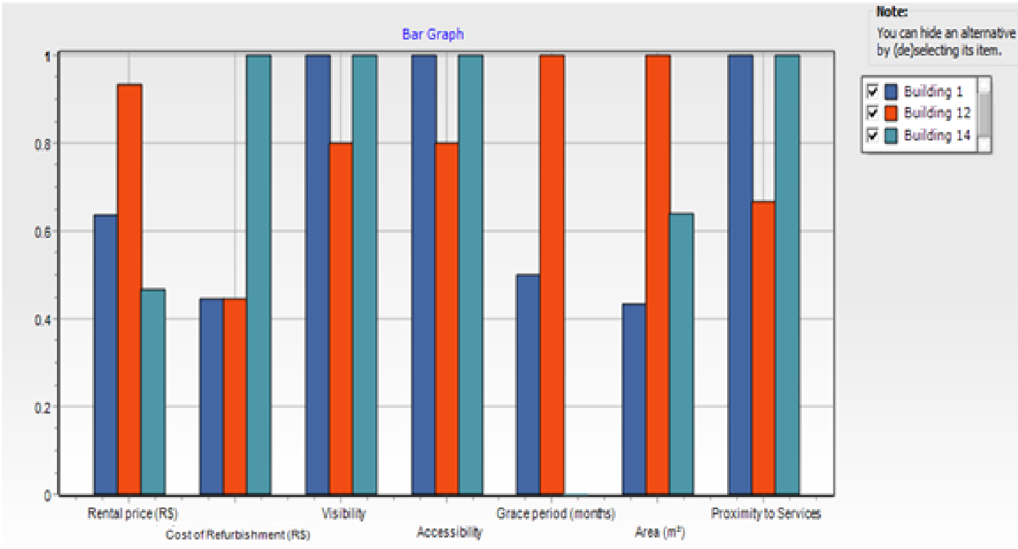

Figure 5 – Bar graphic of the POA subset after three questions have been answered.

had been answered, Building 14 was eliminated, and so only Buildings 1 and 12 remained in the set of POAs. Finally, after the eleventh question had been answered, Building 12 was found as the optimal alternative for this problem, which is in accordance with the holistic judgment performed by the DM after the third question. In Table 5, there is a summary of the application of FITradeoff, with all questions and answers of the DM for each interaction cycle.

Table 5 – Summary of FITradeoff application.

Cycle	Consequence A	Consequence B: Best of	Answer	# P.O.A	P. O. A set
0	ordering criteria scaling constants			4	B 1, B 4, B 12, B 14
1	37000 of Rental price (R$)	Proximity to Services	A	4	B 1, B 4, B 12, B 14
2	37000 of Rental price (R$)	Cost of Reform (R$)	B	4	B 1, B 4, B 12, B 14
3	550000 of Cost of Refurbishment (R$)	Visibility	B	3	B 1, B 12, B 14
4	3 of Visibility	Accessibility	A	3	B 1, B 12, B 14
5	3 of Accessibility	Grace period (months)	B	3	B 1, B 12, B 14
6	6 of Grace period (months)	Area (m^2)	A	3	B 1, B 12, B 14
7	1750 of Area (m^2)	Proximity to Services	A	3	B 1, B 12, B 14
8	25500 of Rental price (R$)	Cost of Reform (R$)	A	3	B 1, B 12, B 14
9	325000 of Cost of Refurbishment (R$)	Visibility	A	3	B 1, B 12, B 14
10	2 of Visibility	Accessibility	B	2	B 1, B 12
11	4 of Accessibility	Grace period (months)	B	1	B 12

The first column has the number of questions (or interaction cycle). Columns 2 and 3 show the two consequences that the DM was asked to compare, as explained in Section 2: Consequence A has the worst outcome for all criteria, except for the criterion specified in column 2, which has an intermediate value; and Consequence B has the worst outcome for all criteria, except for the criterion specified in column 3, which has the best possible outcome. Column 4 shows the answer given by the DM in each comparison, namely, it shows whether his preference was for Consequence A or Consequence B. The fifth column shows how many potentially optimal alternatives were found by the LPPs for that current level of partial information obtained, and in column six there are the alternatives that belong to the POA set (Building is abbreviated to B).

3.3 Finalization phase

After achieving a final solution for the problem, FITradeoff DSS also offers the possibility of performing a sensitivity analysis of the values of the consequences matrix. Therefore, the DM may be asked to choose a criterion or several criteria and to decide to vary their values by a certain percentage. For the present problem, the DM has chosen to vary two criteria: cost of refurbishment and grace period. The cost of refurbishment is estimated based on the current state of the building. Thus, this will depend on what needs to be done in order to make the buildings ready to undertake the academic and administrative activities of the school in line with the relevant legislation and other requirements. However these values in Table 4 were estimated by a civil engineer who visited all the buildings that were originally suggested as possible alternatives. These, quite appropriately, were of an order of magnitude nature, and therefore, the estimates for refurbishing the building selected now need to attempt to take full account of the detailed refurbishments that must now begin to be specified. These are likely to change while the refurbishment is being undertaken, and therefore, the DM may choose to vary the estimates for the costs of refurbishment by $\pm 20\%$. As for the grace period, the DM considered that he could still persuade the owners of the buildings to lengthen the grace period. Hence, he chose to vary the values of this criterion in -10%. A total of 10.000 instances were run in FITradeoff DSS, and the results are shown in Table 6.

Table 6 – Results of sensitivity analysis with 10.000 instances

Optimal alternative	% Occurrence
Building 12	69.57%
Building 1	23.72%
Building 14	6.7%
Building 4	0.01%

On analyzing Table 6, it can be concluded that the result obtained in the elicitation process – Building 12 – is quite robust because this alternative remained the optimal one in almost 70% of the cases when the values of the cost of refurbishment and the grace period are varied. Building 1 is the optimal alternative with the second highest percentage of occurrence, which is in line with the results of Table 5, which shows that this alternative remained potentially optimal until the tenth cycle. Building 14 and Building 4 were also found to be the optimal alternatives in a few of the instances but not nearly enough to make either of them competitive with Buildings 1 and 12.

Another way to verify the robustness of the result obtained is to analyze the range of possible criteria weight values for which Building 12 remains the optimal alternative. FITradeoff DSS provides a graph (see Figure 6) that shows the range of possible weight values that match the preference statements given by the DM in the elicitation process and that would lead to Building 12 being chosen as the optimal alternative.

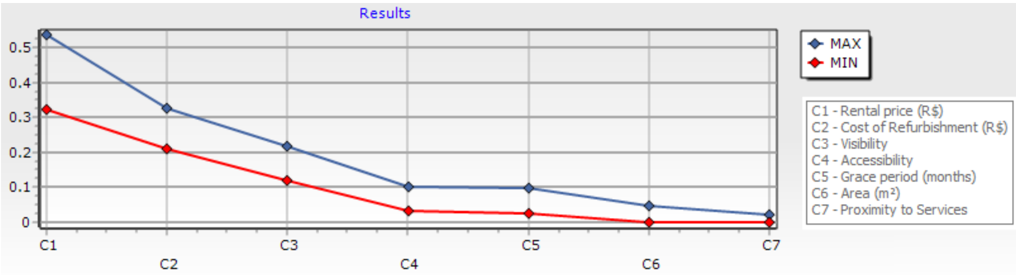

Figure 6 – Final range of criteria weight values.

By following the steps of the framework in Figure 3, the final recommendation to the DM is to proceed to the next steps for renting Building 12. This building has an excellent rental price, which is a fundamental factor for the DM. It also offers the best possible grace period and the greatest area, which allows the school to expand on-site. The main weakness of this alternative is the high cost of refurbishment, but, on the other hand, this is to some extent offset by the long grace period of rental. Similarly, the visibility of the building is not very good, since it is not located on the main avenue of the city, as was previously desired by the actors. As a consequence, the franchisee and his working team will have to think about other ways to publicize it and attract students.

As to implementing the decision, the expectation is that the negotiation process with the owner of the building will be concluded within the next two months, following which refurbishment should take around 8 to 10 months, after which the school will be ready to start its activities.

4 DISCUSSION AND CONCLUSIONS

This paper presented a multicriteria decision model to solve a technical school location problem in a city in the northeast region of Brazil. A 9-step model was proposed, and the whole process was aided by an analyst with a strong background in MCDM. The franchise has designated a franchisee to make the final decision and to conduct operations in the new school. A set of 10 alternative buildings was evaluated with respect to 7 criteria, and the preference modeling was conducted with the flexible and interactive tradeoff method, supported by a Decision Support System.

In this application, the advantages of a combination of preference modeling paradigms could be observed. By performing a holistic evaluation in the middle of the process, the DM could have shortened the elicitation process. With only three elicitation questions answered (plus one holistic judgment), the DM was able to achieve an optimal solution for his problem. If the classical elicitation by decomposition was conducted until the end, a total of eleven elicitation questions would be necessary to find a final solution, which shows that incorporating holistic evaluations within the decision process makes it possible to shorten it, saving time and effort from decision makers. Future studies should, however, investigate deeper this phenomenon, i.e., how the incorporation of holistic evaluations in the decision process can reduce the amount of information provided by the DM when compared to the situation in which the classical elicitation by decomposition process is conducted from the beginning to the end. Simulation studies could be conducted in order to analyze the magnitude of the reduction in the number of elicitation questions when holistic evaluations are incorporated into the process.

The flexibility of the FITradeoff method allows the DM to alternate between these two types of preference elicitation, carrying the process in the way the DM feels more comfortable with. At the end of the process, Building 12 was shown to be quite a robust result according to the sensitivity analysis performed in FITradeoff DSS, and the DM was satisfied with the output of this application.

It is still possible to conduct a comparison with the classical tradeoff procedure, in terms of number of questions needed to find a solution. As a benchmarking for the number of questions answered in elicitation processes, we should remember what happens in the traditional tradeoff procedure. Considering that n is the number of criteria of the MCDM problem, the tradeoff procedure requires the DM to answer at least $n-1$ questions, in order to build an equation system and thus find the values of the weights (Keeney and Raiffa, 1976). However, in order to build these equations, the DM has to specify the exact points at which he/she is indifferent to two consequences. This information is much more difficult to provide, compared to the preference statements given when applying the FITradeoff method. Therefore, the ideal is to ask strict preference questions before reaching the indifference point (de Almeida et al. 2016), and thus the benchmarking for the number of questions would be $3(n-1)$. For the problem of the technical school location addressed here, this would lead to 18 questions. Therefore, the 3 questions answered with the FITradeoff method resulted in the DM saving considerable time and effort compared to what the traditional tradeoff procedure would require, since he answered a smaller number of questions, which were also less cognitively demanding.

The number of questions necessary in FITradeoff to find a solution, however, is not a fixed value. It will depend on the data of the problem. The topology of the alternatives and also the distribution of criteria weights greatly influence this number. The closer the alternatives are to each other in terms of their performance, the higher the amount of information needed to choose only one of them as the optimal alternative, which consequently leads to the DM needing to answer a higher number of questions in the elicitation process. In order to avoid a tedious and very long process with many questions to be answered, the FITradeoff method provides flexibility features, such as the graphical visualization tool, which enables the DM to shorten the elicitation process. Another benefit of this method is that, during the elicitation process, the DM can also skip questions if he/she thinks that a question is too hard for him/her to answer. The FITradeoff DSS used in this application is available on request from the website http://www.fitradeoff.org.

To summarize, the originality of this work relied on solving a real-life decision problem of choosing the best location to place a technical school in the northeast region of Brazil, by proposing a structured decision model with the FITradeoff multicriteria method. The decision support provided to the franchisee with the model proposed in this paper was valuable in the sense that he could analyze several factors that have a high influence on the decision and were not previously considered for placing other units, stating his own tradeoffs between them. The preference modeling with the FITradeoff method is innovative when compared to other MCDM methods since it combines two preference modeling techniques in a flexible manner: decomposition elicitation and holistic judgments. MCDM methods in the literature usually work with one of those two types of preference elicitation (De Almeida et al., 2021), but FITradeoff combines both in a synergic manner, with the possibility of fastening the decision process. Moreover, it works with partial information about the DM's preferences, saving time and effort, and with a great potential to reduce inconsistencies during the process.

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