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MCDM Model for Natural Gas Pressure Reducing Station Site Selection

Naylil Liria Baldin de Lacerda, Universidade Federal de Mato Grosso do Sul, Brazil

João Batista Sarmento dos Santos-Neto, Federal University of Mato Grosso do Sul, Brazil

Carolina Lino Martins, Universidade Federal de Mato Grosso do Sul, Brazil

ABSTRACT

Considering the increasing scenario of natural gas consumption, it is necessary that all agents in the chain use methods that structure decision-making and problem-solving processes. This paper proposes a multicriteria decision model to solve a site selection problem for a pressure reducing station. A natural gas distribution company was selected to test the model and the preference modeling was conducted through the flexible interactive tradeoff (FITradeoff) approach, according to the preferences of the decision maker (DM). FITradeoff's decision support system was used to assess the alternatives of the model, through the inference of the criteria scale constants. The results proved the robustness of the model and the DM evidenced consistency in its preferences. Also, the FITradeoff method demonstrated to be intuitive to apply, since a smaller effort is required from the DM and this is because the procedure does not require complete information in the scale constants elicitation process.

KEYWORDS

FITradeoff, MCDM/A, Natural Gas, Pressure Reducing Station, Site Selection

INTRODUCTION

The energy market has been undergoing changes in supply and demand characteristics as industrial and urban consumption increases, creating new opportunities for economically sustainable energy resources, especially in developing countries such as China, India and Brazil (BP Energy Economics, 2018). In a 2040 projection by BP Energy Economics (2019), natural gas must steal space from more traditional sources, such as oil and coal, due to its increased competitiveness, which is a result of the reduction of the natural gas production cost and because it emits less carbon dioxide (Razi & Ali, 2019).

In the Brazilian energy market, for instance, natural gas use has been growing due to the increase in its supply from the exploitation of fossil fuels in deep waters (pre-salt). (Fioreze et al., 2013) and by government programs that encourage the opening of the natural gas market for global players and by the improvement of processes of exploration, production, transportation, distribution and natural gas trading (MME, 2019).

Moreover, in Brazil, the expansion of gas pipelines is a responsibility of the distribution companies with state regulation, and it is planned to increasingly stimulate natural gas growth, competitiveness in the sector, as well as meet the diverse demands of its stakeholders from the public and private initiative.

These organizations have come across with several difficulties in delivering satisfactory results, an efficient strategic and operational planning process that addresses the varied interests of all their stakeholders. One of these main difficulties is the decision making process of selecting strategic

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sites for the implementation of pressure reducing stations (PRS), which are used to control the outlet pressure of the natural gas in the distribution operations aiming to maintain the necessary flow to meet customer's demand (Hossain, 2009).

Such a decision must consider different financial criteria, technical operating standards, and environmental policies, besides being aligned with the company's expansion plan. Within this context, multiple criteria decision making/aid (MCDM / A) area can be valuable to support the decision process, when it is not possible to represent all the objectives in only one project (Burstein & Holsapple, 2008). They consist in analyzing the possible implementation of an action, assessing its positive and negative characteristics comparatively, side by side (de Almeida et al., 2015), clarifying the decision and usually towards recommending, or simply supporting, a behavior that will increase the consistency between the evolution of the process, the stakeholder's objectives and value system (Roy, 2005).

Thus, this study aims to propose a multicriteria decision model to solve a site selection problem for a pressure reducing station in a natural gas distribution company. For this purpose, the MCDM model is based on a compensatory approach, the Flexible and Interactive Tradeoff method (FITradeoff), which is a value function method (de Almeida, Almeida, Costa & Almeida-Filho, 2016), assisted by means of Decision Support Systems (DSS). An analysis was carried out in a Brazilian natural gas distribution company, since the chosen company is going through an expansion plan of its network and must carry out studies of this nature.

The Brazilian natural gas company in which this application took place operates in the whole state market and distributes natural gas for the following segments: residential, commercial, cogeneration, automotive and industrial. Furthermore, the company serves two thermoelectric plants, which makes it essential in the energy sector, especially in the location of operation.

Thus, the development of an appropriate model to select optimal alternatives for building new natural gas infrastructure can contribute to the company's permanent strategies of increasing client portfolio, network extension and volume of natural gas consumed, improving their quality indicators and providing the opportunity for sustainable growth, considering its constraints to achieve optimal results.

To achieve its results, the paper is structured as follows: after this introduction, there is a theoretical background and a literature review about the natural gas value chain, multiple criteria decision making/aid and the FITRADEOFF method. After this, there are the methodological procedures, which describe the steps to solve the decision problem. The fourth section demonstrates the results from the application of the method and the discussion about the results. Lastly, the fifth topic shows the conclusions of the study.

THEORETICAL BACKGROUND AND LITERATURE REVIEW

The development proposed model is based on the use the FITradeoff method for a site selection decision problem. Therefore, this topic seeks to discuss theoretical aspects about the natural gas physical value chain, multiple criteria decision making/aid and the FITRADEOFF method.

Natural Gas

The natural gas (NG) physical value chain is a very complex technological system and its structure is around a capital-intensive asset base. This system can be divided into upstream, which consists of exploration and production (E&P); midstream, which are the refining and transportation stages and; downstream, which comprises the distribution and consumption phases (Weijermars, 2010).

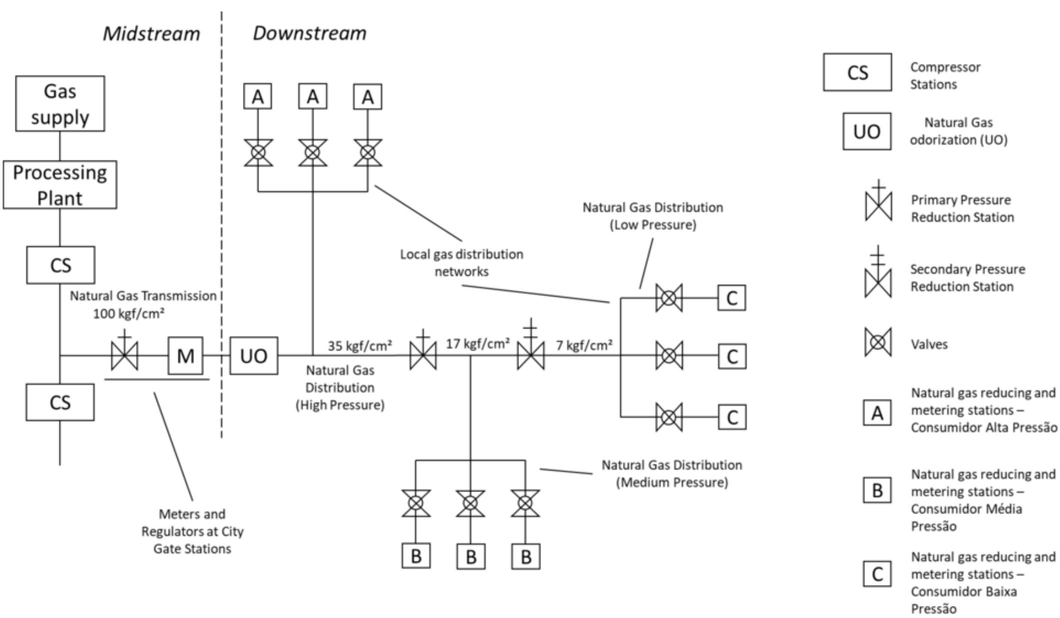
In Brazil, the exploration and production natural gas stages can be carried in three E&P environments: pre-salt, traditional offshore and onshore. The transport of NG can be carried out through transmission pipelines and the liquid form, which is the liquefied natural gas (LNG). Most used is the pipeline, which takes natural gas to the city gates of the distribution companies and the LNG market has been gaining global momentum and has a lot to develop (Weijermars, 2010).

In the case of the company under study, the distribution takes place after the natural gas flows through the *city gates*, which are essential points in the entire natural gas physical value chain. Your function is to reduce the pressure of the natural gas that runs through the transmission pipelines and the city gates be used as sites for flow and pressure measurements (Nikbakht, Sayyah & Zulkifli, 2010).

When entering the downstream step, the gas is reduced to a pressure of 35 kgf/cm^2 and an odorant is added to the natural gas in odorizing units (OU) to signal leaks (Sevenster & Croezen, 2006). Then, the gas is distributed at high pressure, for example for thermoelectric power plants (A) and so that the NG can be distributed in medium and small diameter and low-pressure pipes, primary and secondary pressure reducing stations are fixed in strategic points of the network. These stations are employed to control the natural gas outlet pressure in the distribution network and to maintain the gas flow to meet the end user needs (Hossain, 2009).

The primary pressure reducing station reduces the natural gas pressure to 17 kgf/cm^2 to supply medium pressure consumers (B) and the secondary pressure reducing station, which is the focus of this article, brings the gas to a pressure of 7 kgf /cm^2 for low pressure consumers (C), which would be the commercial and residential segments. Figure 1 shows a summary diagram of the natural gas physical value chain from the midstream stage, adapted from the Brazilian Technical Standard (ABNT)

Figure 1. Diagram of the midstream and downstream steps of the natural gas physical value chain (Adapted from [ABNT, 2002])



NBR 12712: 2002 (ABNT, 2002).

Multiple Criteria Decision Making/Aid and the FITRADEOFF Method

The choice of the method depends on the type of rationality considered for the decision problem. The evaluation of compensation is a question for which the number of studies is still very limited and are of a preliminary nature. Therefore, this evaluation may be subjected to some improvisation, since, everything depends on the context, afterwards. This is an important question when choosing the MCDM/A method, since the main classifications of these methods divide into two representative groups: compensatory and non-compensatory methods (de Almeida et al., 2015).

In the case of this study, the type of rationality that is the most adequate to the decision maker (DM) preferences is the compensatory, which means that a reduction in one deviation compensates for an increase in another (Belton & Stewart, 2002). When the compensatory rationality is indicated, a method related to the additive model is a natural starting point. Then, the properties of this first method are evaluated, before making a final choice (de Almeida et al., 2015).

Thus, to select an optimal site by evaluating multiple criteria, the method to be used could be the tradeoff based method (Keeney, 1992; Keeney & Raiffa, 1976). Although there are numerous multicriteria models for site selection (Table 1), there is a gap in the literature about multicriteria methods to select a natural gas pressure reducing station that require partial DM information and are based on tradeoff procedures. Thus, a study in this context is extremely relevant.

It is possible to note from Table 1 that the family of criteria varies according to the focus of the decision model. Furthermore, there is a tendency in the literature to use fuzzy logic for site selection problems, whether for linguistic treatment and selection associated with other multicriteria method, and/or for sorting problematic.

For this study, we propose the use of a compensatory multicriteria method based on the tradeoff procedure (Keeney, 1992; Keeney & Raiffa, 1976), where the DM must demonstrate a preference between two main consequences that consider tradeoffs between the criteria, in other words, consequence A has the best result (b_i) for one of the criteria and consequence B has the worst result (w_i) for another criterion. Moreover, in the traditional tradeoff procedure, an indifference (I) relationship must be obtained between the two consequences to find the value of the scale constant k_i. Therefore, the traditional tradeoff based method requires complete DM information to find the optimal solution to the problem (de Almeida, Almeida, Costa & Almeida-Filho, 2016).

The main challenge in additive models is to obtain the scale constants. There are several studies aiming to develop most practical methods for weight elicitation. In this sense, the Flexible and Interactive Tradeoff (FITradeoff) method works as a flexible way to elicit the criteria scale constants, starting from the principles of the traditional tradeoff procedure proposed by (Keeney, 1992; Keeney & Raiffa, 1976).

The FITradeoff seeks only the DM's preference judgment, starting from one premise: the difficulty in identifying an indifference relationship between two consequences. So, even if the DM reports such indifference, this information may not be reliable because it has not been consistently obtained. That is, FITradeoff uses partial information about the decision maker's preferences over a set of alternatives, based on the scope of the additive aggregation method (de Almeida, Almeida, Costa & Almeida-Filho, 2016).

In the additive aggregation method, the best alternative is determined by the weighted sum of the performance (v) of the alternative (a) in criterion (i) and its scales constants (ki) (Frej, Roselli, Araújo de Almeida & de Almeida, 2017), as shown in Equation 1:

$$v\left(a_j\right) = \sum_{i=1}^{n} k_i v_i \left(a_j\right) \tag{1}$$

Assuming that:

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

Besides k_j is greater than or equal to zero.

Table 1. Examples of site selection problems

Source	MCDM/A method	Focus	Criteria
Demirel, Demirel, Deveci & Vardar (2017)	Fuzzy multicriteria method	To sort alternatives to location problem of underground natural gas storage	Criteria based in costs, time, usability, risks and social factors
Uddin, Chakravorty, Ray & Sherpa (2018)	TOPSIS (Technique for order preference by similarity to ideal solution) and the COPRAS (Compressed Proportional Assessment) methods	Ranking alternatives to select a sub-station location	Land cost, site preparation cost, capacity to install at sub-station site, nearness to centre of load, feeder gateway and geographic barrier
Kabir & Sumi (2014)	Fuzzy analytic hierarchy process and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) methods	Ranking alternatives for select a power sub-station location	Criteria based in social factors, technological factors, economic factors, environmental factors and site characteristics
Uyan (2013)	Analytic Hierarchy Process (AHP)	To select a site for solar farms	Distance from residential area, land use, distance from roads, slope and distance from transmission line
Devi & Yadav (2013)	Intuitionistic fuzzy-ELECTRE method	Ranking alternatives for select a plant location	Skilled workers, expansion possibility, availability of acquirement material, investment cost, transport facilities and climate
Haaren & Fthenakis (2011)	Spatial Multi-criteria Analysis (SMCA)	To select a site wind farm	Criteria based in economic factors, planning (i.e visual impact, noise, Electromagnetic interference), physical and ecological factors
Verma, Verma & Mahanti (2010)	Fuzzy- TOPSIS (Technique for order preference by similarity to ideal solution) method	Ranking alternatives for facility location selection	Labor climate, proximity to markets, community considerations, quality of life, and proximity to suppliers and resources
Wu, Geng, Zhang & Gao (2014)	Fuzzy and with linguistic Choquet integral (LCI) method	Ranking alternatives for solar thermal power plant site selection	Criteria based in social factors, Infrastructure, land factors, Environmental and Social factors

FITradreoff is a simplified way of determining these scale constants, so that the decision maker can provide partial information about his preferences while an optimal alternative to weights is formed by solving a linear programming problem (de Almeida, Almeida, Costa & Almeida-Filho, 2016). Considering a multicriteria problem with *m* alternatives and *n* criteria, FITradeoff performs the following steps.

The first step is to sort the weights according to the decision maker's preference, where k_1 is the weight for the most preferable criterion and k_n the least preferable:

$$k_1 > k_2 > k_3 > \ldots > k_n \tag{3}$$

Thus, through linear programming, the alternatives will be verified in search of those that were dominated and, therefore, eliminated from the decision process. An alternative is possibly optimal if its value in (1) is greater than or equal to the value of all other alternatives, ie if the following inequality is satisfied:

$$\sum_{i=1}^{n} k_i v_i \left(x_{ij}\right) \geq \sum_{i=1}^{n} k_i v_i \left(x_{iz}\right) \forall_z = 1,\ldots,m, z \neq j \tag{4}$$

To verify the optimal value of an alternative, the a_j value is maximized (5) through a linear programming model, where the decision variable is the weight k_i, subject to constraints (3) and (4):

$$Max \sum_{i=1}^{n} k_i v_i (x_{ij}) \tag{5}$$

If the problem finds a solution to the a_j alternative, then a_j is potentially the optimal solution to the problem, otherwise a_j is eliminated from the process. After executing the process for all m alternatives, if only one alternative is found, then the solution to the problem has been defined. Otherwise, the decision maker must compare two hypothetical consequences, considering compensation between the criteria (a positive performance outweighs a negative one) (de Almeida, Almeida, Costa & Almeida-Filho, 2016).

Unlike other methods of elicitation, FITradeoff works only with the preference relation and partial information in the form of inequalities (6) and (7), while other processes require the decision maker to determine the point at which two consequences are indifferent. that is not always clear (Frej, Roselli, Araújo de Almeida & de Almeida, 2017):

$$k_i v_i \left(x_i^{'}\right) \geq k_{i+1} \tag{6}$$

$$k_i v_i \left(x_i^{''}\right) \geq k_{i+1} \tag{7}$$

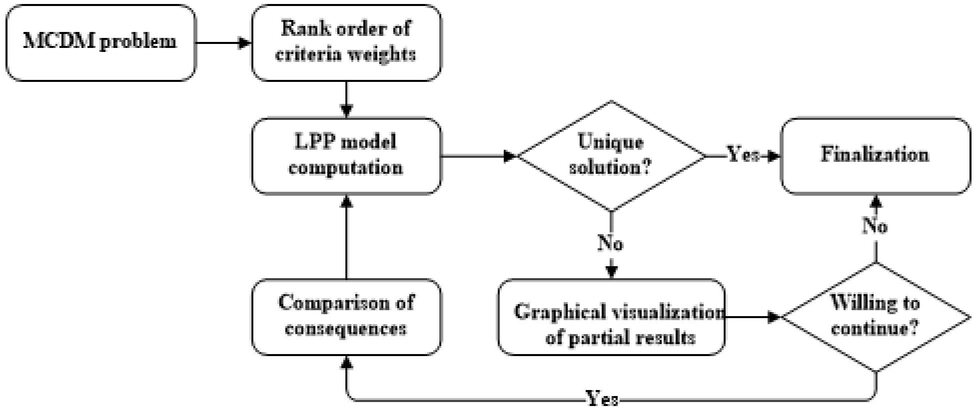
These inequalities (6) and (7) will be part of the new linear programming problem as new constraints in order to find the new set of ideal alternatives to the problem. This process is iterative and should be repeated until the only optimal alternative is found or until the decision maker stops providing additional information. FITradeoff also has a graphical system that helps the decision maker visualize the hypothetical choices and analyze the partial results (de Almeida, Almeida, Costa & Almeida-Filho, 2016). Figure 2 shows the flowchart of the iterative method proposed by FITradeoff, adapted from (Frej, Roselli, Araújo de Almeida & de Almeida, 2017).

For further details about the method, see: de Almeida, Almeida, Costa & Almeida-Filho (2016).

METHODOLOGICAL PROCEDURES

The methodology adopted by this research was based on the model for solving a decision problem proposed by de Almeida et al. (2015) composed of 3 general phases, divided into 12 stages, as shown in Figure 3.

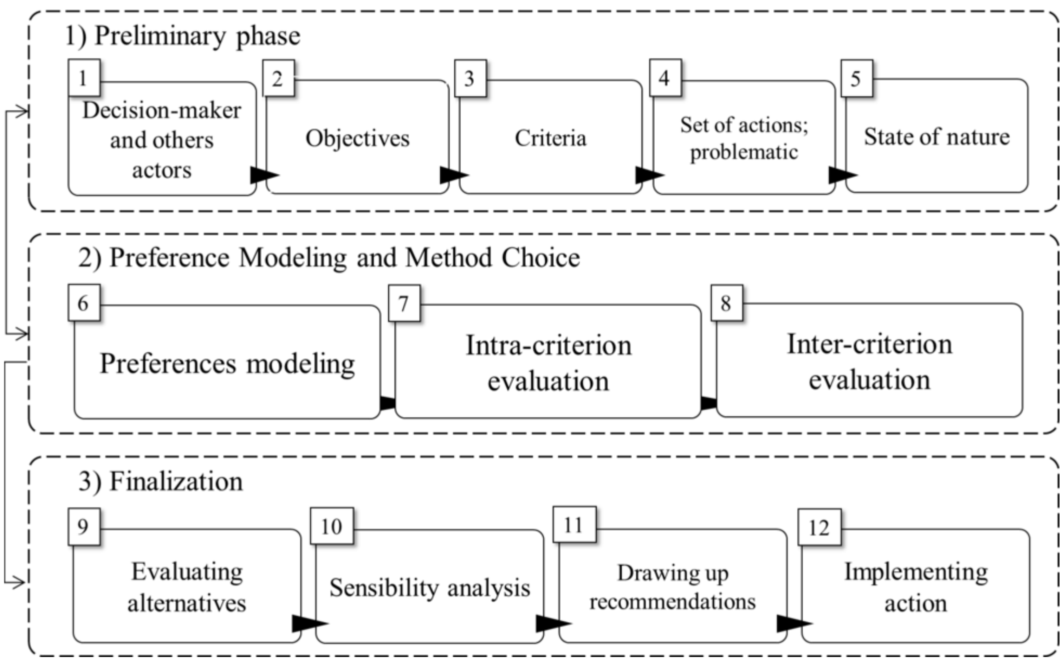
Figure 2. FITradeoff method. (Adapted from [Frej, Roselli, Araújo de Almeida & de Almeida, 2017])



In the case of this problem, which presents a high complexity in the analysis, the decision process presents the situation in which there is the influence of several actors; however, with only one individual directly responsible for the decision in question (de Almeida et al., 2015).

According to the first stage of the model proposed by de Almeida et al. (2015), the decision maker (DM) and the actors involved in the decision-making process were characterized. Thus, the DM was defined as the engineering manager, who is responsible for the progress of the project. The specialists were the engineering analysts and the environmental, commercial, operation and maintenance and planning managers, who were responsible for contributing with necessary information for the site selection, besides the stakeholders, which are public and private initiatives.

Figure 3. Steps for solving a decision problem. (Adapted from [de Almeida et al., 2015])



The second step of the decision problem is the identification of the objectives. In this case, the decision-making process aims to select a site for the implementation of a secondary pressure reduction station that meets all the established criteria, the decision-maker's preferences, which enables the construction of new low pressure distribution pipelines to attracting new residential and commercial customers and promote system operational stability.

MCDM has six general criteria for solving the site selection problem. Technical criteria were not considered because the secondary pressure reducing station is not underground, which facilitates its implementation. In addition, the region to be installed the secondary pressure reducing station is still under commercial and housing development, which makes the use of commercial criteria unfeasible. It is noteworthy that land costs and network deployment costs were separated as alternative S1 already belongs to the organization, impacting the final cost value.

The proposed criteria were based on the study developed by Demirel, Demirel, Deveci & Vardar (2017). These criteria were discussed by the experts and validated by the decision maker, and, usually, they are based on criteria such as cost, usability, social and environmental factors recommended by the study. Therefore, the criteria of the model are described in Table 2.

To define the alternatives of the model an elimination assessment procedure was performed by the experts, based on some basic technical specifications: the location should be easily operable, with the possibility of interconnecting the new networks of carbon steel (CS) and high density polyethylene (HDPE) to the existing network, not susceptible to flooding, and with the possibility of interconnection of water and electric energy; regarding environmental policy, the location must be licensed to build and maintain a pressure reducing station and must meet legal constraints, such as neighborhood area, zoning and building codes.

Table 2. Description of criteria

Parameter	Criteria	Objective	Description
Usability	Area	Maximize	This criterion fits in the usability parameter because of the site's size and the terrain's usage(stipulated on the master plan of the city in question), for the implantation of a pressure reducing station(PRS).
Environmental Factors	Carbon Steel (CS) gas pipeline extension	Minimize	Represents the extention of the gas CS network starting from the existing network up to the PRS. In the case of the CS, regarding sustentability aspects, the smaller the network's extent, the greater the technical,economical and social viability are.
	High Density Polyethylene (HDPE) gas pipeline extension	Minimize	Represents the extention of the gas HDPE network starting from the existing network up to the PRS. In the case of the HDPE, regarding sustentability aspects, the smaller the network's extent, the greater the technical,economical and social viability are.
Social Factors	Neighbor Impact	Minimize	The area of interest for the PRS is located in an area where is necessary to study the impact on the neighborhood according to environmental regulations.
Costs	Location cost	Minimize	The location cost represents the land's sale cost, stipulated by the owner.
	Gas pipeline cost	Minimize	Represents the implantation cost of all the necessary network, including all the resources, like materials, machinery and labor.

Figure 4. Alternatives

Finally, the experts concluded that only eight alternatives were suitable for implementation, and they were also validated by the DM. Figure 4 presents the alternatives considered in the study, representing the set of alternatives, A = {S1, S2, S3, S4, S5, S6, S7}, the already existing HDPE and CS networks and the projected HDPE and CS networks for each alternative.

The problem of finding a site that meets the criteria for the construction of the secondary pressure reducing station has enabled the development of a multicriteria decision model that is meant to support the decision-making process. With the set of alternatives and the criteria, the decision matrix was identified, as observed in Figure 5.

The matrix presents the criteria, the set of alternatives, the information and the type of numerical values, which can be classified as continuous with minimization and maximization and discrete with minimization and maximization. The area criterion fits into the continuous and maximization type; CS and HDPE extensions are continuous and minimized type; neighborhood impact is discrete and minimized type; and the costs are continuous and minimization type. In addition, in the FITradeoff method the performance values of each alternative in each criterion are normalized on a scale between 0 and 1.

The performance of the alternatives to the set of criteria was obtained by gathering information and studies developed by the experts, which are the area measurements, the neighborhood impact study according to current environmental legislation, the measurements of the extension of CS and HDPE pipes and a survey about site and network deployment costs.

Figure 5. Consequence matrix

Alternatives	Criterias					
	Area (m²)	Carbon Steel gas pipeline (m)	High density Polyethylene gas pipeline (m)	Neighbor Impact	Location cost (R$)	Pipe cost (R$)
Type	1-ContMax	0-ContMin	0-ContMin	2-DiscMin	0-ContMin	0-ContMin
S1	451	280	4.210	3 - High	R$ -	R$ 1.936.000,00
S2	720	-	3.440	1 - Low	R$ 1.000.000,00	R$ 1.376.000,00
S3	1.436	1.540	2.620	1 - Low	R$ 660.000,00	R$ 2.434.000,00
S4	750	700	2.730	1 - Low	R$ 550.000,00	R$ 1.722.000,00
S5	765	2.240	1.200	1 - Low	R$ 385.000,00	R$ 2.496.000,00
S6	900	1.730	1.920	3 - High	R$ 330.000,00	R$ 2.325.000,00
S7	10.000	1.450	2.300	1 - Low	R$ 480.000,00	R$ 2.225.000,00
S8	1.549	1.680	2.750	2 - Medium	R$ 400.000,00	R$ 2.612.000,00

RESULTS AND DISCUSSION

As presented before, the alternatives of the model were defined by the experts based on technical specifications and environmental politics. Regarding technical specifications, the site should be easily operable and must not susceptible to flooding, because the PRS requires maintenance activities and an operator must have immediate access at any time to the station. Furthermore, the site must enable the interconnection of water and electric energy, to carry out operations and maintenance activities.

Regarding environmental policy, the site must have a license to build and maintain a PRS, once its implementation and maintenance modifies the environment in which it was installed, and its activities must be performed according to environmental laws. Moreover, the site must meet legal constraints, such as neighborhood area, zoning and building codes, which are specified by municipal legislations.

To enable the implementation of PRS, new carbon steel (CS) and high-density polyethylene (HDPE) networks must be built. Therefore, the site must allow the interconnection the new networks to the existing network.

Finally, the experts accomplished the procedure elimination assessment and concluded that only eight alternatives were suitable for implementation. The alternatives were also validated by the DM. Figure 4 presents the alternatives considered in the study, representing the set of alternatives, A = {S1, S2, S3, S4, S5, S6, S7}, the already existing HDPE and CS networks and the projected HDPE and CS networks for each alternative.

Having defined the alternatives of the model, the first step in the FITradeoff DSS, presented in Figure 6, is to rank the criteria scaling constants according to the DM preferences, which were: neighborhood impact, carbon steel network extension, HDPE network extension, network deployment cost, location cost and lastly, the size of the area.

The area criterion is important since the site must be a broad location, an urban void and an outdoor environment, which avoids the confinement of the natural gas and vapors of the substance that promotes natural gas odor, the mercaptan. The site must have at least 400 m² area extensions to install and allow operations and maintenance of the natural gas pressure reducing station equipment.

The criteria CS gas pipeline and HDPE gas pipeline were considered in the model because they affect the cost and their pipelines create blocking areas that promote operational security to distribution network (Figure 4).

The region of interest to install the pressure reducing station requires neighbor impact studies. So, the specialists analyzed the alternatives according to the impact of risk agents, such as, noise, constant mercaptan odor, fire, explosion and thermal radiation, which operations and maintenance activities or accidents they may generate. Lastly, the site must present lower risks to the quality of life of their resident population in the neighborhood, allowing risk management and monitoring.

The cost criterion was also considered in the model since there are budgetary constraints and the allocation of financial resources must be carried out promoting the best cost/benefit analysis.

After ordering the criteria, the flexible elicitation was performed in the FITradeoff DSS, because the optimal alternative was not defined in the method's first step. The DM compared two hypothetical situations, choosing between one of them, being indifferent to the situation, or skipping to the next cycle until the solution is found.

Figure 6. Ranking the criteria scaling constants step in FITradeoff DSS

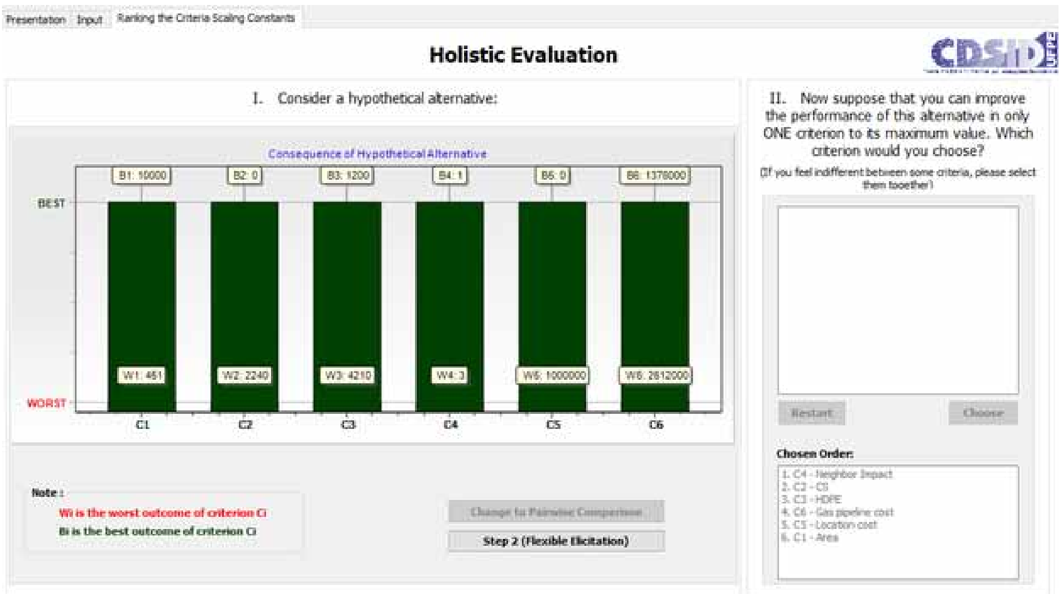


Table 3 presents the decision maker's cycles and preferences for finding the potentially optimal alternative. In each cycle, that can be seen in the Figure 7, consequence *A* represents a value x_n between the best and worst criterion value. The criterion of this consequence *A* is the most important among the pair of criteria of the hypothetical situation, which in this case presented consequences with performance of 50% of the values of the criteria that were evaluated. Consequence *B* represents the best performance of the criteria with the least weight in the criterion pair being compared in the model.

In the first cycle is observed that the neighbor impact is the most important criterion of the model and the area is the least important criterion, thus the DM's choice was the consequence *A*. In the second cycle, the neighbor impact takes priority over the length of the carbon steel network, thus the DM's choice was the consequence *B*. Finally, in the third cycle, the consequences are confirmed, since the CS network extension criterion has a greater outcome than the HDPE network extension criterion and the DM's choice was the consequence *A*. Therefore, the cognitive effort has been reduced with the answers given by the DM.

In ordering the criteria weights, the method presented a subset of five potentially optimal alternatives, excluding those with high neighborhood impact. At the end of the first cycle, the method still continued to present five alternatives in its subset. At the end of the second cycle, the method presented three potentially optimal alternatives, with an equivalence test that presented the maximum performance difference between each one, as shown in Table 3.

The FITradeoff DSS has an option to present the current numerical result for each cycle, presented in Figure 8, which shows potentially optimal alternatives and presents the maximum value and the scale constants for each criterion and graphs for analysis.

Figure 7. Flexible elicitation step in FITradeoff DSS

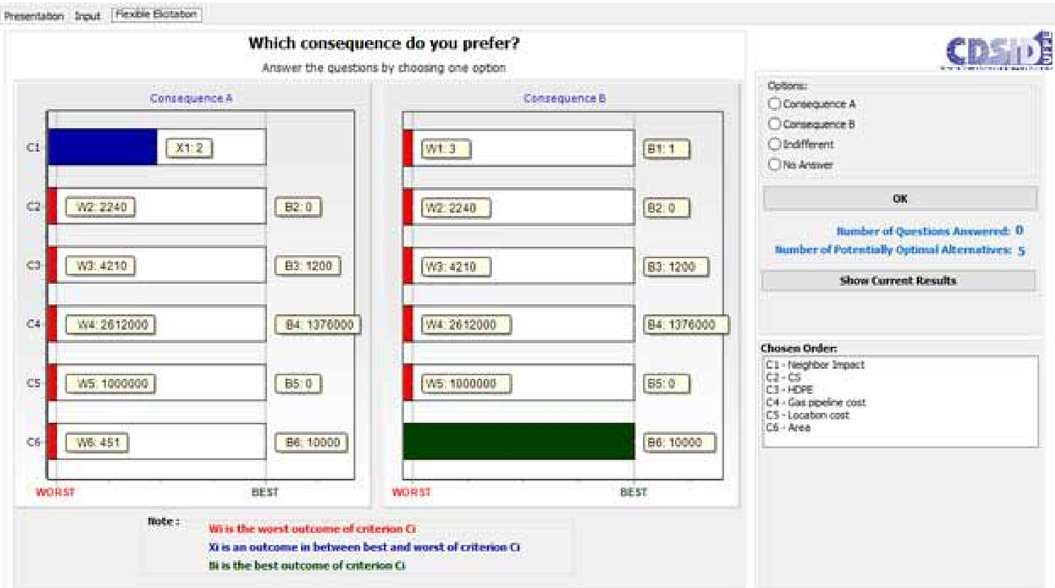
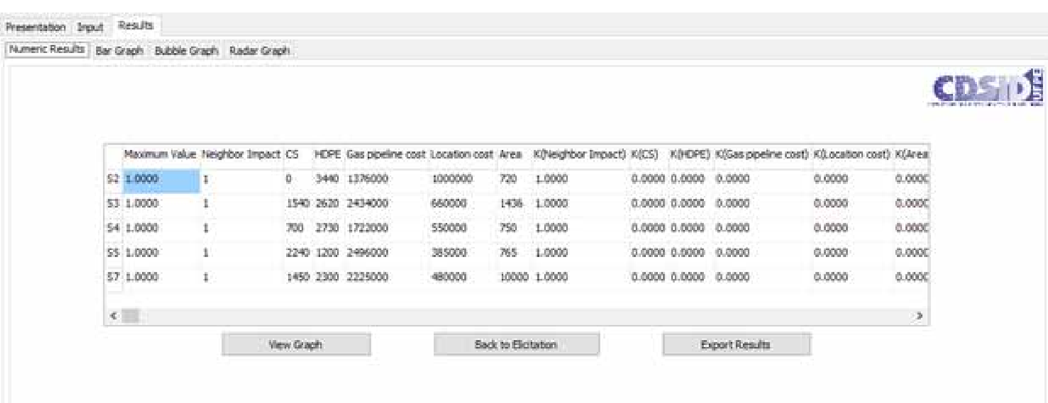


Table 3. Cycles and the inputs considered in the elicitation

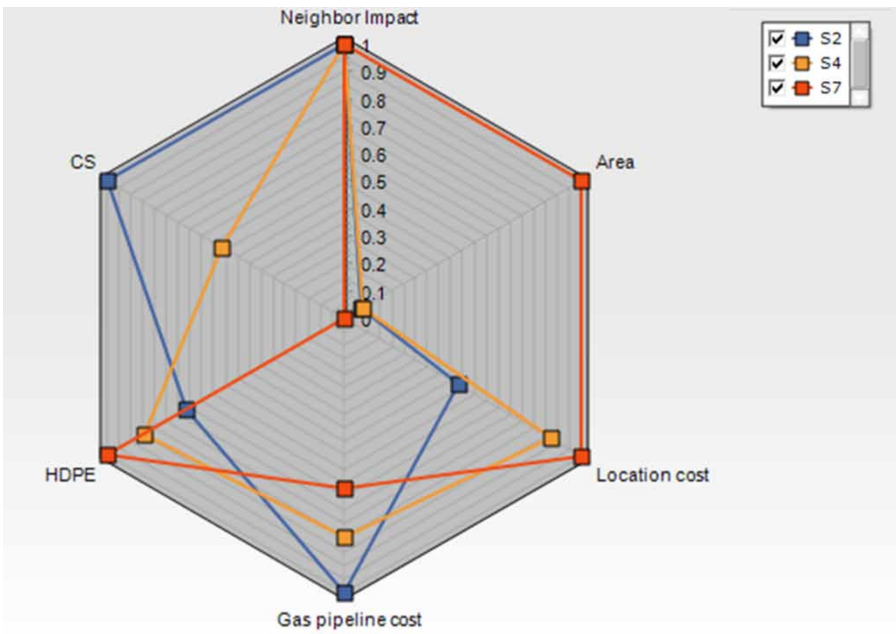
Cycle	Consequence A	Consequence B: Best of	DM's Choice	Potentially Optimal Alternatives
1	50% of Neighbor Impact	Area	A	S2, S3, S4, S5 e S7
2	50% of Neighbor Impact	Carbon Steel gas pipeline extension	B	S2, S3, S4, S5 e S7
3	50% of Carbon Steel gas pipeline extension	High Density Polyethylene gas pipeline extension	A	S2, S4 e S7

Figure 8. First cycle current results in FITradeoff DSS



The radar graph with the three potentially optimal alternatives on an interval scale, shown in Figure 9, was analyzed at the end of the second cycle. In this case, how much closer the vertex line is, better will be the alternative result value on the criterion. So, the alternative S2 is close to the values of 1 in the main criteria, which are the neighborhood impact and the CS network extension. The alternative S4 is close to value 1 only in the neighborhood impact criterion. Finally, the alternative S7 is close to value 1 in the neighborhood impact criterion, however it is not close to the second most important criterion of the model, the network extension in CS.

Figure 9. Interval scale radar chart



So, among the eight alternatives that could have been presented as an optimal solution to the multicriteria problem, the model presented the site S2 as the best alternative to implant the pressure reducing station, according to the intracriteria and intercriteria evaluations.

In analyzing the results provided by the FITradeoff DSS, it was observed that in the first step the method excluded three alternatives that had a high and medium neighborhood impact, since this criterion was classified as a priority by DM, leaving five alternatives. From these five alternatives, it can be observed that the DM chose to prioritize the network extension in CS, leaving three alternatives. Finally, the method provided the equivalence test in which the three alternatives presented small values of difference between them, which proves the robustness of the model.

From the three final alternatives, alternative S2 was obtained as the potential optimal alternative and it was found that the weight distribution patterns presented low variations. The FITradeoff results are presented in Table 4. The scale constant of the impact criterion for the neighborhood presented the highest value of 0.667, followed by the criterion of CS network extension with a value of 0.333, making the maximum value 1 for site S2. Regarding the number of criteria, it is important to take into account that even with the problem presenting six criteria, the application of this model required only three cycles to obtain more information to define the weights and to evaluate the alternatives, which shows the consistency of the preferences DM.

Therefore, we can assume that after only three comparative consequences the DSS was able to show the final answer for the problem. Due to this fact, the model does not require complete information from the DM, which demonstrates reduced cognitive effort with the answers given by him. When analyzing other multicriteria models for site selection problems (Table 1), we couldn't notice any application with these characteristics. Thus, we concluded that the FITradeoff is an interactive process; and allow to find the potentially optimal solution by ranking the scale constants of the criteria after a few cycles of comparative questions to the DM.

Table 4. FITradeoff results

Alternative	Neighbor Impact	CS	HDPE	Gas Pipeline Cost	Location Cost	Area	Maximum Value
S2	0,6667	0,333	0	0	0	0	1

Table 4 shows the HDPE gas pipeline criteria, gas pipeline cost criteria, location cost criteria and area criteria did not influence the results, since the DM prioritized the neighbor impact and CS gas pipeline criteria. The site S3 is the one with the best price, but it has the worst performance in the neighbor impact criteria and the site selected (S2) offers the third best cost, which confirms the importance to analyze other criteria in the model.

The FITradeoff method does not work with exact values for scale constants, it provides a scale constants space and within that space a search for the best compromise solution is made by the LPP model (Frej, Roselli, Araújo de Almeida & de Almeida, 2017). Figure 10 shows the scale constants space and the FITradeoff provides graphs with the maximum and minimum values that the scale constants can vary for each criterion without changing the results. The maximum to the minimum scale constants range for each criterion is: neighborhood impact (0.667-0.25); CS network extension (0.5-0.2); HDPE network extension (0.2-0); Cost of gas distribution network (0.167-0); location cost (0.143-0); and area (0.125-0).

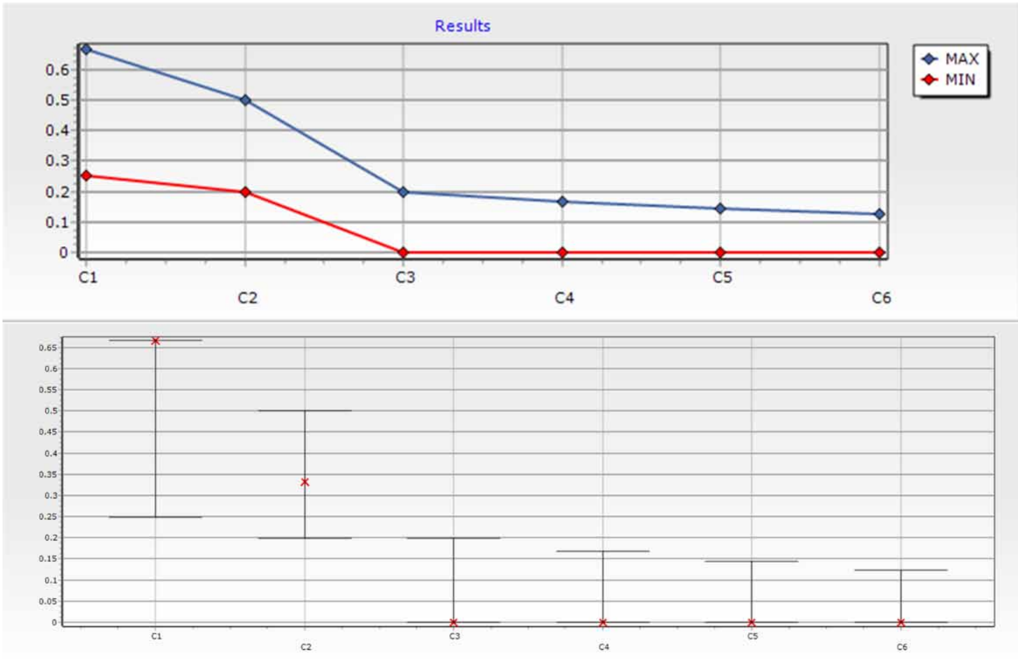
It is possible to observe that the model is reasonably robust, since the range between the maximum and minimum values of the neighborhood impact (C1) and the CS network extension (C2) criteria is considerable. Consequently, the values of the scale constants can vary significantly for these criteria and the alternative S2 is still going to be the best compromise solution. The model follows the DM preferences, even with small variations in the scale constants values of the least prioritized criteria.

Moreover, a sensitivity analysis was performed by the FITradeoff DSS, considering ten thousand iterations. For this analysis, the scale constants of every criterion were varied 10% and the S2 alternative remained 65.03% of the cases in the original subset of the simulated cases. The DSS also provides the alternatives that were included and excluded from the original subset of potential optimal alternatives during the iterations of the sensitivity analysis. For this analysis, alternative S7 is included 29.27% of the cases and alternative S4 is included 9.35% of the cases.

CONCLUSION

In the energy sector, and especially in the natural gas sector, there are several problems in selecting sites for the deployment of various types of infrastructure. Considering the increasing scenario of natural gas consumption, it is extremely important that all agents in the natural gas chain use methods that structure decision-making and problem-solving processes. Hence, this paper presented a structured

Figure 10. Variation range of scaling constant value



multiple criteria decision aiding approach for selecting a site to implement a secondary natural gas pressure reducing station.

A Decision Support System (DSS) of the FITradeoff method was used for the development of the study, in which occurs the evaluation of the eight alternatives through the elicitation of the criteria scale constants. The first step is ordination of the six criteria according to the preferences of the DM and the second step is the choice of comparative consequences in hypothetical situations. The steps of the method allow a wider understanding and evaluation by the engineering manager about the relevance of the criteria, which will be used to define an alternative that is close to reality.

The result was obtained by performing the two steps of the method. The solution was not found by executing the first step of the method, which is the ranking the constant scaling criteria, so it was necessary to execute the second step of FITradeoff, in which "*n*" hypothetical situations were presented, in which the decision maker presented consistency in his preferences when asked questions.

A sensitivity analysis performed by the FITradeoff DSS allowed to demonstrate the robustness of the model, since the recommended alternative remained 65.03% of the cases in the original subset of the simulated cases, when varying the scale constants of the model.

It was possible to verify that the FITradeoff method has an intuitive applicability, due to the fact that the model does not require complete information from the DM. The method is an interactive process; it finds the potentially optimal solution by ranking the scale constants of the criteria and some cycles of comparative questions to the DM.

The exposed problem presents some complexity because it's important that the chosen site is strategical, given that the project must promote the operational stability of the natural gas distribution network and allow the gas supply to a new area, which presents a long term commercial and housing development. Due to this reason it's important to perform deeper studies about the viability of the implantation of the ERS, including commercial parameters, like the number of potential clients and gas volume to be supplied to these clients.

Lastly, it's important to highlight that decision problems like the one presented in this article are common in other natural gas distribution companies. Thus, this study could be replicated or be used as a base for other companies to avoid taking decisions in an empirical way, making the strategic planning inefficient.

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Carolina Lino Martins is an assistant professor of management engineering at Federal University of Mato Grosso do Sul. She holds a PhD in Computer Science from Université Toulouse 1 Capitole and a PhD in Management Engineering from Universidade Federal de Pernambuco. Founding coordinator of the Institute of Information Systems ans Decision Aiding Methods (IISDAM) and member of the Modelling and alignment of portfolio and strategy (MAPS) research group. Her research interests include Multiple Criteria Decision Making/Aid and Decision Support Systems.