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PRIORITIZATION OF TELECOMMUNICATION PROJECTS: DECISION ANALYSIS USING THE PROMÉTHÉE V METHOD

PRIORIZAÇÃO DE PROJETOS DE TELECOMUNICAÇÃO: ANÁLISE DE DECISÃO COM O USO DO MÉTODO PROMÉTHÉE V

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ABSTRACT

This article presents an application of the multicriteria method PROMÉTHÉE V to the problem of prioritizing telecommunication projects. The study was conducted inside of a major telecommunications company in Brazil. The adherence to a multicriteria approach allowed for taking into consideration technical as well as non technical evaluation criteria. Using PROMÉTHÉE V was particularly appropriate not only because the method performed an initial ranking of the set of projects, but also because it led to a constrained optimization of the obtained selection. It is then concluded that the application of PROMÉTHÉE V to the problem in question achieved its key purpose in the sense of organizing and solving a complex process of decision analysis. It also provided for interactivity during the analysis and useful simulations, giving transparency to the analysis and thus providing for a common base of understanding for all involved.

Keywords: Compensatory methods; Outranking methods; Multicriteria Decision Aiding; Project selection; Net flows; Decision Analysis.

RESUMO

Este artigo apresenta uma aplicação do método multicritério PROMÉTHÉE V a um problema de priorização de projetos de telecomunicações. O estudo foi conduzido dentro de uma grande empresa de telecomunicações no Brasil. O emprego do enfoque multicritério permitiu a análise de um problema altamente técnico de engenharia, com restrições não técnicas associadas à futura carteira de projetos. O uso do método PROMÉTHÉE V foi particularmente adequado, uma vez que este produz uma ordenação das alternativas, levando posteriormente à otimização sob-restrições do conjunto de projetos selecionados. Conclui-se que a aplicação do método PROMÉTHÉE V para o problema em questão atingiu sua finalidade principal, no sentido de abordar um processo complexo de análise de decisão com interatividade e permitindo simulações úteis. Alcançou-se desta forma, com transparência, um resultado que proporcionou uma base comum de compreensão para todos os envolvidos.

Palavras-chave: Métodos compensatórios; Métodos de superação; Apoio Multicritério à Decisão; Seleção de projetos; Fluxos líquidos; Análise de Decisão.

1. Introduction

The decision on the allocation of funds to a portfolio of projects can take up a lot of time and work, normally involving the top management of a large company and, in most cases, time is scarce for making decisions (KEISLER, 2004), as well as the funds available. In the specific case of telecommunications projects, this choice is particularly difficult due to the relationship between the projects in the portfolio, meaning that the decision on one item has an influence on the selection of the others. The approach in this article then deals with the creation of a process which facilitates the performance of the agents involved in the decision, constructing a model which permits the choices to be made in a systematic manner, so as to obtain the prioritization of the portfolio according to multiple criteria of common understanding.

The problem in question deals with a decision on the prioritization of projects of a telecommunications company that owns the largest telecommunications network in Brazil, including fiber-optics, underwater cables, satellites and highly qualified professionals. The study presented in this article was carried out as part of its 2008 strategic planning process. In the analysis of projects to be implemented, a survey is made, for the requirements supplied, about the situation of the current installed plant and the expansions already planned in ongoing projects and a comparison is made between that situation and the requirements. The basic question which arises at this moment is that the quantification of the requests usually leads to a sum well above the limit fixed for investment. The company has limited resources for investments and therefore it is highly necessary to allocate resources in a efficient way. In this situation, projects are analyzed individually, with occasional reductions being put into effect. In the current process there is not a clear definition of the criteria according to which the successive cuts are processed. Concerning the resources that have previously been made available for investment the projects are defended without the possibility of inserting, in groups, each project in a category which permits a comparison between the costs and benefits of the projects. As a result of the recurrences in this process, historically a final number is reached which normally is between 20% and 30% in excess. From this point a proportional reduction is carried out in all the items proposed so as to reach the limit.

Thus the objective of this article is to present a multicriteria methodology to prioritize telecommunications projects in the presence of multiple criteria, both qualitative and quantitative. The multicriteria method PROMETHEE V will be the analytical tool behind that methodology. For this purpose, a set of criteria accepted by the participants in the process is defined, against which the alternatives will be judged. The set of alternatives is structured in groups of projects and the interdependence among these groups analyzed by means of a multicriteria decision aiding method which makes it possible to prepare a plan of investments containing all the prioritized alternatives. This prioritization occurs from the viewpoint of the engineering strategy with later submission to other business restrictions, organizing and documenting the process in such a way as to guarantee, in future reviews, the complete recovery of the original plan and the decisions made.

The prioritizing of projects is a recurrent issue in the reality of companies. If resources are unlimited, the planners could opt to start all the projects and, as in a bet, wait to see to which ones the market will react most favorably (BRACHE, BODLEY-SCOT, 2006). The choice of criteria for prioritizing projects is intimately connected to portfolio management. According to Cánez and Garfias (2006), the construction of a portfolio of projects is essential, as the individual evaluation can lead to problems of imbalance of results in the short and long term (CÁNEZ, GARFIAS, 2006). While portfolio management is addressed in diverse ways when writing on the subject, the criteria for the classification of projects and their consequent ranking can be grouped in two categories: quantitative and qualitative (CÁNEZ, GARFIAS, 2006). It is usual to identify financial analysis in the quantitative approach, with its recognized indicators: net present value (NPV); internal rate of return (IRR); and payback.

Nevertheless, evaluating projects only from a financial point of view has been shown to be insufficient because it neglects other factors, whether quantitative or qualitative, which can have a strong impact on the results. The criteria used to prioritize the projects normally belong to one of the following categories (BRACHE, BODLEY-SCOT, 2006): alignment with the strategy; sales growth; establishing competitive advantage or elimination of a competitive disadvantage; increase in customer satisfaction; reduction in costs; retaining employees and improving their satisfaction; and meeting regulatory requirements.

The research question to be answered is therefore the following: which projects should be selected taking into consideration multiple objectives and the related decision-makers’ preferences? By pursuing this research the company will allocate its resources in an efficient way according to their availabilities for investing in the period.

2. Multicriteria Decision Support

By decision we understand the process by which a choice is arrived at for at least one alternative from among various candidates (BELTON, STEWART, 2002). According to Clemen and Reilly (2001), decisions are difficult due to their natural complexity, inherent uncertainty, conflicting objectives and results dependent on different perspectives. The study of decision making includes diverse disciplines, such as mathematics, sociology, psychology, economics and political science, merely to mention the most relevant (BUCHANAN, O'CONNEL, 2006). Although decision makers have good reasons to trust their instincts and even considering that their way of working has, according to Mintzberg (1997), more to do with creativity and synthesis, the declared dichotomy between instinct and reasoning is, to a great extent, false (MINTZBERG, 1997). In spite of the mystique of instinct, in real life few decision makers neglect to make use of valuable information when they can have access to it. In fact, it is rare to manage to make decisions based solely on instinct. The decision analysis process essentially serves as the instrument to help the decision agent (CLEMEN, REILLY, 2001).

Decision-making also deals with which type of problem merits a methodological analysis that justifies the relation between the cost (time spent, complexity, involvement of various people, etc.) and the benefit expected of having a more transparent process and which may, as well, be used in similar situations in the future.

When studying the role designed for decision analysis as a tool for decision aid, in no way can decision analysis be thought of as something that produces results by itself. The three main myths associated with this analysis are: *i.* supplying the correct answer; *ii.* removing the responsibility from those who decide; and *iii.* eliminating the suffering from the process (BELTON, STEWART, 2002). As subjectivity is inherent to the decision process, particularly in the presence of multiple, conflicting criteria, the main role of analysis is to make the understanding of the problem in question, with all the variables and actors involved, evident to those involved in the decision making process. Additionally, a good analysis must focus on the controversies, discovering the differences of values and uncertainties, facilitating committed debate and eliminating rhetorical discussions (KEENEY, RAIFFA, 1993).

Basically two great schools of thought were developed for the methods related to multicriteria decision support (GELDERMAN, RENTZ, 2000): *i*. The compensatory methods, which assumes the condition of a perfect conception on the part of the decision maker of the utility of the scores of each alternative and the weights of each criterion. Those methods support the concept of transitivity, that is, if a is better than b and b is better than c, then a is better than c, as the basic premise (POMEROL, BARBA-ROMERO, 2000). Major examples of compensatory methods are Multiattribute Utility Theory (KEENEY, RAIFFA, 1993), and AHP (Analytic Hierarchy Process) (SAATY, 1980); and *ii*. The outranking or non-compensatory methods, which emphasize the limitations of the objectivity of the decision maker. Examples of outranking methods are: ELECTRE (***EL**imination **E**t **C**hoix **T**raduisant la **RÉ**alité*), including all the methods of the family from the initial ELECTRE I (ROY, BOUYSSOU, 1993), proposed by Roy in 1968, and PROMÉTHÉE (***P**reference **R**anking **O**rganization **MÉTH**od for **E**nrichment **E**valuations*), and all their variants, (BRANS, MARESCHAL, 2002). The outranking methods also permit the concept of non-comparability; in other words, certain alternatives cannot be compared. Different methods can represent diverse approximations on the decision making process (OZERNOY, 1992). Basically, the various methods differ from each other in how they structure the problem, and from this, how they establish measurements for the actions and the criteria weights.

The MAUT (***M**ulti-**A**ttribute **U**tility **T**heory*) method (CASTANHAR, GOMES, 2006) has the advantage of being based on Utility Theory, determining preferences as utility functions, with a strong mathematical base applicable to various complex multicriteria decision making problems (KEENEY, RAIFFA, 1993). Its major drawback comes from its tendency to objectify all subjectivities, which may lead to situations in which the mathematical model can distort the real problem (BELTON, STEWART, 2002). The principal advantage of the AHP method, in turn, is its facility to clarify the problem, as a result of hierarchical decomposition, thus permitting an easier understanding and evaluation on the part of those involved. Its main disadvantage is that the evaluations can lead to inconsistencies in the hierarchy of the criteria, as the relative position of the alternatives can alter, as a result of the inclusion or withdrawal of an alternative (POMEROL, BARBA-ROMERO, 2000). There are various other multicriteria methods which are available in the specialized writing on the subject, although those mentioned above are historically the most important (BELTON, STEWART, 2002).

In the case of the classic outranking methods, the main questioning in relation to the ELECTRE family is related to the determination of the limit of concordance and the limit of discordance. As regards the PROMÉTHÉE family, its authors (BRANS, MARESCHAL, 2002) cite the need to understand the preference functions so that the method can be implemented correctly. In this methodology, indifference and preference thresholds can be considered according to the preference function employed to represent the criteria. PROMÉTHÉE V offers the possibility of analyzing problems with segments submitted to restrictions (OZERNOY, 1992). These questions are present in the current scenario, such as restrictions regarding the quantity of projects, geographical distribution, and budgetary limitations. This facility, allied to the existence of support software, justified the choice of this method for the solution of the problem under analysis. The methods related as follows, with their respective objectives (BRANS, MARESCHAL, 2002), belong to the PROMETHEE family methods: PROMÉTHÉE I: partial pre-ordering, selection problem; PROMÉTHÉE II: complete pre-ordering, ranking problem; PROMÉTHÉE III: complete pre-ordering, with amplification of the notion of indifference; PROMÉTHÉE IV: complete or partial pre-ordering, continuous set of solutions; PROMÉTHÉE V: complete pre-ordering, with restrictions of segments; and PROMÉTHÉE VI: complete or partial pre-ordering, degrees of difficulty in weights (BRANS, VINCKE, MARESCHAL, 1986).

2.1 The PROMETHEE II Method

PROMÉTHÉE methods are designed to solve all the multicriteria problems according to the function: Max $\{f_1(x), f_2(x), f_3(x), ..., f_j(x), ..., f_k(x), |x \in A\}$, with, *A* the finite numbered set of *n* potential alternatives; $f_j(.)$, for *j* varying from *1* to *k*. The *k* criteria can have their own units, and the general case considers the possibility of minimizing the criteria, as in Table 1, which includes *n.k* evaluations (BRANS, MARESCHAL, 1992).

PROMÉTHÉE methods seek a relation of outranking which takes into account the set of criteria proposed. For each pair of alternatives, a general degree of preference of one over the other is established for any particular criteria *j*, so that the actions between any two pairs *a* and *b* can be associated to a relation of natural dominance (*I*, *P*), *I* – signifying indifference and *P* preference, as represented by the relations: $f_i(a) > f_i(b) \Leftrightarrow aP_ib$, and $f_i(a) = f_i(b) \Leftrightarrow aI_ib$, respectively.

Table1 - Evaluation of *n* Alternatives by *k* Criteria

Alternatives	Criteria					
	$f_1(\cdot)$	$f_2(\cdot)$	. . .	$f_j(\cdot)$	. . .	$f_k(\cdot)$
a_1	$f_1(a_1)$	$f_2(a_1)$	. . .	$f_j(a_1)$	. . .	$f_k(a_1)$
. . .	. . .	. . .	. . .		. . .	
a_i	$f_1(a_i)$	$f_2(a_i)$	. . .	$f_j(a_i)$	. . .	$f_k(a_i)$
. . .	....	....	. . .	....	. . .	....
a_n	$f_1(a_n)$	$f_2(a_n)$	. . .	$f_j(a_n)$	. . .	$f_k(a_n)$

Considering that $d_j(a,b) = f_j(a) - f_j(b)$, the relation of dominance can be considered very poor or even erroneous by the decision maker, as it is only concerned with a positive or negative signal, not taking into account the amplitude. In order to give greater consistency to the relation of dominance, a P_j function is created to determine the degree of preference of action *a* in relation to action *b* in function of $d_j(a,b)$, in other words: $P_j(a,b)$ in function of $[d_j(a,b)]$. With the premise of the normalized degree so that: $0 \leq P_j(a,b) \leq 1$, $P_j(a,b)$ is represented as a decreasing function which is annulled for $d_j(a,b)=0$, as in Figure 1.

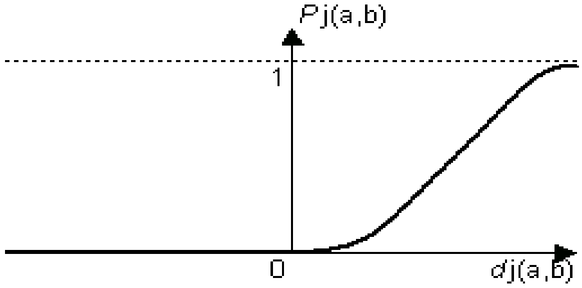

Figure 1 - Preference functions P_j (...,...)

It is observed that, when $[d_j(a,b)] \leq 0$, $P_j(a,b) = 0$, it does not mean that $P_j(a,b)$ cannot be positive. Function $H_j(d_j)$ in Figure 2 covers with greater clarity the zones of indifference and weak preference.

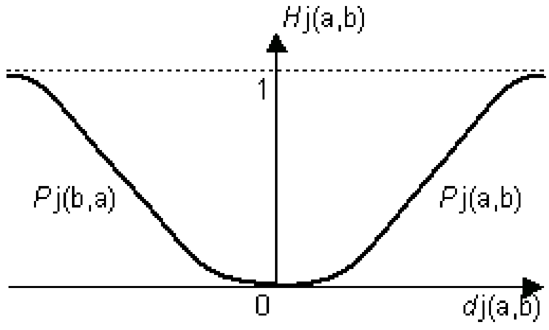

Figure 2 - Preference functions H_j (...,...)

Once the preference functions have been defined, a table of the evaluation of all the alternatives can be obtained with the following data: $\forall j,\ \forall a,b \in A$: $\{f_j(a), f_j(b) \rightarrow f_j(a), f_j(b), P_j(a,b)\}$. Thus, $H_j(a,b)$ is determined in function of $P_j(a,b)$ and of $d_j(a,b)$. If $d_j(a,b) \geq 0$, one has $P_j(a,b)$, and if $d_j(a,b) \leq 0$, $P_j(b,a)$.

Considering $w_j>0$, $j=1, 2, 3,..., k$, the weights representing the relative importance among the criteria, the equation (1) is reached:

$$\pi(a,b) = \sum_{j=1}^{k} P_j(a,b).w_j \qquad (1)$$

where the equation (2) is used to normalize the values of the criteria weights:

$$\sum_{j=1}^{k} w_j = 1 \qquad (2)$$

The authors of PROMÉTHÉE II propose six types of preference functions that can be used (BRANS, MARESCHAL, 2002). Establishing the weights w_j is of great importance. It is suggested that the decision maker adopts, as a starting point, an equitable distribution and from there go on to progressively fix the weights, by means of a sensitivity analysis.

PROMÉTHÉE methods present this interactive characteristic and, as shown later, the visual analysis of GAIA also performs an important role in this requirement. Having created the function $\pi(a,x)$, the objective is to establish an evaluation of the relationships of outranking of a in relation to the other alternatives x. Three outranking flows are defined: the outflow, according to the equation (3), where a outranks the n-1 actions – represents the force of a; the input flow, according to the equation (4), where a is outranked by the n-1 actions – represents the weakness of a; and the net flow, according to the equation (5), which expresses the balance of the input and output flows of the action a:

$$\phi^+(a) = \sum_{x \in A} \frac{\pi(a,x)}{(n-1)} \qquad (3)$$

$$\phi^{-}(a) = \sum_{x \in A} \frac{\pi(x,a)}{(n-1)} \quad (4)$$

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a) \quad (5)$$

In this way, with the use of equation (5), PROMÉTHÉE II manages to determine the ranking of the alternatives present in the analysis.

2.2 The GAIA Plan

The GAIA (***G**eometrical **A**nalysis for **I**nteractive **A**ssistance*) plan is a method by which it is possible to describe and visualize the data of PROMÉTHÉE methods interactively, in such a manner that it completes in a harmonious way the analysis of the results. The information related to a decision problem with k criteria can be represented in a k-dimensional space (BRANS, MARESCHAL, 2002). In the GAIA plan, points are projected which represent: *i.* Actions $\alpha_i(\phi_1(\mathrm{a_i}), \phi_2(\mathrm{a_i}), \phi_3(\mathrm{a_i}), ..., \phi_n(\mathrm{a_i}))$, such as A_i (i=1, 2, ..., n); *ii.* Criteria c_j (j=1, 2, ..., k); and *iii.* The vector of weights w: (w_1, w_2, w_3, ..., w_k), projected as the decision axis, which points towards actions with better net flows in the evaluation of alternatives. As the weights are modified, only the decision axis is altered, which provides a visualization of the sensitivity of the actions to the weights.

The parameter δ makes it possible to measure the percentage of information preserved in the projection on the plan. In the majority of real-world applications, the value of δ is higher than 80%. Figure 3 shows an example of the visual representation in the GAIA plan for the case of 12 actions and 6 criteria.

The following conclusions can be obtained in the GAIA visualization: *i.* Actions with close projections have similar performances in the set of criteria; *ii.* If the image of an action is situated in the direction of certain criteria axes, its performance is better in relation to the respective criteria; *iii*. Actions are non-comparable (or compared with difficulty) if they are situated in opposite directions in the plan such as, for example, the groups of actions marked in Figure 3; *iv*. The size of the vector π (decision axis) is inversely proportional to the conflict of the criteria; and *v*. The action will be better the more distant it is, in the direction of the decision axis π.

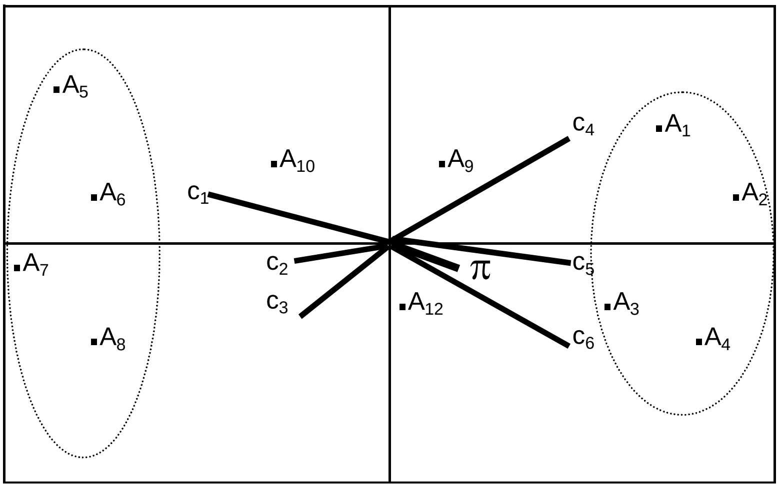

Figure 3 - Visualisation of the actions, criteria and decision axis.

2.3 The Support Software for PROMÉTHÉE

Two support softwares have been developed, PROMCALC and DECISION LAB (BRANS, MARESCHAL, 2002). The second option was adopted for use in this work, due to the possibility of the graphic interface *Windows*. Since no integrated software has been made available for applying PROMÉTHÉE V yet, the software *LINDO* (***L****inear* ***I****nteractive a****ND*** ***D****iscrete* ***O****ptimizer*) (LINDO, 2011) was used, with resources for integer linear programming. The software DECISION LAB (VISUAL DECISION, 2011) allows the data to be generated in a spreadsheet, classifying the actions according to the PROMÉTHÉE I and II methods, analyzing the data in GAIA, carrying out sensitivity analyses.

2.4 PROMETHEE V Method

This is designed to solve problems of the type of the following equation: $Max\ \{f_1(a_i), f_2(a_i), f_3(a_i), ..., f_j(a_i), ..., f_k(a_i), \mid a_i \in A, i=1, 2, , ...,n\}$, in which additionally the alternatives are submitted to restrictions of segmentation (BRANS, MARESCHAL, 2002). In this way, PROMÉTHÉE V includes two stages:

i. Step 1: the problem is solved by PROMÉTHÉE-GAIA without considering the question of restrictions. By applying the resources of the method the flows of net dominance are obtained $\phi(a_i)$; and *ii*. Step 2: the segmentation restrictions are introduced, preparing an integer linear programming with the objective of reaching the maximization of the flows (1) under constraints (2) and (3):

$$Max \quad \{\sum_{i=1}^{k} \phi(a_i) x_i\} \tag{1}$$

Subject to

$$\sum_{i=1}^{n} \lambda_{p,i} x_i \approx \mathrm{B}_p \qquad p = 1,2,\ldots,P \tag{2}$$

$$x_i \in \{0,1\} \qquad i = 1,2,\ldots,n \tag{3}$$

The coefficients of the objective function (1) are the net outranking flows. Constraints (2) concern each decision problem. After having solved the {0, 1} linear program, a subset of alternatives satisfying the constraints and providing as much net flow as possible is obtained (BRANS, MARESCHAL, 2002).

Although a number of applications of PROMÉTHÉE methods have been published in the Brazilian Operations Research literature (CAVALCANTE, ALMEIDA, 2005; MORAIS, ALMEIDA, 2006; MORAIS, CAVALCANTE, ALMEIDA, 2010), practically no uses of PROMÉTHÉE V to real problem solving have appeared so far.

3. **Case Study: Preparation of an Investment Plan**

The set of projects to be evaluated in the year 2008 are presented in Table 2. The codified projects such as BB IP and TL are presented in the form of alternatives. Any combination of these projects is accepted, though only one can be chosen, and for each combination there is a corresponding TR Project. Due to the nature of the network, these projects are not divided by region. The projects numbered from 9 to 16 in the table are designed to meet needs specific to the regions. From the technical point of view any project in this set can be selected for execution. In Table 2, the Value 2008 criteria (value of the project in 2008), Value 2009 (value of the project in 2009), Total. (total), A.I. (annual income), and A.E. (annual expenses) are represented in a scale of millions of *reais* (the Brazilian currency real is denoted by R$, where US$ 1.00 was equivalent to R$ 1.67 when the case study was performed).

Table 2 - Initial Proposal for the 2008 Plan

Alter.	Description	G.	R.	Value 2008	Value 2009	Total	A.I.	A.E.	D.I.	Inn.
A_1	BBIPALT1	A	All	150	20	170	102.0	5.1	5	7
A_2	TLALT1	A	All	50	15	65	43.3	2.6	4	6
A_3	BBIPALT2	A	All	205	25	230	110.4	3.3	7	9
A_4	TLALT2	A	All	80	20	100	60.0	3.0	6	8
A_5	TRTL1BB1	A	All	80	20	100	54.5	2.7	4	6
A_6	TRTL1BB2	A	All	100	30	130	57.8	2.9	4	6
A_7	TRTL2BB1	A	All	90	23	113	59.0	2.9	4	6
A_8	TRTL2BB2	A	All	120	40	160	66.2	2.0	6	9
A_9	COT1RG1	B	1	20	8	28	28.0	2.2	3	3
A_{10}	COT2RG1	B	1	30	10	40	32.0	2.2	5	5
A_{11}	COT1RG2	B	2	12	3	15	13.8	1.4	2	3
A_{12}	COT2RG2	B	2	20	5	25	17.6	1.6	4	6
A_{13}	COT1RG3	B	3	50	10	60	80.0	4.8	2	3
A_{14}	COT2RG3	B	3	60	15	75	75.0	3.8	3	6
A_{15}	COT1RG4	B	4	25	5	30	30.0	2.7	3	3
A_{16}	COT2RG4	B	4	30	8	38	32.6	2.6	6	6
A_{17}	LEGE1	C	All	15	2	17	22.7	2.3	2	3
A_{18}	TRANSPD	C	All	5	3	8	8.7	0.9	4	3
A_{19}	VAD1	D	All	8	2	10	20.0	1.6	5	4
A_{20}	VAD2	D	All	12	2	14	18.7	1.3	6	5

Alter. – alternative; G – Group; R – Region; Value 2008 – value of the Project in 2008; Value 2009 – value of the Project in 2009; A.I. – Annual Income; A.E. – Annual Expenses; D.I. – distribution of investment; Innov. – Innovation. The second column ('Description') contains the list of projects as they are denoted by the company.

The LEGE1 and TRANSPAD projects are interdependent. This does not mean that it does not make sense to select only one of them. The company has indeed imposed this constraint in the proposal of these two projects. In the classification of the groups of projects it is considered that the projects from group *A* are to attend to core business. One, and only one, combination of the projects BB IP, TL and TR must be chosen. Group *B* contains the regionalized projects. Any combination can be selected. Those in group *C* are projects already planned, and must be selected as a set. Finally, group *D* refers to added value projects, of which only one projected should be selected. The following additional restrictions must be considered in the proposal: *i.* The total value of the investment in 2008 cannot surpass R$800 million; *ii.* The value of the carry-over for 2009 cannot be above R$150 million; *iii.* Each region must be considered with at least one programme from the regional group; *iv.* The expense associated with the execution of the projects cannot surpass R$30 million; *v.* The total income of all the programmes of the selected projects must be above R$550 million; *vi.* The number of programmes must not be less than 10 and not above 15.

3.1 Criteria and weights for the evaluation of the alternatives

In this evaluation the criteria which presented a vision of the technological strategy were selected for evaluation. The basic concepts used for the criteria of a technical nature are based on the list of major criteria presented in a publication of the New York State Office of Technology (NYSOT, 2002). That list led to the following criteria: Strategic Alignment; Difficulty of Implementation; Innovation; Environmental Impact; Sales Growth; Competitive Advantage; Customer Satisfaction; Employee Satisfaction; and Operational Security. Considering these concepts and the information from the stakeholders, three criteria were selected to be employed in this evaluation: *i.* Strategic Alignment; *ii.* Sales Growth; and *iii.* Competitive Advantage.

The prioritization and weights of the criteria were done by means of research with thirteen stakeholders, from the level of technical managers to directors. Priority 1 was attributed to the most important criterion and 9 to the least important. A scale of 1 to 10 was used for the definition of the criteria weights, representing the increasing order of the weights. The weights must be referenced to the criterion with the highest weight (10), it being possible to repeat the numbers. A degree of precision was attributed to each criterion reflecting the knowledge which the individual involved had in relation to obtaining the data, attributing the scores: 1-inexistent data; 2-low precision; 3-average precision; 4-high precision; and 5-absolute precision. The score attributed to precision is a relevant factor to determine the importance and weight of the criterion, as it measures the quality of the data available. Based on the priorities and weights given to the criteria by each evaluator, a compilation of the results weighted by precision was made, as shown in Table 3.

A more conservative attitude was adopted for establishing the weights, with a variation of one unit starting from the most important, due to the imprecision of the data. The criteria of innovation and difficulty of implementation also had a high frequency with adjusted priority of 5.38 and 7.1 respectively. The chosen preference function was of type III, adequate for operational criteria, according to HERMAN (2007). The threshold ***p*** starting from which the decision maker considers the preference to be strict was defined for Strategic Alignment as 3; Sales Growth as 2; and Competitive Advantage as 2. Table 4 presents the matrix of evaluation of the alternatives in relation to the criteria used in this evaluation.

Table 3 - Compilation of Criteria and their Weights

Criteria	Priority			Weight		
	SD	AJ	ADT	SD	AJ	ADT
SA	2.31	2.14	1	9.54	10.29	10
SG	3.31	4.02	2	9.36	7.79	9
CA	3.23	4.34	3	8.62	6.42	8

SD – means average; AJ – means adjusted values; and ADT – means adopted values.

3.2 Processing of PROMETHEE II by Decision LAB

The values of the alternatives proposed for the selected criteria, as well as the weights, preference functions and thresholds are introduced in DECISION LAB, in the form of their codes A_1 to A_{20}. The execution of the command *View*, option *Rankings*, presents the results of the ranking of the net flows of the alternatives.

Table 4 - Evaluation Matrix

Alternatives	Strategic Alignment	Sales Growth	Competitive Advantage
A_1	8	7	9
A_2	8	7	10
A_3	10	9	7
A_4	10	9	8
A_5	6	6	7
A_6	7	9	6
A_7	8	7	6
A_8	9	9	9
A_9	6	5	4
A_{10}	7	8	5
A_{11}	6	5	5
A_{12}	7	7	4
A_{13}	6	5	7
A_{14}	7	9	6
A_{15}	6	5	3
A_{16}	7	8	4
A_{17}	5	3	8
A_{18}	5	3	6
A_{19}	8	7	7
A_{20}	9	8	8

Using the software GAIA, a check was made that the projection of the parameter δ was equal to 95.55%, achieving the minimum of 80% for the proportion of information preserved in the projection on the plan.

3.3 Sensitivity Analysis of PROMETHEE II

The sensitivity analysis of the results was performed in relation to the weights, thresholds and preference functions, with the purpose of evaluating the alterations due to fluctuations in the values of those variables. Five additional options to the scenario were analyzed for the weights, in which results were obtained, namely: Uniform: considering all the weights distributed equally (C_1=C_2=C_3); Research: weights with average values close to those found in the research (C_1=10, C_2=8, C_3=6); Reduction: reducing the values of the criteria of least weight (C_1=10, C_2=6, C_3=4); Inversion 1: greater importance to the second criterion (C_2=10, C_3=9, C_1=8); and Inversion 2: greater importance to the second criterion and reduction for the others (C_2=10, C_3=8, C_1=6).

The results processed in DECISION LAB show that in all the scenarios tested, the net flows are not significantly altered, demonstrating a trend of small alterations in the order of the alternatives and values of the flows, implying the consistency of the results obtained with the weights selected when they are evaluated in relation to other scenarios judged to be probable. For the analysis in relation to the preference thresholds and generalized criteria in comparison with the scenario used, another four evaluations were carried out, for the scenarios denominated below: *i*. Minimum III**:** preference thresholds for all the criteria equal to 1, maintaining criterion III; *ii*. Maximum III: stipulating as the preference threshold for each criterion the maximum divergences of the scores attributed in the values given to the attributes, maintaining the generalized criterion III; *iii*. Result V: using the same preference thresholds of the scenario used in the result, but adopting the generalized criterion V, with an indifference threshold q=1 for all the criteria; *iv*. Standard V: software standard preference thresholds for the criteria C_1, C_2 and C_3, with indifference thresholds respectively equal to 1, 2 and 3 and preference thresholds with the maximum variations; and *v*. Criterion V was chosen for simulation based on the fact that criterion III deals with a specific case of the same type. No significant variations in the ranking were found, confirming the relative changes already checked in the variations of the weights. The minimum scenario presents the greatest dispersion of the net flows, and the standard scenario the largest ones, justified by the calculations of the global preferences.

3.4 Processing of the data by PROMÉTHÉE V

In this stage the net flows of PROMÉTHÉE II are submitted to the restrictions in an integer linear programming problem using the software LINDO. The objective function of this linear programming problem seeks to maximize the net flows multiplied by each alternative. The restrictions of this problem were described in the previous items. The optimum solution was found after 111 interactions.

The selected projects with their codes are those shown in Table 5, with their respective values for the verification of the restrictions, confirming that the selected programmes satisfy them.

The sensitivity analysis of the results was carried out in relation to the weights, thresholds and preference functions, with the aim of evaluating the alterations due to fluctuations in the values of these variables. For the analysis of the weights five additional options to the scenario were analysed, in which results were obtained, namely: Uniform: considering all the weights distributed equally (C_1=C_2=C_3); Research: weights with average values close to those found in the research (C_1=10, C_2=8, C_3=6); Reduction: reducing the values of the criteria of least weight (C_1=10, C_2=6, C_3=4); Inversion 1: greater importance to the second criterion (C_2=10, C_3=9, C_1=8); and Inversion 2: greater importance to the second criterion and reduction to the others (C_2=10, C_3=8, C_1=6).

In Table 5, the criteria V.8 (value of the project in 2008), V.9 (value of the project in 2009), Tot. (total), A.I. (annual income), and A.E. (annual expenses) are represented in a scale of millions of reais (the Brazilian currency real is denoted by R$, where 1 US$ was equivalent to R$ 1.67 when the case study was performed).

3.5 Sensitivity Analysis of PROMÉTHÉE V

In the analysis of the final results of the method, the sensitivity of the method to variations of the restrictions was tested. In the current case, it was judged to be more important to evaluate the scores related to the distribution of the annual investments, because of their importance in the framing of the projects, and the questions related to the degrees of difficulty of implementation and innovation, because they enrich the premises used in the choice of projects, leading to improvements in the process.

Table 5 - Results

Alternatives	Region	Value 2008	Value 2009	Total	Annual Income	Annual Expense
A_3	All	205	25	230	110.4	3.3
A_4	All	80	20	100	60.0	3.0
A_8	All	120	40	160	66.2	2.0
A_9	1	20	8	28	28.0	2.2
A_{10}	1	30	10	40	32.0	2.2
A_{12}	2	20	5	25	17.6	1.6
A_{13}	3	50	10	60	80.0	4.8
A_{14}	3	60	15	75	75.0	3.8
A_{16}	4	30	8	38	32.6	2.6
A_{17}	All	15	2	17	22.7	2.3
A_{18}	All	5	3	8	8.7	0.9
A_{20}	All	12	2	14	18.7	1.3
Total		647	148	795	551.9	29.97

Region – region of activity of the companies; Value 2008 – 2008 values; Value 2009 – 2009 values; Total – total investment.

With regards to the financial restrictions, a solution is sought in which, maintaining the total value of investments as R$ 800 million, the maximum in 2008 is R$700 million and R$100 million in 2009. The data was processed through the use of the software LINDO.

The results indicate that there is no viable solution in these conditions. Simulations performed show that the result of the linear programming is extremely sensitive to the flow of annual investments, which serves as an alert for the team for the composition of values so as to meet this restriction. On the other hand, this is a factor under the domain of the planners, which permits adequate solutions to be found altering the rhythm of the execution of the projects. In relation to the degree of difficulty and innovation, already considering the number of projects as twelve, a degree of difficulty less than 65 and a degree of innovation greater than 60 are sought. These restrictions are incorporated into the previous linear programming.

The last two lines of programming include the new restrictions and the results were not affected. In the attempt to reduce the degree of difficulty of the set of projects selected, the non-viability of the solution was reached, which shows the sensitivity in relation to this requirement, with 53 the first value from which non-viability is found. The same happens in relation to the degree of innovation, with the first value from which non-viability is observed being 67.

4. Conclusion

The PROMÉTHÉE V method was shown to be very useful in the case studied. Among the more positive results obtained with the implementation of the method was the establishing of an organized way of thinking about the interdependent alternatives, which creates opportunities to see different points of view clearly, permitting a multidisciplinary evaluation which reduces conflicts of interest.

From the initial construction of the table of alternatives, criteria and weights, the solutions can be shared with easy understanding and their validation obtained in an extremely practical manner, with the simulations of the results made by variations of scores and weights, preference functions and restrictions, permitting the discussion to remain restricted to the concepts and not to personal opinions. The ease of recovering information contributed to maintaining the motivation of the team, as the possibility of tracking the data avoids the repetition of work in the future.

In relation to the application of the method, regarding the results processed, they were robust, with the results of the net flows of PROMÉTHÉE II tested in sensitivity analyses, which permit clear observation of fluctuations in relation to the modification of the values. In the particular case under study, the generalized criterion chosen guaranteed the linear transition in the determination of the preferences between alternatives. This fact was revealed to be very important, given the reservation that subjective scores can radically influence the decisions. The preference threshold performed an important role in the acceptance of the best solution by the group involved in the process.

The processing in DECISION LAB was carried out in a very simple way, with sensitivity analyses leading to results which were understood by the participants, until a final result was reached, representing a common view. In relation to the submission of the results of the net flows to processing by the LINDO software, various solutions from PROMÉTHÉE II were discovered without the possibility of optimization, thus leading to the conclusion that meeting the restrictions in the integer linear programming is much more critical. In spite of the additional work necessary, these occurrences serve to demonstrate the complexity of the problem. This type of question, which was previously solved in the form of linear cuts, comes to be treated in a more efficient way, making the assumed premises clear, reevaluating the data of the alternatives and restrictions with the aim of obtaining compromise solutions. In this case, the advantage of the method is to make available computational tools which permit the realization of the calculations in an extremely rapid manner.

This research has been limited to the analysis of investments of a company in the telecommunications business. However, the same multicriteria methodology that was used here can be utilized in investment selection in different areas. As a follow-up from this research the authors plan to compare their results against these to be obtained by making use of other multicriteria analytical tools.

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REFERENCES

[1] BELTON, V., STEWART, T.J. *Multiple criteria decision analysis: an integrated approach.* Boston: Kluwer Academic Press, 2002.

[2] BRACHE, A.P., BODLEY-SCOT, S. Which Initiatives Should You Pursue? *Harvard Management Update*, v.11, n.10, p.3-5, out 2006.

[3] BRANS, J.P., MARESCHAL, B. *PROMÉTHÉE-GAIA Une Méthodologie D'Aide à la Décision en Présence de Critéres Multiples.* Bruxelas: Éditions de l'Université de Bruxelles, 2002.

[4] BRANS, J.P., MARESCHAL. B. PROMÉTHÉE V: MCDM Problems with Segmentation Constraint. INFOR Journal: *Information Systems and Operational Research*, v.30, n.2, p.85-96, mai 1992.

[5] BRANS, J.P., VINCKE, P., MARESCHAL. B. How to select and how to rank projects: The PROMÉTHÉE method. *European Journal of Operational Research*, n.24, p.297-310, 1986.

[6] BUCHANAN, L., O'CONNEL, A. *A Brief History of Decision Making*. Harvard: Harvard Business Review, 2006.

[7] CÁNEZ, L., GARFIAS, M. Portfolio Management in the Literature. *Research Tecnology Management*, v. 49,n. 4, p. 52-54, jul-ago 2006.

[8] CASTANHAR, D.G., GOMES, L.F.A.M. A entrada de uma microempresa brasileira no mercado internacional. *Economia e Gestão*, v. 6, p. 1-19, 2006.

[9] CAVALCANTE, C.A.V., ALMEIDA, A.T. de. Modelo multicritério de apoio à decisão para o planejamento de manutenção preventiva utilizando PROMETHEE II em situações de incerteza. *Pesquisa Operacional*, v. 25, n.2, p.279-296, 2005.

[10] CLEMEN, R.T., REILLY, T. *Making Hard Decisions: An Introduction to Decision Analysis.* Pacific Grove: Duxbury, 2001.

[11] GELDERMAN, J., RENTZ, O. Bridging the Gap between American and European MADM - Approaches. Apresentado no 51° *Encontro do Grupo Europeu de Trabalho "Multicriteria Aid for Decisions"*, 30-31-mai-2000.

[12] HERMAN JR., M.A. Multi-Criterion Decision Making Approach to Problem Solving. Available in: <http://www.poms.ucl.ac.be/etudes/notes/qant2100/Promethee%20Shape.ppt>. Access in: October 8, 2007.

[13] KEENEY, R.L., RAIFFA, H. *Decisions with multiple objectives: preferences and value tradeoffs.* Cambridge: Cambridge University Press, 1993.

[14] KEISLER, J. Value of Information in Portfolio Decision Analysis. *Decision Analysis*, v.1, n.3, p.177-189, set 2004.

[15] LINDO Systems. Lindo 6.1 for Windows. Demo Version. Chicago: LINDO Systems Inc, 2011.

[16] MINTZBERG, H. Managing on the edges. *International Journal of Public Sector Management*, v.10, n.3, p.131-154, 1997.

[17] MORAIS, D.C., ALMEIDA, A.T. de. Modelo de decisão em grupo para gerenciar perdas de água. *Pesquisa Operacional*, v. 26, n.3, p.567-584. 2006.

[18] MORAIS, D.C., CAVALCANTE, C.A.V., ALMEIDA, A.T. de. Priorização de áreas de controle de perdas em redes de distribuição de água. *Pesquisa Operacional*, v. 30, n.1, p.15-32, 2010.

[19] MORAIS, D.C., CAVALCANTE, C.A.V., ALMEIDA, A.T. Priorização de áreas de controle de perdas em redes de distribuição de água. *Pesquisa Operacional*, v.30, n.1, p.15-32, 2010.

[20] NYSOT. Management Guide to Project Success. New York: New York State Office of Technology, 2002.
[21] OZERNOY, V.M. Choosing the “Best” Multiple Criteria Decision-Making Method. *INFOR*, v.30, n.2, p.159-171, May 1992.
[22] POMEROL, J.C., BARBA-ROMERO, S. *Multicriterion Decision in Management: Principles and Practice.* Norwell: Kluwer, 2000.
[23] ROY, B., BOUYSSOU, D. *Aide Multicritère à la Décision: Methods et Cas.* Paris: Economica, 1993.
[24] SAATY, T.L. *The Analytic Hierarchy Process*. New York: McGraw-Hill, 1980.
[25] VISUAL DECISION. Decision Lab. Prométhée-Gaia software. Version 1.01.0386, ULB/VLB Students. Visual Decision Inc, 2011.