LOCATION OF AN INTERNET PROVIDER IN THE LAKES REGION USING THE COPPE-COSENZA METHOD

Ruan Carlos A. Pereira[1,] and Marcos Santos[2]

[1] Federal Fluminense University, UFF, Brazil
[2] Military Engineering Institute, IME, Brazil

Abstract. This present study aims to assist the decision making about which city in the lakes region, in the state of Rio de Janeiro, would be the most suitable city for installing a new internet provider. As the main method for conducting this study, the hierarchical location model COPPE-COSENZA will be used. Prior to the application of the model, its functioning will be exposed and analyzes will be carried out on the behavior of the model in relation to the number and types of variables. In this application, to indicate the location for the installation of a reliable and stable internet network, it will be analyzed in addition to the socioeconomic aspects of the region's need, factors that will support the entrepreneur so that he can structure the network and contribute in a positive way so that it can expand in a safety way without affecting users. In this context, in order to translate less tangible aspects of reality more closely, the COPPE-COSENZA hierarchical analysis model, which has its concepts based on fuzzy logic, will play an important role in the interpretation of fuzzy data and in the defuzzification of these data, showing as result a ranking of favorability for installation of the enterprise, compared to the chosen cities.

Keywords: Fuzzy logic, Industrial location, Optimization and COPPE-COSENZA.

1 Introduction

The present paper intends to determine a ranking indicating which are the best locations, considering the cities of the lakes region – RJ - Brazil, for the installation of a reliable and stable internet provider network, analyzing in addition to the socioeconomic aspects of the region's need, factors that will support to the entrepreneur so that he can structure his network and expand it safely without affecting users. For this ranking and selection, the COPPE-COSENZA hierarchical analysis model will be used.

The COPPE-COSENZA hierarchical location model intends to analyze the proposed criteria and indicate, within the region delimited by the study, which city would be the most suitable for installing an internet network that makes broad access to the internet possible and provides good growth possibilities for the entrepreneur responsible for installing the network. Through these two guidelines, the model aims to balance the cost factors of installing/maintaining the network and offering reliable and stable Internet access points.

The balance between the needs of the analyzed cities and the growth possibility of the network to be installed is relevant, according to Cosenza [2], confirmed by Pereira *et al.* [6], because if the entrepreneur does not start his network in an appropriate location, it may make its expansion and service to other cities in the region unfeasible, keeping the population deprived of safe and stable internet access.

According to Cosenza *et al.* [3] this problem has several variables to be analyzed, with different importance and subject to subjective analysis for its definition, thus characterizing a multicriteria fuzzy problem. Due to the objective of this article to promote a balance between the socioeconomic needs of the analyzed regions and the perspective of growth of the installed internet network, the COPPE-COSENZA model was chosen, as it classically treats these supply and demand relationships in their fuzzy value matrices.

The city selection will be carried out by evaluating information such as median per capita income of cities, access to electricity, population density, population, average population age, lack of internet access, population growth and analysis of local competition. Based on this information, a hierarchical direction will be given as to which city in the region would benefit most from receiving the offer from this network.

2 The COPPE-COSENZA hierarchical fuzzy model

According to Cosenza *et al.*[2] the COPPE-COSENZA model was elaborated to allowing more in-depth studies on the location of enterprises. This fuzzy model presents a linear relationship between its fuzzy spaces, defined as supply and demand, which translate the relationship between the desired level of certain criteria and the levels presented by these criteria for each alternative, respectively. Based on this principle, the level of service and satisfaction of a set of factors required by an enterprise is analyzed considering the availability of these factors in different territories. Its main differential is to enable the analysis of not only economic factors of the project, bringing together quantitative and qualitative variables.

As described in the work by Barros *et al.* [1], each space defined by fuzzy numbers is delimited by degrees of relevance in the proposed criteria for a particular analyzed element. The criticality curves for defining the criteria requirement are established at four levels, called: CRITICAL, CONDITIONING, SLIGHTLY CONDITIONING and IRRELEVANT. For demand function *A*; and SUPERIOR, GOOD, REGULAR and WEAK for the supply function *B*. The MatLab 2014a software has used, as shown in Figure 1, to describe the fuzzy spaces of demand and supply, in Figures 2 and 3, respectively. The curves of different degrees of criticality, both in the demand and supply space, are define by triangular fuzzy functions. The use of triangular functions in the model is an interpretation of the authors of the present work with a possibility of standard operationalization of the model.

About the settings established to operate the model in the MatLab R2014a software, it is important to note that the Mandani type algorithm was used as a *fuzzyfication* rule, due to its wide use and flexibility in the interpretation of different variables and *defuzzyfication* by centroid, being a method *of defuzzyfication* that faithfully considers the geometric relationship formed by the fuzzy spaces. Both methods has applied, above all, seeking an interpretation of the model Pereira *et al.* [5].

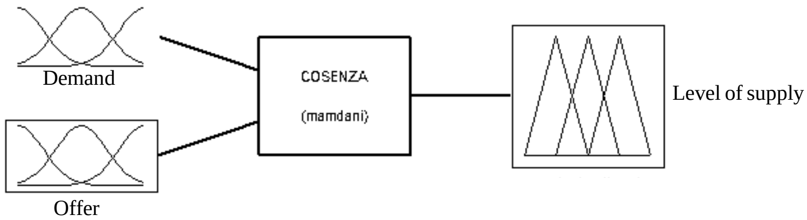


Fig. 1. MatLab R2014a Modeling - COPPE-COSENZA Model

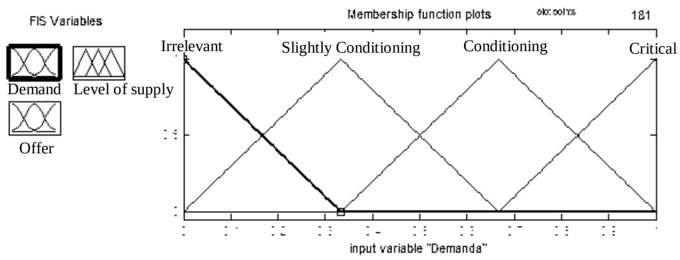


Fig. 2. Demand - COPPE-COSENZA Model

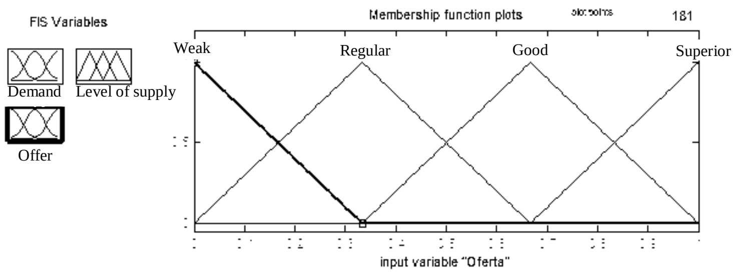


Fig. 3. Offer - COPPE-COSENZA Model

In Figures 2 and 3, it is possible to observe that for both demand and supply, the functions defined within the spaces are equidistant, considering the measurement from the point with the highest degree of relevance of each curve.

In agreement with the work by Cosenza *et al.* [2], due to the possibility of interpreting non-quantitative variables, the evaluation of demand and supply (fuzzy sets *A* and *B*) commonly present imprecision, due to this the information must be filtered by experts and inferred through a cognitive stream methodologically guided. The matrix structure of sets *A* and *B*, demand and supply criteria are precisely defined by the membership relationship matrices as follows:

$$A = (aij)_{hxn} \; e \; B = (bjk)_{nxm} \qquad (1)$$

In this version, *aij* is a fuzzy coefficient of project demand *i* by demand factor *j* and *bjk* is a fuzzy coefficient produced by one by one attribute *j* existing in locality *k*. *A* is an abstract fuzzy set looking for elements of membership identical to or greater than its own membership in *B*. Matrix *A*, as a fuzzy set, can be represented by *Ã* and matrix *B*, when represented by fuzzy numbers, is represented by ~*B*. The supply of a criterion from a given region may be higher or lower than the level demanded. For each case there is a membership value between the variables. The dimensions of these matrices above still represent, respectively, *h* different types of projects by *n* location criteria and the offer of criteria by *m* location alternatives.

$$F = \{(f_i \; | i = 1, \dots, n)\} \qquad (2)$$

Been *F* a finite set of location criteria generically called *f*. Then the fuzzy set *Ã* in *F* is an ordered set of pairs:

$$\tilde{A} = \{(f, \mu_{\tilde{A}} \; (f) | f \; \in F)\} \qquad (3)$$

Where *Ã* is a fuzzy representation of the demand matrix *A*, and *μÃ (f)* represents the degree of importance of the factors, defined between CRITICAL; CONDITIONING; LITTLE CONDITIONATE; IRRELEVANT.

Table 1. Matrix *A* - Criteria required by type of enterprise

	Criteria demanded				
	f_1	f_2	…	f_{n-1}	f_n
Type of enterprise	***Demand level of the criteria for each enterprise***				
A_1	a_{1_1}	a_{1_2}	…	a_{1_n-1}	a_{1_n}
A_2	a_{2_1}	a_{2_2}	…	a_{2_n-1}	a_{2_n}
…	…	…	…	…	…
A_{h-1}	a_{h-1_1}	a_{h-1_2}	…	a_{h-1_n-1}	a_{h-1_n}
A_h	a_{h_1}	a_{h_2}	…	a_{h_n-1}	a_{h_n}

Where *aij* is a fuzzy coefficient of the design *h* with respect to the factor *n*.
Similarly,

$$\sim B = \{(f, \mu_{\sim B}(f) | f \in F)\} \qquad (4)$$

Where ~*B* is a fuzzy representation of the supply matrix *B* and *μ~B (f)* represents the degree of compliance with the available criteria by the different location alternatives defined in SUPERIOR; WELL; REGULAR; WEAK.

Table 2. Matrix *B* - Criteria offered by each location

	Locations				
Offer criterias	B_1	B_2	...	B_{m-1}	B_m
F_1	b_{1_1}	b_{1_2}	...	b_{1_m-1}	b_{1_m}
F_2	b_{2_1}	b_{2_2}	...	b_{2_m-1}	b_{2_m}
...	...	...	...	...	...
F_{p-1}	b_{p-1_1}	b_{p-1_2}	...	b_{p-1_m-1}	b_{p-1_m}
F_p	b_{p_1}	b_{p_2}	...	b_{p_m-1}	b_{p_m}

Where *bjk* is a fuzzy coefficient of location *m* with respect to factor *n*.

Considering two generic elements *aij* and *bjk*, the comparison between *aij* and *bjk* will be obtained through the operator *aij* ⨂ *bjk*, as Table 3.

Table 3. aij ⨂ bjk - Comparison between the general demand and supply criteria

aij ⨂ bjk	***Offer***			
Demand	**A**	**B**	**C**	**D**
A	1	1- 1/n	1 - 2/n	0
B	1 + 1/n	1	1- 1/n	1- 2/n
C	1 + 2/n	1 + 1/n	1	1 - 1/n
D	1 + 3/n	1 + 2/n	1 + 1/n	1

$$C = (C_{ik})_{hxm} = A_{hxn} \otimes \mathrm{B}_{nxm} \qquad (5)$$

Let *C* be the possibility matrix that represents the sum of the location indices of project *i* in the *k* selected zones. Thus, if the application of the model has only general criteria and does not depend on specific criteria for its realization, *Maxi{Cik}=Ci*, indicates the best location of project *i*, in the set of territorial offers and *Maxk{Cik}=Ck*, indicates the best design type for the *k* selected zones.

The distances between the demand curves are inversely proportional to the number of criteria evaluated at a rate of *1/n*. In this way, by defining a small number of criteria for analysis - 5 criteria, - the model assigns great relevance to each criterion, making its analysis more impactful on the result and making the systemic view of the problem limited to the few criteria analyzed.

On the other hand, when analyzing a problem from the perspective of many criteria despite the increase in the scope in the analysis of the problem,- 40 criteria - now from different perspectives, the curves flatten, reducing the impact of the analysis of each criterion for the problem, generating energy expenditure for the collection, analysis and treatment of each criterion, which may, perhaps, be being observed by another criterion.

In this way, when defining the set of criteria under which the model will analyze the problem, it is important to choose independent criteria, to avoid the replication of information from the same criterion and to avoid the loss of significance of the other criteria.

As shown by Rheingantz P. A. [7] and Gertner, R. K. [4], in different applications, the model can be built in several directions without losing its basic characteristics. In situations where the enterprise requires specific characteristics for its installation, specific demand factors *A** must be used, which will compose the matrix *C**. Specific factors are essential factors for the vitality of the enterprise or project, they are strictly restrictive. The matrix of possibilities according to specific criteria *C*hxm* is the result of the confrontation between the demand matrix and the supply matrix of specific criteria, where:

$$C^* = (C_{ik})_{hxm} = A^*{}_{hxr} \otimes B^*{}_{rxm}. \quad (6)$$

$$A^* = (a^*ij)_{hxr} \quad (7)$$

Let *A** be the matrix of specific factors, Where,

$$\tilde{A}^* = \{(f, \mu_{\tilde{A}^*} (f) | f \in F)\} \quad (8)$$

It is the fuzzy representation of the matrix *A**.

Assuming *B** as,

$$B^* = (b^*jk)_{rxm}, \quad (9)$$

It is the matrix of territorial supply factors of specific factors.
Where,

$$\sim B^* = \{(f, \mu_{\sim B^*} (f) | f \in F)\} \quad (10)$$

It is the fuzzy representation of the matrix *B**.

The comparison between demand and supply of specific factors follows the same logic as general factors.

Table 4. *a*ij ⊗ b*jk* - Comparison between specific demand and supply factors

a*ij ⊗ b*jk	***Offer***			
Demand	**A**	**B**	**C**	**D**
A	1	1- 1/n	1 - 2/n	0
B	1 + 1/n	1	1- 1/n	1- 2/n
C	1 + 2/n	1 + 1/n	1	1 - 1/n
D	1 + 3/n	1 + 2/n	1 + 1/n	1

It is important to emphasize that the probable non-fulfillment of some specific criterion makes it impossible to select the alternative in the demanding category.

When there is a need to use specific criteria, their fuzzy spaces must be composed in the same way that the general criteria were composed, and to obtain a result that integrates the general criteria and specific criteria, the aggregation matrix of possibility, described in Table 5.

According to [8] Vianna's work, J. et al. (2020), the matrix of aggregation of possibilities Γ_{hxm} brings together the two matrices of possibilities described above, *C* and *C**, presenting the situations of abundance or lack in relation to the viability of the considered alternatives. This new matrix Γ_{hxm}, is the result of the operation:

$$\Gamma = (\gamma ik)_{hxm} = C_{hxm} + C^*{}_{hxm}, \qquad (11)$$

Where each γik results from the operation a described in Table 5.

Table 5. Γ_{hxm} – Possibilities aggregation matrix

Cik / ***C*ik***	***>0***	***0***
0	*0*	*0*
>0	*Cik+C*ik*	*C*ik*

The matrix Γ_{hxm} described above provides information about the efficiency of the considered alternatives, thus allowing the proper observation of the best alternatives according to the values accumulated by *C* and *C**, so that:

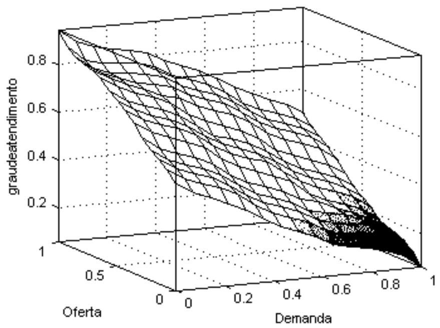
$\gamma i : Max\{\gamma ik\}$ indicates the best alternative location *k* , for each project *i*;
$\gamma k : Max\{\gamma ik\}$ indicates the best enterprise *i* for each locational alternative *k*.

Thus, it is possible to indicate the enterprise that best suits each of the pre-selected regions and determine the most suitable region for each type of enterprise.

In the evaluation of the criteria through the fuzzy spaces, it is possible to observe the relationship established between the functions of the fuzzy spaces of demand and supply, which generates a surface of possible solutions, as shown in Figure 6. This surface of possible solutions for the model has a linear, with small variations, caused by the ambiguity relations translated by the fuzzy algorithm.

This behavior has already predicted, considering that the relationship between the curves in the demand function is linear, equidistant from each other, in the same way that the curves in the supply function also present the same distance from each other, both cases considering the point of greatest relevance for each level of supply or demand analyzed.

Figure 6. Surface of solutions - COPPE-COSENZA Model



3 Locating an internet provider in the lakes region

The lakes region, target of this study, is composed by the cities of Araruama, Armação dos Búzios, Arraial do Cabo, Cabo Frio, Casimiro de abreu, Iguaba Grande, Maricá, Rio da Ostras, São Pedro da Aldeia and Saquarema, in the state of Rio de Janeiro - BR. The choice of the region to carry out this study was carried out through the results obtained by the application of a questionnaire to 200 people residing in the region. The questionnaire revealed that about 99% of the sample has internet access, but 56% say that the network is not stable and 69% reveal that the speed is lower than the contracted one, reflecting a general percentage of 53% of dissatisfaction.

The project to be implemented in the indicated location must be a long-term project, with expansion planning of three years and a useful life of the network of about 20 years. The expansion plan reflects the time in which the network will be fully structured in the region, allowing a positive advance in relation to the company's cash flow.

The model will assist in decision making for location in light of eight criterias: Municipality per capita income; Access to electricity; Lack of internet access; Population density; Population; Population growth; Average age of the population and Competitors.

To carry out the location for the installation of a reliable and stable internet network, analyzing, in addition to the socioeconomic aspects of the region, factors that will support the entrepreneur so that he can structure his network and allow it to expand safely without affecting users and providing a healthy cash flow for the offering company, in light of the eight criteria mentioned, using the COPPE-COSENZA Model, we must define, in addition to the analysis criteria, the Criticality Level of each of the factors. Thus, we will structure the demand matrix *A*, shown on Table 6.

Table 6. Matrix *A* - Demand Level of Factors

Factors	Demand level
Per capita income	Little conditioning
Access to electricity	Critical
Lack of internet access	Critical
Population density	Conditioning
Population	Little conditioning
Population growth	Critical
Average age of population	Irrelevant
Competitors	Conditioning

To proceed the application of the model, after defining the level of demand for each factor, aiming at the focus of this location analysis, it is necessary to translate the level of supply related to each of the factors for each alternative. This step is crucial for the presence of specialists and the collection and analysis of data on the relevance of the supply level of the factors listed for each alternative.

After carrying out the work of analyzing the alternatives through systemic analysis, collecting historical data, statistical inferences, expert perception and other relevant means, the offer matrix *B* must has be developed, as shown on Table 7.

After the supply levels have been determined in the light of the defined criteria, for each alternative, the comparison between matrices *A* and *B* will be carried out according to the guidelines of the COPPE-COSENZA model. It is important to emphasize that both the assessment of the level of demand for factors and the level of supply of factors for each alternative must be carried out through a broad interpretation of the scenario that involves the variables relevant to the factors raised.

Table 7. Matrix *B* - Level of supply of the factors

	Per capita income	Access to electricity	Lack of internet access	Population density	Population	Population growth	Average age of population	Competitors
Araruama	Regular	Good	Superior	Regular	Good	Weak	Regular	Superior
Armação dos Búzios	Good	Superior	Regular	Superior	Weak	Regular	Superior	Regular
Arraial do Cabo	Good	Superior	Weak	Regular	Weak	Weak	Regular	Good
Cabo frio	Regular	Good	Regular	Superior	Superior	Regular	Superior	Weak
Casimiro de Abreu	Good	Superior	Superior	Weak	Weak	Weak	Superior	Superior
Iguaba Grande	Regular	Superior	Good	Superior	Weak	Regular	Weak	Superior
Maricá	Weak	Weak	Good	Good	Good	Weak	Regular	Good
Rio das Ostras	Superior	Superior	Weak	Superior	Good	Superior	Superior	Weak
São Pedro da Aldeia	Regular	Good	Good	Regular	Regular	Weak	Superior	Superior
Saquarema	Regular	Good	Superior	Regular	Regular	Weak	Regular	Superior

Thus, following the comparison described in Table 4, we will have Matrix *C* (Table 9), exposing the fuzzy coefficients of each alternative. The Table 8 show the result of each demand factor comparing to each city.

Table 8. Collating between *A* and *B*

Alternative	**Collate between matrix *A* and *B***							
Araruama	1	0,875	1	0,875	1,125	0,625	1,125	1,125
Armação dos Búzios	1,125	1	0,75	1,125	0,875	0,75	1,375	0,875
Arraial do Cabo	1,125	1	0,625	0,875	0,875	0,625	1,125	1
Cabo frio	1	0,875	0,75	1,125	1,25	0,75	1,375	0,75
Casimiro de Abreu	1,125	1	1	0,75	0,875	0,625	1,375	1,125
Iguaba Grande	1	1	0,875	1,125	0,875	0,75	1	1,125
Maricá	0,875	0,625	0,875	1	1,125	0,625	1,125	1
Rio das Os-tras	1,25	1	0,625	1,125	1,125	1	1,375	0,75
São Pedro da Aldeia	1	0,875	0,875	0,875	1	0,625	1,375	1,125
Saquarema	1	0,875	1	0,875	1	0,625	1,125	1,125

Table 9. Matrix C - Fuzzy Coefficient

Alternative	Fuzzy Coefficient
Araruama	7,75
Armação dos Búzios	7,875
Arraial do Cabo	7,25
Cabo frio	7,875
Casimiro de Abreu	7,875
Iguaba Grande	7,75
Maricá	7,25
Rio das Ostras	8,25
São Pedro da Aldeia	7,75
Saquarema	7,625

For this application, it was not necessary to define specific criteria, so the aggregation matrix Γ_{hxm} of possibilities will be the same as Matrix *C*.

In this application, we are considering the study of only one type of enterprise, in this way; the matrix Γ_{hxm} will indicate the most suitable location for the installation of this enterprise, without ordering the evaluated enterprises.

The Γ_{hxm}Matrix continues to rank the alternatives evaluated and indicate the most appropriate location for the installation of the evaluated project, as showed in Table 10.

Table 10. Γ_{hxm}– Hierarchy of alternatives

Alternatives	Index Fuzzy	Ranking
Rio das Ostras	8,25	1º
Armação dos Búzios	7,875	2º
Cabo frio	7,875	2º
Casimiro de Abreu	7,875	2º
Araruama	7,75	2º
Iguaba Grande	7,75	3º
São Pedro da Aldeia	7,75	3º
Saquarema	7,625	4º
Arraial do cabo	7,25	5º
Maricá	7,25	5º

4 Conclusions

As a practical result, the city of Rio das Ostras was chosen as the most suitable alternative for the enterprise. It is a result with good correlation with reality and has significance within the possibilities for those who want to start a venture of this kind.

The COPPE-COSENZA Model presents interesting aspects for the evaluation of scenarios with homogeneous variables and presents a degree of linear compensation between the said supply and demand matrices. However, there are problems where the undefined variables are not homogeneous, present viable alternatives and want different degrees of evaluation between the levels of criteria defined between the factors. For such problems, a hierarchical fuzzy evaluation model with variable distances between the criticality curves of the model would be necessary. Scenarios where high complexity problems of this nature are present, for example in Logistics and Supply Chain, thus leaving opportunities for situations to be evaluated under a new methodology

References

1. BARROS, Carlos Frederico; COSENZA, Carlos Alberto N. Usando lógica fuzzy em mega-eventos de esportes: um sistema de avaliação de impactos. Rios International Journal on Sciences of Industrial and Systems Engineering and Management, v. 2, 2008.
2. COSENZA, Carlos A. - "A Industrial Location Model"- Working paper, Martin Centre for Architectural and Urban Studies, Cambridge University ,1981.
3. COSENZA, Carlos Alberto Nunes; DORIA, Francisco Antônio; PESSÔA, Leonardo Antônio Monteiro. Hierarchy models for the organization of economic spaces. Procedia Computer Science, v. 55, p. 82-91, 2015.
4. GERTNER, Rosane K. , "A Decisão de Localização Industrial em Mercados Globalizados: Uma Aplicação do Modelo Cosenza em Empresas do Setor Automobilístico instaladas no Brasil"- Rio de Janeiro, Tese de Doutorado, COPPE/UFRJ, 2000.
5. PEREIRA, Ruan Carlos Alves; BARROS, Carlos Frederico Oliveira; PEREIRA, Valdecy. APLICAÇÃO E ANÁLISE DO MODELO FUZZY HIERÁRQUICO COPPE-COSENZA EM UMA DECISÃO DE LOCALIZAÇÃO. Engevista, v. 20, n. 1, p. 79-98, 2018
6. PEREIRA, Ruan Carlos Alves; BARROS, Carlos Frederico; IGNACIO, Anibal Alberto Vilcapoma. MODELO DE LOCALIZAÇÃO HIERÁRQUICA DE USINAS DE PIRÓLISE. Simpósio de Pesquisa Operacional e Logística da Marinha-Publicação Online, v. 1, n. 1, p. 582-593, 2014.
7. RHEINGANTZ, P.A., Aplicação do Modelo de Análise Hierárquica COPPETEC – Cosenza na Avaliação do Desempenho de Edifícios de Escritório. Tese de Doutorado. UFRJ, Programa de Pós-Graduação de Engenharia de Produção. Rio de Janeiro. 2000.
8. VIANNA, J., Carvalho, P. V., Cosenza, C. A., & Grecco, C. H. A Fuzzy Decision Making Method for Preventing the Loss of Knowledge in Nuclear Organizations. In International Conference on Applied Human Factors and Ergonomics (pp. 160-167). Springer, Cham. 2020.