A MODELING TOOL TO ASSIST ON THE DECISION PROCESS OF DETERMINING THE OPTIMAL LOCATION OF AN INDUSTRIAL AIRPORT IN BRAZIL

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Abstract

This paper considers the problem of determining the optimal location of an industrial airport in Brazil, a special approach custom entrepot. The methodology applied is the AHP (Analytic Hierarchy Process), widely utilized in the area of discrete multicriteria decision making, that obtain numerical values from verbal judgments. Firstly, the concept of industrial airport is presented. Then, the AHP is described. The methodology is applied considering three criteria and four possible locations. After the optimal location is proposed, the results are analyzed and a new research with a wider approach is proposed.

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1. INTRODUTION

An industrial airport is characterized by a customs regime that incentives companies to become more competitive and more cost-reduce. The companies located at the airport site contribute to the country exports and usually generate several job positions (directly or indirectly). The airport management (Infraero – federal company that owns and manages the 67 largest Brazilian airports) is benefited as well, because it collects several handling and storage cargo fees.

The industrial airport will not be built, but it will be implemented into an existent airport. INFRAERO has selected preliminarily four alternative sites: the international airports at Rio de Janeiro (Galeão-RJ), São José dos Campos (SP), Petrolina (PE) and Confins, (MG).

The industrial airport concept is a custom entrepot dedicated to importation and exportation, using tax exemption with customs place being a public domain. The merchandise admitted in special approach can be submitted to the following activities:

- Storage,
- display, demonstration and working test,
- industrialization, and
- maintenance or repair.

When the custom place is registered for industrialization activities and it is located in an airport, this airport will be called an industrial airport. The activity range includes packing, assemblying, improving, reconditioning and transformation, in the event of catering food to be consumed on international passenger flights and export freights. The process starts with importing parts and with the aforementioned activities, adding local value to the exports. An important advantage of an industrial airport for Brazilian companies is the time optimization between the initial activities and the final delivery to customers, thus enhancing the competition, since many companies will settle down in the area under jurisdiction of the airport. Another advantage is the cost reduction related to transportation, since larger quantities of manufactured products will be transported by the aircrafts at once.

Considering the relevant economic benefits of an industria airport in the areas of air traffic control, importation and exportation business and employment, the objective of this paper is to provide qualitative and quantitative information of a modeling tool to assist decision makers on the decision process concerning the optimal location of an industrial airport in Brazil.

2. LITERATURE REVIEW

There are several methods within the literature about airport benchmarking. Most of these methods use performance measures (level of service, capacity, or efficiency) in order to provide an objective basis for comparison. A thorough review of level of service and capacity methods was provided by Correia and Wirasinghe (2004), which concluded that overall airport measures are one of the most critical research topics today.

Fernandes and Pacheco (2002) utilizes data envelopment analysis to evaluate the capacity of 35 Brazilian domestic airports, based on several operational parameters (e.g. number of check-in counters, average space available per passenger, etc). DEA (Data Envelopment Analysis) was employed to provide a synthesized efficiency measurement. The work concentrated mainly on passenger handling as opposed to cargo handling.

Correia (2004) compared several Brazilian airports according to their level of service offered to passengers. Psychometric scaling technique was employed to convert qualitative data (passengers responses) into quantitative data (numerical level of service ratings). Once again, the work concentrated mainly on passenger handling, as opposed to cargo handling.

Oliveira et. al (2006) apply the AHP method to evaluate the change in the level of services for passengers in the event of transferring a considerable portion of flights from the São Paulo Domestic Airport (Congonhas) to the São Paulo International Airport (Guarulhos). A personal interview of more than 300 departing passengers at Congonhas and interviews with airlines managers indicated that the level of service for passengers would be drastically degraded in the event of the mentioned flight transfer.

Considering the brief literature review and the purposes of this research, the AHP method has been identified as being capable of processing several subjective judgments into quantitative measures, which are useful to compare various airport site alternatives. The method will be presented and illustrated in detail on the following sections.

3. METHOD OF ANALYSIS - AHP

The Analytic Hierarchy Process (AHP) will be the multicriteria decision making method applied in this research analysis, in which the elements of the problem (goal, criteria and alternatives) are divided into hierarchical levels, facilitating the comprehension and the assessment of the research problem. The AHP is applied in two phases: structure of hierarchy and modeling. The first phase depends on knowledge of the factors involved in the problem. The modeling phase is based on pairwise comparisons. The four axioms of the method are as follows:

- Reciprocal comparison axiom: the judgments performed by the decision maker must satisfy the reciprocal condition: if an element E_1 is *x times* more preferred than E_2, then E_2 is *1/x times* more preferred than E_1;
- Homogeneity axiom: the elements in a same hierarchical level must have the same importance and specificity degrees;
- Independence axiom: the comparisons performed among the criteria for yield weights must be independent of the alternatives; and
- Expectation axiom: during application, all important criteria and alternatives must be considered by the decision maker, in order to make a complete hierarchy structure.

3.1. Structure of hierarchy

This phase includes three non-sequential interrelated processes. The first process is the identification of levels, elements (goal, criteria and alternatives) and the concept definition for each criteria. The second process involves the question formulation, for instance if a given criterion must be constituent for a problem resolution or not. The third process is the evaluation of the hierarchy. The hierarchy structure is an iterative process where the concepts, the questions, and the answers associated to questions determine the elements and the levels of the hierarchy. If all questions are answered with consistency using the information obtained, it means that the hierarchy is strongly structured. The three processes of the structure of hierarchy and their relationship are illustrated in Figure 1.

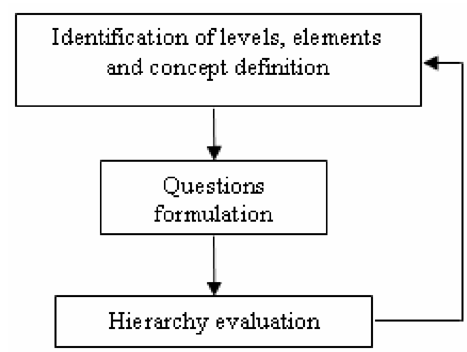


Figure 1: Processes of the structure of the hierarchy and their relationship

3.2. Modeling

The analysis model is based on pair wise comparisons in order to derive priority vectors, whose components indicate the weights of the criteria or alternatives related to the criteria located at upper levels. Many methods were proposed in order to derive priority vectors, however Saaty (1980) has suggested that the best alternative is the right eigenvalue method, that allows the estimation of the priority vectors with consistency. Consider n criteria or alternatives to be compared. Consider the priority vector $W = (w_1, w_2, \ldots, w_n)$, whose components w_i

indicate the weights of the criteria or alternatives related to the criteria located at upper level. Consider A = [a_{ij}] / i,j = 1,2, ... , n, called *decision matrix*, where each row i provides the ratios of the weight of each criterion or alternative of index i with respect to all others. If all judgments are perfect, the following matrix equation is obtained:

$$\begin{matrix}\text{Row 1 =>}\\ \text{Row 2 =>}\\ \\ \text{Row n =>}\end{matrix}\quad \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \cdots & \cdots & \cdots & \cdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ \cdots \\ w_n \end{bmatrix} = n \cdot \begin{bmatrix} w_1 \\ w_2 \\ \cdots \\ w_n \end{bmatrix} \quad (1)$$

Equation 1 can be similarly written as follows: $AW = nW$. Therefore, it is correct to affirm that n is an eigenvalue of A and $W = (w_1, w_2, \ldots, w_n)^T$ is the eigenvector of A associated to n. The decision matrix has all positive entries and it is a reciprocal matrix, since $a_{ji} = 1/a_{ij}$. Moreover, A is consistent, since $a_{ij} \times a_{jk} = a_{ik} \forall i, j, k = 1, \ldots, n$. However, in the decision-making context, the exact values of $a_{ij} = w_i/w_j$ cannot be obtained, but estimated. Considering that even a person or group with experience in the subject of the decision making process could perform small errors. If a perturbation occurs, in an element a_{ij} of the matrix A, such that the equation $AW = nW$ is no more satisfied by n, it will be necessary to find out the maximum eigenvalue of A (λ_{max}) that allows the maintenance of its reciprocal matrix condition. This situation raises the following problem:

$$AW = \lambda maxW \quad (2)$$

where

A: decision matrix;

λ_{max}: maximum eigenvalue of A; and

W: eigenvector of A associated with λ_{max}.

From (2) and after normalizing W, the eigenvalue λ_{max} is obtained by Equation 3:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{[A\overline{w}]_i}{\overline{w}_i} \quad (3)$$

where

A: decision matrix;

$\lambda_{\max}$: maximum eigenvalue of A;

n: decision matrix order; and

$\overline{w}_i$: normalized component of vector $\overline{W}$.

After λ_{max} is obtained, it brings the following question: to what extent is W trustworthy? This question is very appropriate, since W is no more associated with the eigenvalue n, but with λ_{max}. Saaty (1990) presented two theorems that indicate a causal relationship between λ_{max} and n. From these theorems, an index was adopted to allow the measurement of the W trustworthiness.

In the first theorem, it is proved that if $a_{ij} = (1 + \delta_{ij}) \cdot \frac{w_i}{w_j}$ and $\delta_{ij} > -1$ is a perturbation in an element $a_{ij} = w_i/w_j$ of the decision matrix A, so $\lambda_{max} \geq n$.

In the second theorem, it is proved that A is consistent if and only if $\lambda_{max} = n$. Thus, the value ($\lambda_{max} - n$) is utilized to measure the consistency of the judgments after construction of A and the obtainment of the normalized vector W. The closer to zero, the greater it will be the consistency of the judgments. It is important to note that this value should assist the decision maker with a warning and not only with an undesirable fact.

From these two theorems, Saaty (1980) proposed the calculation of the consistency ratio (CR) of the decision matrix A as follows:

$$CR = \frac{CI}{RI} \quad (4)$$

where

CR: consistency ratio;

CI: consistency index; and

RI: random index.

CI is obtained by:

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (5)$$

where

CI: consistency index;

λ_{max}: maximum eigenvalue of A; and

n: order of A.

RI has been previously obtained for an n order matrix by the OAK RIDGE National Laboratory in the United States. Some RI values are shown in table 1.

Table 1: RI values for n order matrix

n	2	3	4	5	6	7
RI	0	0.58	0.90	1.12	1.24	1.32

The inconsistency is directly proportional to the CR value. Table 2 shows CR values associated with n.

Table 2: Upper limits for CR

N	2	3	4	> 4
CR	= 0	< 0.05	< 0.09	≤ 0.10

3.3. The fundamental scale

The fundamental scale of the method was constructed from previous research of the psychologist George Miller during the 1950's (Saaty, 1990). He stated that people could deal with information involving (7 ± 2) simultaneously facts and yet achieving good results. Beyond nine factors, they probably would get confused. The fundamental scale allows the usage of values of the absolute scale thus the construction of a relative scale. Thus, verbal judgments are translated into numbers that represent the importance of an element (criterion or alternative) over another. The main application of the relative scales is to measure the relative importance of intangible elements, established by a number. They are always used when individual judgments are necessary. The scale is presented in Table 3.

Table 3: Fundamental scale of AHP method

Importance on an absolute scale	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	An element is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise between elements is needed

4. METHOD APPLICATION

4.1. Structure of the hierarchy

4.1.1. Levels and elements identification

The hierarchy will be structured into three levels. At the first level, it will be the goal, that is the optimal location of an industrial airport in Brazil. The second level will encompass three criteria: runways and aprons, acessibility and receiving/flowing off. At the third level, four location alternatives of the airports are considered: Rio de Janeiro/Galeão (GL), São José dos Campos (SJ), Petrolina (PE) and Confins (CF). The structure of the hierarchy of the problem is shown in Figure 2. Henceforth, the locations will be referred by their abbreviations, when convenient.

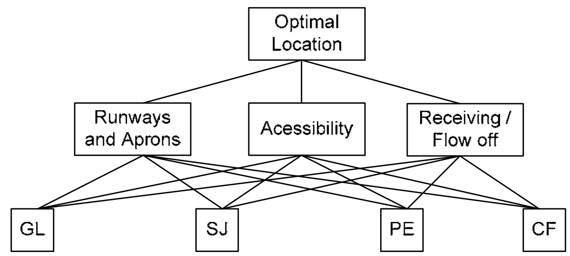


Figure 2: Structure of the hierarchy

4.1.2. Concepts of criteria definitions

In order to originate the decision matrix associated to the second level of the hierarchy and then to obtain the respective priorities vector, some concepts should be outlined:

- Runways and aprons (C_1): related to the number of runways and their length/altitude in relation to landing and takeoff of regular aircrafts used on international transportation freights, operating with the highest landing and taking-off weights. Apron capacity in actual operation will also be considered.
- Acessibility (C_2): related to the access conditions to/from airports by main local highways, pavement existence, number of lanes in the highways and traffic congestion;

- Receiving/flow off (C_3): related to the proximity of other ports and airports that can serve as transshipment points, to shipping imported parts to the four airports (receiving), as to flow off manufactured products from airports. The proximity to freight-carrying railroad will also be considered.

4.2. Modeling

4.2.1. Criteria

Based on the concept of the criteria, a decision matrix C will be provided. Subsequently, the priority vector $\overline{W}$ will be obtained.

C_1 is a fundamental criterion determining the success of an industrial airport, since it indicates the level of airside infra-structure necessary to operate wide-body aircrafts, which are usually used for international cargo flights. In this case, the runway class and capacity are the main proxies of this criterion. The apron area is also a key success element of an industry airport, since a bigger apron could allow the operation of higher number of daily flights. As a consequence, it would allow handling larger cargo volumes.

C_2 and C_3 have a compromised condition; however C_3 has wider geographical approach than C_2. Thus, the decision-matrix-related-criteria, constructed from these judgments is as follows:

C = (6)

	C_1	C_2	C_3
C_1	1	7	7
C_2	1/7	1	½
C_3	1/7	2	1

The normalized matrix $\overline{C}$ will be obtained by Equation 7:

$$\overline{C} = \frac{c_{ij}}{\sum_{i=1}^{m} c_{ij}}, j = 1, \ldots, m \tag{7}$$

where

$\overline{C}$: normalized matrix C;

c_{ij}: element of row i and column j; and

m: number of criteria located at the same level.

$\overline{C}$ = (8)

	C_1	C_2	C_3
C_1	7/9	7/10	14/17
C_2	1/9	1/10	1/17
C_3	1/9	2/10	2/17

Each normalized component of the priorities vector criteria $\overline{W} = (\overline{w}_1, \overline{w}_2, \ldots, \overline{w}_m)$ will be obtained by Equation 9:

$$\overline{w}_i = \frac{\sum_{j=1}^{m} c_{ij}}{m}, i = 1, \ldots, m \tag{9}$$

where

$\overline{w}_i$: normalized component of the vector $\overline{W}$

c_{ij}: element of row i and column j; and

m: number of criteria at the same level.

$$\overline{w}_1 = \frac{\frac{7}{9}+\frac{7}{10}+\frac{14}{17}}{3} = \frac{3521}{4590} = 0.7674$$

$$\overline{w}_2 = \frac{\frac{1}{9}+\frac{1}{10}+\frac{1}{17}}{3} = \frac{413}{4590} = 0.0899$$

$$\overline{w}_3 = \frac{\frac{1}{9}+\frac{2}{10}+\frac{2}{17}}{3} = \frac{656}{4590} = 0.1427 .$$

Thus, $\overline{W} = (0.7674 ,\ 0.0899,\ 0.1427)$. CI is calculated according to Equation 5 and CR according to Equation 4, considering n = 3 and RI = 0.58 according to Table 1. The first step is to calculate $\lambda_{\max}$ according to Equation 3, replacing A by C, that indicates the criteria decision matrix.

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{[C\overline{w}]_i}{\overline{w}_i} \quad (10)$$

$$C\overline{w} = \begin{bmatrix} 1 & 7 & 7 \\ 1/7 & 1 & 1/2 \\ 1/7 & 2 & 1 \end{bmatrix} \times \begin{bmatrix} 0.7674 \\ 0.0899 \\ 0.1427 \end{bmatrix} = \begin{bmatrix} 2.3953 \\ 0.2702 \\ 0.4313 \end{bmatrix} \begin{matrix} \Rightarrow C\overline{w}_1 \\ \Rightarrow C\overline{w}_2 \\ \Rightarrow C\overline{w}_3 \end{matrix}$$

$$\lambda_{\max} = \frac{1}{3}\left(\frac{2.3953}{0.7674}+\frac{0.2702}{0.0899}+\frac{0.4313}{0.1427}\right) = 3.0504$$

$$CI = \frac{\lambda_{\max}-n}{n-1} = \frac{3.0504-3}{3-1} = 0.0252$$

and $$CR = \frac{CI}{RI} = \frac{0.0252}{0.58} = 0.0434.$$

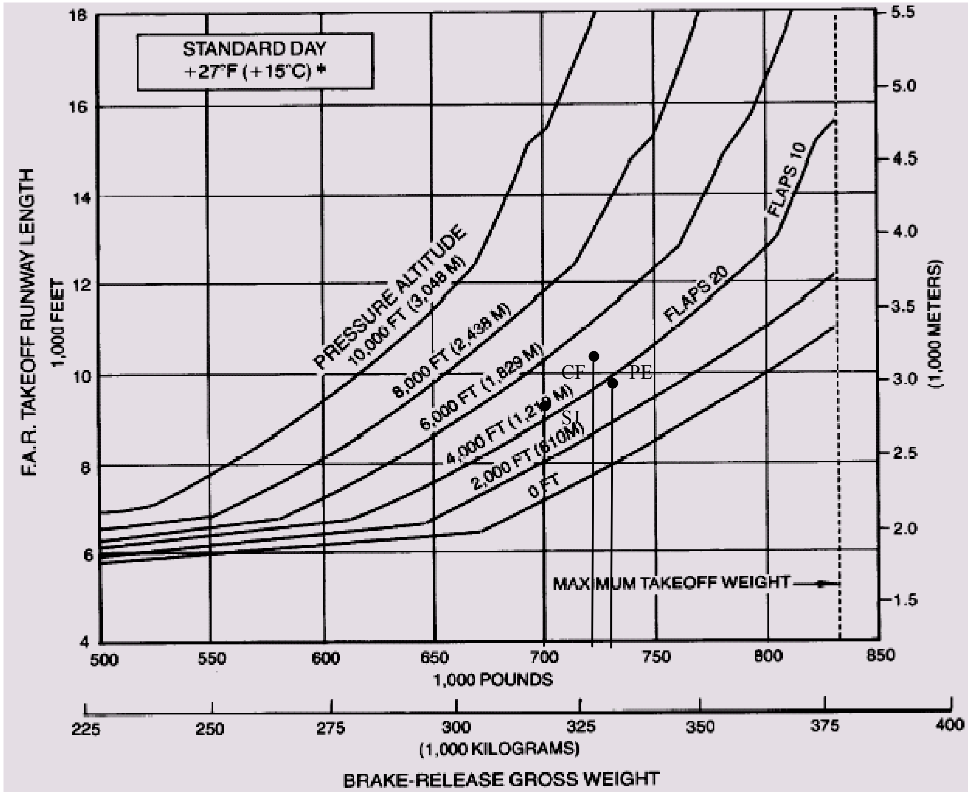
The upper limit of RC for n = 3 is 0.05, according to Table 2. Hence, if CR = 0.0434, the judgments are consistent. The decision matrix C, the priorities vector $\overline{W}$, λ_{max}, CI and CR are included in Table 4.

Table 4: Arranged data of the criteria

	C_1	C_2	C_3	$\overline{W}$
C_1	1	7	7	0.7674
C_2	1/7	1	½	0.0899
C_3	1/7	2	1	0.1427
λ_{max} =3.0504 CI = 0.0252		CR = 0.0434		

4.2.2. Alternatives related to Criterion 1

In this phase, the alternative locations will be analyzed according to each on of the criteria In relation to the criterion C_1 (runways and aprons), fleets of ten carriers were searched, including the two Brazilian carriers, trying to adopt an aircraft model as a reference, used in international transportation freights, in order to realistically compare the airport runways. However, due to the variety of models and engines present in a same model, which changes the requirements of landing and takeoff, it was not possible to select an aircraft model of the most common carrier fleets. Hence the model Boeing 747-300 was adopted as a reference. Its maximum takeoff weight (MTW) is around 375 t, with engines RB211-524D4 installed. The chart for analysis is *Standard day + 15ºC*, due to reference temperature of the aerodromes. In order to continue the analysis, the manufacturer information is presented in Figure 3 and Table 5.



3.3.22 F.A.R. TAKEOFF RUNWAY-LENGTH REQUIREMENTS
STANDARD DAY +27°F (+15°C)*
MODELS 747-200, -300 (RB211-524D4 ENGINES)

Figure 3: Chart (takeoff weight x runway lenght) (Boeing,2005)

Table 5: Aerodrome and parking charts data (ROTAER,2005)

Alternative	Elevation (ft)	Runway lenght (m)	Apron	Reference temperature (ºC)
GL	28	3,180	Yes	30
		4,000		
SJ	2,120	2,676	No	33
PE	1,263	2,760	No	28
CF	2,715	3,000	Yes	30

GL is the only site of the sample with two runways. The longest runway is 4,000 m long, which allows takeoffs of this model in the *MTW of the aircraft*, indicated in the chart by dotted vertical line. Moreover, the apron requirement is also observed. In the GL case, elevation of 28 ft can be considered in technical terms as zero for the purposes of this research. However, for the other three alternatives, it is not possible to construct exact pressure-altitude curves by interpolation because:

- the intervals of 25 ft between the takeoff weights and 500 m between runway lenghts does not provide accuracy for this procedure;
- the flap angular values of each curve must be considered.

Due to these reasons, the chart provides the estimated locations of the intersection points between runway lengths and pressure-altitude curves of each airport, allowing the plotting of *MTW references* from this model for each airport. *The a*ltitude at CF is higher than altitudes at PE and SJ, constituting a negative factor regarding takeoffs. The point position related to CF indicates a lower MTW value compared to PE. However, CF has apron with infrastructure prepared to operate a 747-300 model, that allows to operate a higher number of aircrafts than PE, in any time frame, enhancing its importation and exportation capacities. Considering those two airports that do not have apron, PE has a longer runway length and a lower altitude, which allows takeoffs with higher MTW values than SJ, related to the model in analysis. After these analyses, the decision matrix M_1, related to criterion *Runways and aprons* is as follows.

M_1 = (11)

	GL	SJ	PE	CF
GL	1	7	6	4
SJ	1/7	1	1/2	1/3
PE	1/6	2	1	1/4
CF	1/4	3	4	1

To obtain the vector $\overline{A}_1$, related to alternative priorities of the first criterion (C_1), we proceed with similar calculation that was used to obtain $\overline{W}$, however considering $n = 4$ to calculate *CI* according to the Equation 5, *RI* = 0.9 taken Table 1 for calculation of *CR* according to Equation 4 and *CR* upper limit < 0.09 (Table 2). The arranged data is shown in Table 6.

Table 6: Arranged data of C1

	GL	SJ	PE	CF	$\overline{A}_1$
GL	1	7	6	4	0.6045
SJ	1/7	1	1/2	1/3	0.0679
PE	1/6	2	1	¼	0.0981
CF	1/4	3	4	1	0.2295
λ_{max} = 4.1628 *CI* = 0.0543				*CR* =0.0603	

By the vector $\overline{A}_1$, the priority order of the alternatives related to C_1 is as follows: 60.45% of the priority to GL, 6.79% to SJ, 9.81% to PE and 22.95% to CF.

4.2.3. Alternatives related to Criterion 2

GL is accessed by the Highway Galeão. The roads are asphalt paved with double runways. Highway Galeão presents traffic jams during business hours of weekdays, especially early in the morning and late in the afternoon, and it is the unique access to the 20th de Janeiro

Avenue. SJ is situates at less than ten kilometers (km) away from the Highway President Dutra (BR-116), that is paved and with two runways with double lanes. Highway BR-116 allows access of vehicles from São Paulo city and from cities located in the Vale do Paraíba (river). It can also be accessed by Highway Dom Pedro I (SP-065), that is paved, with double runways. It originates in the interior of the state of São Paulo. SJ is easily accessed by the Highway Tamoios (SP-099), that is paved but with single runway and is originated in the North of the littoral of the Sao Paulo state. Highway Presidente Dutra and all highways referred do not usually present major concerns about traffic jams, except during main national holidays. PE can be accessed by Highway Asa Branca (BR-122) by vehicles from the Pernambuco State and also by Highway Lomanto Jr. (BR-407), for vehicles from the Piauí State. Vehicles from the Bahia State can access PE by Highway BA-314, that has a stretch of 60 Km, poorly maintained in terms of traffic conditions.. Both Highways, Asa Branca and Lomanto Jr. are paved, with single runways and do not usually present traffic jams. CF can be accessed by Highway Américo René Gianetti (MG-424), by vehicles from the metropolitan region of the Belo Horizonte city (to the south) and by vehicles from regions of the Sete Lagoas city (to the north). The Highway is paved and do not present traffic flow problems. The decision matrix M_2, related to criterion *Acessibility*, constructed by judgments based on the facts previously mentioned is as follows:

M_2 =

	GL	SJ	PE	CF
GL	1	1/5	3	1
SJ	5	1	7	5
PE	1/3	1/7	1	1/3
CF	1	1/5	3	1

(12) (12)

The priority vector $\overline{A}_2$ will be calculated in the same way as $\overline{A}_1$, attributing the same values to the parameters *n* and *RI* and the same upper limit to *CR*. The arranged data of C_2 are shown in Table 7.

Table 7: Arranged data of C2

	GL	SJ	PE	CF	$\overline{A}_2$
GL	1	1/5	3	1	0.1542
SJ	5	1	7	5	0.6279
PE	1/3	1/7	1	1/3	0.0637
CF	1	1/5	3	1	0.1542
λ_{max} = 4.0739 CI = 0.0246				CR = 0.0274	

Vector $\overline{A}_2$ indicates that the highest priority alternative according to C_2 is SJ. Both GL and CF have the same priority and PE has the lowest priority related to Criterion 2.

4.2.4. Alternatives related to Criterion 3

GL is 130 km, 53 km, 25 km, and 10 km far from the Ports of Angra dos Reis, Sepetiba, Niterói and Rio de Janeiro, respectively. GL is reasonably close to the Santos Dumont Airport but it is a domestic airport. There is no proximity to freight-carrying railroad. SJ is 110 km and 169 km far from the Ports of São Sebastião and Santos, respectively. It is also 150 km far from the Campinas Airport, the second largest Brazilian cargo airport, and 90 km far from the São Paulo / Guarulhos Airport, the largest airport in South America. Parallel to Highway Rodovia Presidente Dutra (BR-116), there is a railroad integrated to the Port of Santos and it is 150 Km far from the SJ. PE is 15 km away from the Fluvial Port of Petrolina. It is somewhat far from airports or railroads. CF is located 270 km away from the Fluvial Port of Pirapora (MG) and 560 km away from the Port of Vitória (ES). However it is close to the Pampulha Airport, in Belo Horizonte. This isn't favourable either since this is a domestic airport only. The railroad parallel to Highway Américo René Gianetti (MG-424) leads to the Fluvial Port of Pirapora, whose rail distance is 270 km far from CF. The judgments based on the data previously mentioned allows to derive the decision matrix M_3 , related to criterion *Receiving/flow off*.

M_3 = (13)

	GL	SJ	PE	CF
GL	1	1/3	3	3
SJ	3	1	5	5
PE	1/3	1/5	1	2
CF	1/3	1/5	1/2	1

The values attributed to the parameters *n* and *RI* and to the upper limit of *CR* are equals to the ones employed to calculate $\overline{A}_1$ and $\overline{A}_2$. The arranged data of C_3 is presented in Table 8.

Table 8: Arranged data of C3

	GL	SJ	PE	CF	$\overline{A}_3$
GL	1	1/3	3	3	0.2487
SJ	3	1	5	5	0.5502
PE	1/3	1/5	1	2	0.1185
CF	1/3	1/5	1/2	1	0.0826
λ_{max} = 4.1055 CI = 0.0352					CR = 0.0391

Vector $\overline{A}_3$ indicates that the alternative with the highest priority according to C_3 is SJ.

Obtained the priorities vector of the criteria $\overline{W}$ = (0.7674 , 0.0899, 0.1427) and the priorities vectors of the alternatives related to each criterion $\overline{A}_1$ = (0.6045, 0.0679, 0.0981, 0.2295), $\overline{A}_2$ = (0.1542, 0.6279, 0.0637, 0.1542) and $\overline{A}_3$ = (0.2487, 0.5502, 0.1185, 0.0826), the additive function $\bar{f}(A_j)$ is defined as follows::

$$\bar{f}(A_j) = \sum_{i=1}^{m} \overline{w}_i \times \mathbf{a}_j^i, \; j = 1,2,3,4 \qquad (14)$$

where

$\bar{f}(A_j)$: additive function that provide the weight of the alternative *j* related to the goal;

$\overline{w}_i$: normalized component of the vector $\overline{W}$;

$\mathbf{\bar{a}}_j^i$: weight of the alternative j related to the criterion i, obtained from the normalized vector $\bar{A}_i$; and
m : number of criteria.

The indices *subscripts j* of the alternatives are: 1=GL, 2=SJ, 3=PE and 4=CF and the indices i of the criteria are: 1= Runways and aprons, 2=Accessibility and 3= Receiving/flow off .

The priorities vectors are shown in Table 9 and result at the column $\bar{f}(A_j)$.

Table 9: Priorities vectors and results

$\bar{a}_j^i$ \ $\bar{w}_i$	0.7674	0.0899	0.1427	$\bar{f}(A_j)$
$\bar{a}_1^i$	0.6045	0.1542	0.2487	0.5132
$\bar{a}_2^i$	0.0679	0.6279	0.5502	0.1871
$\bar{a}_3^i$	0.0981	0.0637	0.1185	0.0979
$\bar{a}_4^i$	0.2295	0.1542	0.0826	0.2018

At the end of the modeling phase and the application of the method, it was obtained the priority of each alternative related to the goal. Considering the three criteria defined and the judgments of the four alternatives related to each criterion, *the optimal location of an industrial airport in Brazil is in Galeão Airport, whose priority is 51.32%.*

5. DISCUSSIONS AND CONCLUSIONS

The result of this research indicates that, considering the criteria and judgments of the author, the GL (Rio de Janeiro International Airport) is the optimal location for implementation of an industrial airport. CF (Confins Airport) and SJ (São José dos Campos Airport) have achieved same technical level of importance and both are good options, but at a lower level. On the other hand, PE (Petrolina Airport) did not provide the minimum necessary infra-structure according to the analysis.

Add-value processes located withing the airport infra-structure were at great importance to final results of this work. The authors considered that the airport infra-structure criterion (runway length, apron area, etc) strongly favored the GL site. Considering the enormous economic impact on important areas such as air traffic control, importation and exportation business, and employment, involving billions of dollars, the ideal procedure would be to arrange an expert panel for discussion. Even though such an expert panel could originate different results, the methodology provided in this paper could be similarly applied. Such research effort is being currently developed at the Aeronautical Institute of Technology.

6. FINAL CONSIDERATIONS

The problem of selection of the optimal location of an industrial airport in Brazil was proposed wth the application of the multi-criteria-decision-making-method AHP (Analytic Hierarchy Process). Additionally, the industrial airport concept was characterized. Then, the method was described and applied, considering three criteria and four alternatives. It was suggested further research involving critera with wide data banks and the reasons for possible different results obtained by the same method. Additional information about industrial airport can be obtained with the Brazilian Customs.

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