KEY FACTORS IN AIRCRAFT ASSESSMENT AND FLEET PLANNING: A MULTICRITERIA APPROACH

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ABSTRACT

The criteria identification to evaluate aircraft is crucial for fleet planning on air transport operations. Therefore, the objective of this study is to identify the key factors in aircraft evaluation from documentary research and analytical material. The results, based on the opinion of experts from these areas, showed that price, range, MTOW, seats and payload are the key factors to fleet planning. With these key factors, a decision-making model based on the Analytic Hierarchy Process (AHP) is presented. The hierarchical outcome listed three jet models to Brazilian regional aviation, the Embraer 195, SSJ 100 and CRJ 900, respectively.

Keywords: Airlines, Aircraft Evaluation, Analytic Hierarchy Process (AHP), Decision Making Process, Fleet Planning.

1 INTRODUCTION

From significant financial investment involved in the purchasing or aircraft leasing, it is necessary to evaluate and select technical and operational aspects in order to obtain the best balance between supply and demand in business management. Air fleet planning is therefore a strategic and multi-criteria process for companies in which it is necessary to identify the chief attributes required for such planning.

The literature shows that aircraft evaluation takes into consideration multiple attributes. It no longer relies just on traditional characteristics such as economic and financial aspects, but also on other relevant factors for the air transport industry (BRUNO; ESPOSITO; GENOVESE, 2015), in an increasingly competitive and complex market. In the Brazilian context, some studies have evaluated multiple criteria applied to the aerospace industry (LIMA; DAMIANI, 2010; SALGADO, BELDERRAIN; PALMÉRIO, 2010; FERREIRA FILHO; SALOMON, 2010). However, studies that address the identification of factors for air fleet evaluation and composition are still necessary.

Therefore, the objective of this study is to identify key factors for the acquisition and composition of an air fleet. As a secondary objective, the issue of aircraft assessment is addressed through a multicriteria approach using the Analytic Hierarchy Process (AHP) method. This method has been used in several areas (ZEYDAN; COLPAN; COBANOGLU, 2011; LI; LIU; CHEN, 2012; CALABRESE; COSTA; MENICHINI, 2013) as a support system for resource allocation, estimation and a process for selecting alternatives.

2 LITERATURE REVIEW

Due to the competitiveness of the air transport industry, fleet planning has become an increasingly complex process for airlines, because it involves multiple factors (DOZIC; KALIC, 2015). Since the second half of the 20th century, major aircraft manufacturers and international airlines have developed specific approaches to assessment and decision-making regarding aircraft acquisition. However, these approaches have been based mainly on direct operating costs and the analysis of net present value (BRUNO; ESPOSITO; GENOVESE, 2015).

In order to cast new light on this issue, Gibson and Morrell (2004), for example, present the use of Monte Carlo Simulation and the Real Options Analysis for aircraft assessment. Although these approaches improved the analysis by consideration of only operating costs and net present value, they were, nevertheless, based on a financial perspective.

Acknowledging the growing complexity of these processes, researchers have developed multi-attribute studies (SEE *et al.*, 2004; YEH; CHANG, 2009; GOMES; MATTOS FERNANDES; MELLO, 2012; DOZIC; KALIC, 2014). In these studies, in addition to financial variables, other criteria were considered, such as speed, range, cargo or passenger capacity, quality of services and environmental impacts. Although the academic literature presents some studies on the subject, there is still needs for new studies that evaluate aircraft from a broader perspective (BRUNO; ESPOSITO; GENOVESE, 2015).

See *et al.* (2004) present a broader approach, involving technical attributes such as speed, range and number of passengers. Although it was a step forward, because it analyzed the issue with new criteria, some attributes such as the costs, quality and issues related to environmental impacts were not considered. In addition, the mathematical formulation of the proposed method has become increasingly difficult to interpret with the appearance of new alternatives and attributes.

Yeh and Chang (2009) consider three criteria such as technological advances, social responsibility and economic efficiency, which were articulated with eleven subcriteria. For each criterion, the performance of each aircraft was evaluated. Using a pair-to-pair comparison, the authors evaluate the weights between the criteria and the weights between the sub-criteria within each criterion. These are translated into a classification that represented the general value for each type of aircraft. The proposed algorithm, however, was also quite complex, since the indicators of general performance

were highly correlated with the results of the proposed algorithm.

Gomes, Mattos Fernandes and Mello (2012) present an approach in which the evaluation process is based on three criteria, as financial, logistic and quality. These aspects are divided into 12 subcriteria (acquisition cost, liquidity, operating costs, range, flexibility, cruising speed, availability of spare parts, take-off and landing distance, comfort, avionics availability and safety). The result consisted of a set of alternatives resulting from a superior classification procedure, adapted from the PROMÉTHEE method. The method is relatively simple, but in practical applications, mathematical calculations are complex and the analysis of alternatives difficult to evaluate.

Dozic and Kalic (2014) present an approach based on a tool to support the decision-making. The proposal is to estimate the size of an air fleet based on the demand for travel. The attributes that are dealt with considered the demand and capacity for passengers, the investment necessary to purchase the aircrafts, payment conditions, cargo capacity, maximum take-off weight and total cost per available seat per mile. Several classifications are obtained by means of a paired evaluation of both the criteria and the presented options. The authors carried out a sensitivity analysis, by altering each element of the comparison matrix and keeping the others constant. In this way, they could monitor the process and identify possibilities and alternatives.

In summary, the literature review shows that the aircraft assessment process is being increasingly approached through the use of multiple attributes, not only considering traditional characteristics such as financial aspects, but other factors relevant to the air transport industry (BRUNO; ESPOSITO; GENOVESE, 2015). In the Brazilian context, some studies consider multiple criteria applied to the aerospace industry (LIMA; DAMIANI, 2010; SALGADO; BELDERRAIN; PALMERIO, 2010; FERREIRA FILHO; SALOMON, 2010). However, research that addresses the identification of factors for air fleet assessment and composition is still necessary.

3 METHODOLOGY

In order to achieve the objectives of the study, exploratory, bibliographic, documentary and applied researches were carried out. The exploratory research aimed at clarifying ideas in order to provide a broad view about the study subject and the formulation of hypotheses for new studies (GONSALVES, 2012). Therefore, this study tried to identify the factors and criteria, or possible attributes, required for the evaluation and acquisition of aircraft based on the current scientific literature and new advances.

The bibliographic research consisted of a systematic study on this subject in scientific articles and specialized literature. According to Vergara (2016), bibliographic research provides the analytical tools for other studies as well as first contact with the subject of study. Furthermore, research of the documents made available by the manufacturers (Embraer, Bombardier and Sukhoi Corporation) was carried out regarding the attributes of the respective aircraft under evaluation. Documentary research examines data, already collected and dealt with by other individuals or specific entities, with the aim of providing thorough analysis.

The motivation for conducting this applied research originated from the specific objective of finding an approach to solve a concrete problem, which in this case was the evaluation of aircraft for the composition of air transport fleets. In contrast to pure research, which seeks to create knowledge to contribute to the theoretical body of a particular field, applied research uses the articulated theory to a practical problem in order to verify its functionality (FELLOWS; LIU, 2008).

In order to carry out the applied research, the Analytic Hierarchy Process (AHP) developed by Saaty (1980) was used as a multicriteria decision-making method. This method is used to create a better foundation for the decision-making process in complex environments. In this study, the AHP stages were:

- **Stage 1:** Identification of the relevant factors for the definition of the characteristics of the model, of the criteria, of the subcriteria and of possible alternatives;
- **Stage 2:** Once the relevant factors in the literature were identified, interviews were conducted with experts from the air transport industry to weigh the criteria, subcriteria and possible alternatives.
- **Stage 3:** Construction of the structure for the hierarchical analysis process. After defining this structure, a pairwise comparison of the relative importance between the established criteria was conducted for each hierarchical level of matrix A based on the judgment of the decision maker $\mathbf{a_{ij}}$.

$$A = \begin{array}{c} \\ C_1 \\ C_2 \\ \dots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & 1 & \dots \\ a_{n1} & a_{n2} & \dots & 1 \end{bmatrix} \end{array}$$

Where $\mathbf{a_{ij} = 1/a_{ji}}$; i, j = 1,2, ..., n

- **Stage 4:** Determination of the weights to express the importance of the elements of a given level in the hierarchical matrix over those of a lower level using the pairwise comparison process between criteria and subcriteria. The criteria are compared according to the scale of judgments (SAATY, 1990) described in Table 1.
- **Stage 5:** Assessment of consistency. The pairwise judgment matrix was used to obtain a vector of priorities that corresponds to the weights

$$\mathbf{W} = [\mathbf{w_1}, \mathbf{w_2}, \dots, \mathbf{w_n}]^T \quad \mathbf{i = 1, 2, ..., n}$$

The weights vector was calculated from the mean value of the rows from the normalized pairwise comparison matrix A.

$$w_i = \frac{1}{n}\sum_j \left(\frac{a_{ij}}{\sum_i a_{ij}}\right) \quad i, j, = 1,2, \dots, n$$

- **Stage 6:** Assessment of the logical consistency of the judgment matrix. For an order n matrix, the number of judgments required is n(n – 1)/2. The consistency ratio, CR, is calculated by CR = CI / RI

Where: CI = $((\lambda_{max} - n)/(n - 1)$ and λ_{max} is the largest eigenvalue of A, RI is the mean value of CI (Consistency Index) and RI (Random Index) was obtained from Table 2 for different values of n.

Table 1 – Judgment Scale - Source: Saaty (1990).

Intensity of importance	Definition	Explanation
1	Equal Importance	Two activities equally contribute to the object
3	Weak importance of one over the other	Experience and judgment slightly favor one activity over the other.
5	Strong importance	Experience and judgment strongly favor one activity over the other.
7	Very strong importance	An activity is strongly favored over another and its dominance is demonstrated in practice.
9	Absolute importance	The evidence favoring one activity over another is of the highest order of affirmation
2, 4, 6 e 8	Intermediate values between two adjacent judgments	When a compromise condition is required between two settings.
Reciprocal of the values above	If an activity ***i*** has one of the non-zero values above when compared with the activity ***j***, then ***j*** has a reciprocal value when compared with ***i***	
Rationals	Ratios resulting from the Scale	If the consistency was forced to obtain n numerical values to cover the matrix.

Table 2 – Random indices

n	1	2	3	4	5	6	7	8	9	10	11	12
IR	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.51	1.54

Saaty (1990) propose a table of random indexes (RI) of matrices of order 1 to 15 calculated in the laboratory. Table 2 (Consistency Assessment) limits the number of items to be compared in one matrix to 15 criteria. Saaty (1990) still suggests the use of the Consistency Ratio, considering the Consistency Index (CI) and the Random Index (RI), which varies with the sample size (n). Consistency Ratio values so that the matrix is considered consistent are shown in Table 3.

Table 3 - CR values to analyze consistency

Number of criteria	**Consistency ratio**
3	< 0.05
4	< 0.09
> 4	< 0.10

When the matrix obtained from the matched comparison between the criteria is inconsistent, it becomes necessary for the evaluator to revise this comparison until it becomes consistent. Next, the priority vector is determined.

- **Step 7:** The comparison matrix between the alternatives was then constructed for each criterion, and the performance of each alternative compared with the considered criteria could be judged.
- **Step 8:** Thus, the global priorities were obtained by means of a simple weighted sum, and the score of each alternative enabled the determination of the final classification.

4 RESULTS

The analysis and interpretation of the findings in scientific literature enabled identification of factors and criteria related to the evaluation of aircraft for the composition of fleets. Therefore, it was possible to answer the study question and helped achieve the specific objective of addressing decision-making factors on aircraft assessment through a multicriteria approach. For the organization of the study, a summary of the main attributes identified in the literature review was elaborated, as presented at Table 4.

From these factors presented on Table 4, criteria and/or attributes guided the documentary research, which was carried out considering regional aviation, due to its growth potential especially in Brazil (IPEA, 2010). Based on the analysis of the manuals and catalogs of technical specifications of several manufacturers, the following aircrafts and their attributes were evaluated: *Bombardier* CRJ 900 jets (Canada), Embraer 195 (Emb 195) by Embraer (Brazil) and the SSJ 100 by *Sukhoi Corporation* (Russia). The choice for these aircraft was justified by their similarity and because they were designed for the regional aviation market. In addition, these manufacturers are direct competitors. Table 5 shows data from the analysis of the documents with the attributes assessed in the applied research.

After the bibliographic and documentary research completed, the structural modeling of the applied research problem, (i.e., the elaboration of the hierarchy of the problem) was carried out Figure 1

The pairwise comparison matrix of the criteria of the first level of the hierarchical structure of the problem is shown in Table 6, followed by the priority vector. According to Saaty (1990), the priority vector is the eigenvalue of the matrix; therefore priorities are calculated from the pairwise comparison using the AHP method.

Table 4 - Summary of studies on air fleet assessment and composition - Source: literature review.

Authors	Factors and criteria for Aircraft Assessment
GIBSON and MORRELL (2004)	- Operational costs; - Net present value.
SEE *et al*. (2004)	- Speed; - Range; - Number of passengers.
YEH and CHANG (2009)	- Technological advancements; - Social responsibility; - Economic efficiency.
GOMES, MATTOS FERNANDES and MELLO (2012)	- Acquisition costs, liquidity; - Operational costs; - Range; - Flexibility; - Cruising velocity; - Availability of replacement parts; - Take-off and landing distance; - Avionics availability, comfort, and security.
DOZIC and KALIC (2014)	- Passenger Capacity; - Necessary investment for aircraft purchase; - Payment conditions; - Cargo capacity, - Maximum take-off weight (MTOW); - Total cost per seat available per miles.

Table 5 - Aircraft factors and characteristics to be considered in decision-making process. Source: data from documentary research.

Aircraft	Price (US$ Millions)	Number of seats	Maximum take-off weight (ton.)	Payload (kg)	Range (km)
CRJ 900	41	79 – 90	36.5	10.319	3.620
Emb 195	39.5	108 – 124	52.3	13.950	4.077
SSJ 100	35	98	49.4	12.147	4.578

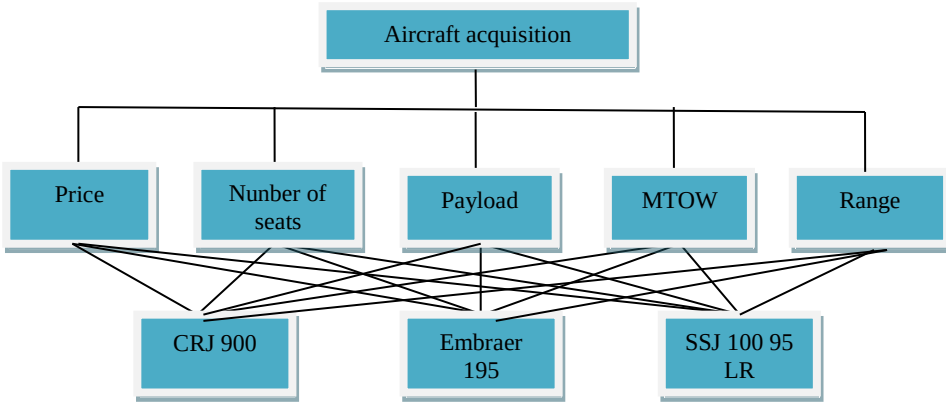


Figure 1 – Hierarchy of criteria and alternatives

Table 6 - Pair-by-pair comparison matrix for the first level

	Price	Number of seats	Payload	MTOW	Range	Priority vector
Price	1	5	5	7	3	0.468
Number of seats	0.20	1	0.20	6	3	0.163
Payload	0.33	1	1	3	3	0.193
MTOW	0.20	0.50	0.33	1	3	0.108
Range	0.33	0.33	0.14	0.33	1	0.067

$\lambda_{máx}$ = 5.284 ***CI*** = 0.071 ***CR*** = 0.0633

Price had the highest priority (0.468) followed by the payload (0.193) and the number of seats (0.163). The consistency ratio (CR) indicates the level of acceptable inconsistency (0.0633).

Table 7 shows the comparison matrix of the aircraft considering the price and the respective vectors of local priorities.

Table 7 - Matrix of comparison of the aircraft with respect to price

Price	CRJ 900	Emb 195	SSJ 100	Priority vector
CRJ 900	1	0.50	0.33	0.170
Emb 195	2	1	1.0	0.387
SSJ 100	3	1	1	0.443

$\lambda_{máx}$ = 3.051 ***CI*** = 0.025 ***CR*** = 0.044

Table 7 shows that the SSJ 100 aircraft has the highest price priority (0.443), followed by the Embraer 195 aircraft (0.387).

Table 8 shows the aircraft comparison matrix with the criterion of number of seats and the respective local priority vectors.

Table 8 - Matrix of comparison in relation to the number of seats

Number of seats	CRJ 900	Emb 195	SSJ 100	Priority vector
CRJ 900	1	0.33	0,40	0.151
Emb 195	3	1	2	0.532
SSJ 100	2.50	0.50	1	0.317

$\lambda_{máx}$ = 3.036 ***CI*** = 0.018 ***CR*** = 0.031

According to Table 8, the Embraer 195 aircraft has the highest priority in relation to the number of seats (0.532) followed by the aircraft SSJ 100 (0.317).

Table 9 – Matrix of comparison in relation to the MTOW

MTOW	CRJ 900	Emb 195	SSJ 100	Priority vector
CRJ 900	1	0.29	0.50	0.152
Emb 195	3.5	1	2	0.557
SSJ 100	2	0.50	1	0.291

$\lambda_{máx}$ = 3.008 ***CI*** = 0.004 ***CR*** = 0.007

Table 9 shows the comparison matrix of the aircraft with respect to the maximum take-off weight (MTOW) and the respective local priority vectors.

From the Table 9, the Embraer 195 aircraft has the highest priority with respect to MTOW (0.557), followed by the SSJ 100 (0.291).

Table 10 shows the comparison matrix of the aircraft in relation to the payload and its priority vectors.

Table 10 - Comparison matrix with respect to payload

Payload	CRJ 900	Emb 190	SSJ 100	Priority vector
CRJ 900	1	0.33	0.40	0.151
Emb 195	3	1	2	0.532
SSJ 100	2.50	0.50	1	0.317

$\lambda_{máx}$ = 3.036 ***CI*** = 0.018 ***CR*** = 0.031

The Table 10 shows that the Embraer 195 aircraft has the highest priority with respect to the payload (0.532) followed by the SSJ 95 (0.317).

At the Table 11 is presented a comparison matrix of the aircraft with respect to their range and respective local priorities vectors.

Table 11 - Comparison matrix regarding range

Range	CRJ 900	Emb 190	SSJ 100	Priority vector
CRJ 900	1	3	3	0.148
Emb 195	7	1	7	0.581
SSJ 100	5	0,20	1	0.271
$\lambda_{máx}$ = 3.001	***CI*** = 0.000		***CR*** = 0.001	

According to Table 11, the Embraer 190 aircraft has the highest priority (0.581) with respect to the range followed by the SSJ 100 95 (0.271).

The solution to the problem proposed in this study, after conducting the Analytic Hierarchy Process (AHP), is presented in Table 11. The consistency ratio for the matrix represented in Table 3 was less than 0.10 and lower than 0.05 (below 10%) for Tables 6 through 11. Therefore, the validity of the solution achieved could be verified.

Table 12 - Local and global priority measures

	Price	Number of seats	Payload	MTOW	Range	Priority vector
CRJ 900	0.170	0.151	0.151	0.152	0.148	0.154
Emb 195	0.387	0.532	0.532	0.557	0.581	0.517
SSJ 100	0.443	0.317	0.317	0.291	0.271	0.327

According to the procedure applied and the Table 12, the most appropriate aircraft for the proposed situation is the Embraer 195 aircraft, followed by the SSJ 100 and the CRJ 900.

5 FINAL CONSIDERATIONS

Aircraft fleet planning is a strategic process for an airline. Its relevance rests in the attempt to adapt the transport capacity to the estimated demand, market conditions and the technical and financial criteria. Aircraft acquisition involves the mobilization of large investments. Therefore, the selection of aircraft that meet the key criteria to minimize inherent risks of airline operations is crucial to business viability and passenger satisfaction.

In addition to executing traffic planning with a minimum possible number of aircraft, lower operating costs and maximum possible utilization, airlines must not neglect the fact that passengers are interested in a high level of service with the right quality. For example, frequent and direct flights with the minimum connections, high safety and comfort. Therefore, planners and managers in the decision-making process should seek the best solution that harmonizes these conflicting interests.

The aircraft selection problem considered in the present study is part of a more complex multicriteria decision. Considering the criteria selected here (number of seats, aircraft price, payload, maximum take-off weight and range), other aspects for the acquisition of aircraft could be contemplated, allowing the planner to choose the best aircraft from a set of alternatives. In this study it was shown that the AHP is a useful tool to support the decision-making process according to the criteria defined for this study.

In future studies, these results could be compared with results obtained by the application of other multicriteria methods of a decision-making process so that the sensitivity of the solution to these types of changes can be seen.

In addition, other relevant variables to the aircraft selection and acquisition process could be incorporated and analyzed.

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