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MULTI ATTRIBUTE DECISION MAKING: ASSESSING THE TECHNOLOGICAL AND OPERATIONAL PARAMETERS OF AN AIRCRAFT

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Abstract. Regional aircraft are playing a significant role in airline operations. This paper considers the problem of selecting an appropriate aircraft from the airline fleet for optimal regional air travel realization. Complexity balance between air travel demand (passengers, goods) and the proposed aircraft capacity presents the priority in airline operations. A principal feature of the methodology considered in this paper is a multi attribute analysis of technological and operational aircraft characteristics (turboprop and turbojet). A comparison of the presented regional aircraft parameters is based on the following criteria: technological (aerodynamic efficiency, structural efficiency, fuel flow at the optional FL, cruise endurance and requested trip fuel for the fixed cruise range), operational (max range with max payload, ground efficiency (aircraft maintainability based on external dimensions) and climb capability. With the aim of defining aircraft rank, the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method was applied. Therefore, the Saaty scale was used for developing the weight of different criteria. The conducted research included a sample of four representative regional aircraft: Do328, CRJ100er, Saab2000 and ERJ145. The results obtained would help in determining the airline fleet or selecting the optional solution from the existing fleet.

Keywords: multi attribute decision making method, aircraft ranking, aircraft technological parameters, aircraft operational parameters.

1. Introduction

Regional aircraft are playing a significant role in airline operations. Nowadays, the results of technological evolution indicate a constant increase in the number of aircraft in an airline fleet. The fleet having a large number of regional aircraft similar in their performances, technological or operational parameters sometimes causes a serious problem of selecting an appropriate aircraft for flight realization. Which one is the right choice? This is a question frequently addressed to airline management. With the aim to avoid doubts about specific flight circumstances, an algorithm for a fast evaluation of aircraft ranking was developed.

According to (Brauers *at al.* 2008; Zavadskas *et al.* 2008, 2010a; Šelih *et al.* 2008; Ginevičius *et al.* 2008; Ginevičius and Podvezko 2009; Jakimavičius and Burinskienė 2009a, 2009b; Turskis *et al.* 2009; Antuchevičienė *et al.* 2010), our values, beliefs and perceptions are forces behind almost any decision-making activity. They are responsible for the perceived discrepancy between the present and a desirable state. Different stakeholders with different interests and values make a decision-making process on different decision alternatives even much more complicated. In the Multi-Objective Decision-Making (MODM) context, the evaluation of each alternative on the set of objectives facilitates selection. MODM is also referred as:

– Multi-Criteria Decision Analysis (MCDA);
– Multi-Dimensions Decision-Making (MDDM);
– Multi-Attributes Decision-Making (MADM).

Therefore, multi-objective techniques seem to be an appropriate tool for ranking or selecting one or more alternatives from a set of the available options based on multiple and sometimes even conflicting objectives.

Considering the nature of information available to decision makers, MODM can be divided into several groups (Ustinovichius *et al.* 2007) where the paper presents the methods based on a reference point or goal such as the Reference Point Method used in TOPSIS (Hwang 1981; Zagorskas and Turskis 2006; Zavadskas *et al.* 2006, 2010b; Liu 2009; Liaudanskienė *et al.* 2009; Jakimavičius and Burinskienė 2007; Kapliński and Janusz 2006).

The results obtained in the paper would help with determining the airline fleet or selecting the optional

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solution to the existing fleet. With the aim of defining aircraft rank, the TOPSIS method was applied. Therefore, the method based on the Saaty scale was used for developing the weights of different criteria. The analytic hierarchy process of Thomas L. Saaty has emerged in the last 15–18 years as a major tool for multi attribute decision analysis. The method was well documented by Saaty himself (Saaty 1977, 1980).

2. Description of the Method for Aircraft Ranking Based on Operational and Technological Parameters

The paper describes a decision making methodology for aircraft ranking based on the TOPSIS method. According to (Hwang 1981), the TOPSIS (Techniques for Order Preference by Similarity to Ideal Solution) method is a multiple criteria method that identifies a solution from a finite set of points. The basic principle is that the chosen points should have the 'shortest' distance from the positive ideal and the farthest 'distance' from the negative ideal solution. In the TOPSIS model, the measurement of weights and qualitative attributes do not consider uncertainty associated with mapping human perception to a number. Generally, aircraft (the alternative) comparison is based on different criteria the weights of which are normalized and evaluated subjectively. This method reviews an ideal and non-ideal solution from the perspective of criteria matrix. Finally, the TOPSIS method is used for order preference taking into account similarity to an ideal solution. The goal of this paper is setting aircraft rank from the airlines point of view. For that reason, priority is given to operational criteria such as maximum range with maximum payload.

2.1. The Method of the Normalized Weight of Criteria Based on the Saaty scale

As noticed before, the final outputs from this method are the normalized weights of criteria. The following algorithm performs a methodology for weight normalization presented in Eq. (1):

1. Define the total number of criteria for alternative ranking (n_k).
2. Estimate relationship between each pair of criteria (k_i, k_j; $i, j=1..m$) applying the Saaty scale (1–9).
3. Apply the following formula (Eq. 1) to calculate normalized weight for certain criteria:

$$w_i = \frac{\sum_{j=1}^{m} \frac{k_j}{\sum_{i=1}^{m} k_j}}{n_k}. \quad (1)$$

2.2. Algorithm

The proposed algorithm considers the following steps:

1. Select 2 or more aircraft (alternatives);
2. Select technological and operational aircraft parameters (criteria) for certain flight conditions (e.g. same FL);
3. Apply the method of the normalized weights of criteria based on the Saaty scale to compare each pair of criteria by transforming subjective linguistic expressions into the normalized weights;
4. Apply the TOPSIS method for the chosen alternatives (aircraft), defined criteria (technological and operational parameters) and the normalized weights of criteria;
5. Analyze the obtained results and propose countermeasures (the obtained aircraft rank presents an aircraft sorted list from the best to the worst solution for the settled flight conditions).

3. Case Study: Assessment of the Technological and Operational Parameters of a Regional Aircraft Applying the Multi Attribute Decision Making Method

This example evaluates aircraft priority based on technological and operational performances for four typical regional aircraft (Do328, CRJ100er, Saab2000 and ERJ145) frequently used worldwide for the scheduled and non-scheduled flights (Vujić *at al.* 2004). Data collection is based on the published manuals of a manufacturer (Maintainability and Reliability Features 1972; 328JET Program 1998; Canadair Regional Jet… 1994) and aircraft annual publications (Lambert 1990).

3.1. Technological Parameters of Aircraft

3.1.1. Aerodynamic Efficiency

Investigation into aerodynamic efficiency is based on the previously defined flight conditions chosen to be common for each observed aircraft. For this purpose, parasite drag coefficients were established for assumption cruising altitude FL290. Maximal lift-drag rate (C_z/C_x) enables a flight with max range. The evaluation of *L/D* rate is based on typical cruise speed (*TAS*), parasite drag coefficient (C_{x0}) and induced drag coefficient (κ) at FL290 (Table 1).

Depending on the engine type (turboprop or turbojet), a single aircraft is able to realize max range for given FL if *L/D* rate is equal to appropriate formulas:

$$\text{Turboprop} \left(\frac{c_z}{c_x}\right)_{\max} = \frac{\sqrt{c_{x0}\kappa}}{2c_{x0}}; \quad (2)$$

$$\text{Turbojet} \left(\frac{c_z^{\frac{1}{2}}}{c_x}\right)_{\max} = \frac{\sqrt[4]{\frac{1}{3}c_{x0}\kappa}}{\frac{4}{3}c_{x0}}. \quad (3)$$

Based on Eq. (2) and Eq. (3), the aerodynamic efficiency of the proposed aircraft is calculated as shown in Table 2.

Table 1. Aerodynamic parameters (FL290)

	Do328	CRJ100er	Saab2000	ERJ145
TAS [kts]	349	438	367	416
C_{x0}	0.028 000	0.023 178	0.033 000	0.017 718
κ	0.045 000	0.035 434	0.047 000	0.032 898

Table 2. Aerodynamic efficiency

	Do328	CRJ100er	Saab2000	ERJ145
$(C_z/C_x)_{max}$	14.086	X	12.696	X
$(C_z^{1/2}/C_x)_{max}$	X	22.110	X	27.550

3.1.2. Structural Efficiency

Aircraft structural efficiency (σ) could be defined from the rate of max useful load – max payload (*P/L*) and max structural load (*MTOW*) (Table 3).

$$\sigma = \frac{Payload_{\max}}{MTOW}. \quad (4)$$

Table 3. Structural efficiency

	Do328	CRJ100er	Saab2000	ERJ145
Max P/L [kg]	3450	6295	5896	4500
MTOW [kg]	12500	23133	21320	17000
σ	0.276	0.272	0.277	0.265

3.1.3. Fuel Flow, Endurance and Trip Fuel

Based on contemporary aircraft databases (Base of Aircraft Data 2007), fuel flow is established for each aircraft under FL290 and nominal flight regime. In order to set the same conditions for the whole observed aircraft, the chosen flight parameters such as endurance (cruising flight time) and trip fuel were calculated for 200 nm cruise section with cruise clean configuration (Table 4).

Table 4. Fuel flow, endurance and trip fuel (FL290, *R* = 200 nm)

	Do328	CRJ100er	Saab2000	ERJ145
Fuel flow [kg/min]	10.7	20.6	13.4	19.3
Endurance [min]	34.4	27.4	32.8	28.85
Trip fuel [kg]	368	564.44	439.52	556.73

3.2. Operational Parameters of an Aircraft

3.2.1. Max Range with Max Payload

Max range with max payload represents one of the most important parameters from the airline operator's perspective. As previously described, a significant priority is given to this criterion (Table 5).

3.2.2. Ground Efficiency

Ground efficiency represents aircraft maintainability and aircraft handling availability. These parameters could be analyzed through the external dimensions of an aircraft. Aircraft maintenance is a complex and high cost procedure (12–15% of the total annual company costs). It is possible to reduce regular aircraft check time and handling time if systems, engines, structure, doors height to sill etc. have a high degree of maintainability. From this point of view, an aircraft having a lower value of external dimensions is warmly recommended. This kind of system position requires simple and fast handling and maintenance equipment. This paper has found useful the following parameters to be minimized: wing span, nacelle clearance, wing tip height, landing gear height, service door height to sill, baggage door height to sill, horizontal tail tip height, vertical tail height, APU clearance and length overall.

Considering the purpose of this article, ground efficiency (Table 6) is calculated by ground efficiency parameter (*g*) obtained from the following (Eq. (5)):

$$g = \frac{\sum_{i=1}^{10} n_i}{i}, \quad (5)$$

where: n_i is *i-th* ground efficiency parameter expressed in meters.

Table 6. Aircraft ground efficiency

[m]	Do328	CRJ100er	Saab2000	ERJ145
Wing span	20.98	21.21	24.76	22.57
Nacelle clearance	2.38	2.018	0.91	1.03
Wing tip height	3.356	1.358	2.45	2.36
Landing gear height	0.839	1.1	1	1.28
Service door height to sill	1.203	1.63	1.63	1.76
Baggage door height to sill	1.371	1.63	1.68	1.89
Horizontal tail tip height	7.623	5.688	3.66	6.13
Vertical tail height	7.971	6.238	6.71	6.30
APU clearance	2.823	2.75	X	3.30
Length overall	21.22	26.77	27.03	25.47
g	7.438	7.039	7.759	7.209

Table 5. Max range with max payload

Aircraft	Description	Range
Do328	Range with 30 passengers, with allowance for 100 nm (185 km) diversion at max cruising speed	701 nm/1300 km
CRJ100er	Range with max payload (50 passengers) at long range cruising speed FAR Pt121 reserves	1620 nm/3000 km
Saab2000	Range with 50 passengers and baggage, reserves for 45 min hold at 1525 m (5000 ft) and 100 nm (185 km) diversion at max cruising speed	1345 nm/2492 km
ERJ145	Range with reserves for 100 nm (185 km) diversion, 10% block fuel remaining and 30 min hold with 45 passengers (4082 kg: 9000 lb payload)	1340 nm/2483 km

3.2.3. Climb Capabilities

Aircraft climb capabilities up to the cruise flight level are defined through the polar equation of an aircraft (results for a certain aircraft are shown in Table 7):

$$\partial\left(\frac{c_z^3}{c_x^2}\right) = 0 . \qquad (6)$$

Table 7. Climb Capabilities

	Do328	CRJ100er	Saab2000	ERJ145
$(C_z^3/C_x^2)_{max}$	43.16	60.25	38.07	74.22

3.3. Multi-Attribute Analysis of the Technological and Operational Parameters of an Aircraft

A subjective evaluation of criteria based on the Saaty scale is shown in Table 8. The method of the normalized weight of criteria provides the following results for a certain aircraft (Table 9).

Aircraft rank based on the previous weight of criteria and the TOPSIS method is (from the best to the worst solution) as follows:

1. CRJ100er;
2. Saab2000;
3. ERJ145;
4. Do328.

Table 8. The evaluation of criterion weight

W1	W2	W3	W4	W5	W6	W7	W8
0.049	0.074	0.157	0.157	0.163	0.344	0.021	0.042

4. Conclusions

1. This paper aims at aircraft rank assessment based on technological and operational parameters. The proposed multi attribute decision making methodology considers the items determined to be important to understanding the most important technological and operational characteristics of a regional aircraft. These items include aerodynamic efficiency, structural efficiency, fuel flow at the optional FL, cruise endurance and requested trip fuel for the fixed cruise range, max range with max payload, ground efficiency (aircraft maintainability based on external dimensions) and climb capability. Although this research considers four representative regional aircraft (CRJ100er, Saab2000, ERJ145 and Do328), it is probably exportable to any regional aircraft.
2. In addition, airline management could use this method as assistance in determining an adequate aircraft for specific flight realization or for determining a new aircraft in the fleet. The proposed methodology applied to different regional aircraft types could provide a consistent database. Further research can debate the utilization of the outputs from the proposed methodology to establish an extended database to improve a tool for airline decision-making which depends on the operating conditions and financial soundness of the carrier etc.

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Table 9. The estimation of relationship between criteria

	Aerodynamic efficiency	Structural efficiency	Fuel flow	Endurance	Trip fuel	Max range	Ground efficiency	Climb capabilities
Aerodynamic efficiency	1	0.5	0.25	0.25	0.25	0.14	5	1
Structural efficiency	2	1	0.33	0.33	0.33	0.2	6	2
Fuel flow	4	3	1	1	1	0.33	7	4
Endurance	4	3	1	1	1	0.33	7	4
Trip fuel	4	3	1	1	1	0.33	7	4
Max range	7	5	3	3	3	1	9	6
Ground efficiency	0.2	0.17	0.14	0.14	0.14	0.11	1	0.5
Climb capabilities	1	0.5	0.25	0.25	0.25	0.17	2	1

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