Aircraft Type Selection Problem: Application of Different MCDM Methods

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Abstract. In order to make a proper choice when selecting aircraft type, planners can apply some of multiple criteria decision-making (MCDM) methods as an aid to decision making. In this paper, three MCDM methods, Analytic Hierarchy Process (AHP) and Fuzzy Analytic Hierarchy Process (FAHP) as widely used methods based on hierarchy and Even Swaps Method (ESM) that belongs to group of so-called dominance methods, are applied onto the same problem, under the same conditions and illustrated with a case study of a hypothetical airline. These methods are compared, as well as solutions they arrived at. Considering the difference among the methods, a sensitivity analysis is carried out in different ways. In the AHP and FAHP, the sensitivity of alternative ratings in respect to different pairwise comparisons of the alternatives is analyzed, showing that the methods are sensitive to this kind of changing. In the even swaps method, the objective ranking across alternatives is varied, showing that the ESM is not sensitive at all.

Keywords: Aircraft type selection · AHP · FAHP · Even Swaps Method

1 Introduction

One of the main factors that affects airline success is bringing supply and demand in observed market conditions and economic environment as closely together as possible. Moreover, airlines should both make profit and keep their customers (passengers) satisfied, while costs should be as low as possible. In order to be able to accomplish their mission in the market most suitably, airlines need appropriate methodological approach for the fleet planning process, corresponding fleet selection and permanent fleet management.

When it comes to airline fleet, it should be noted that the two main fleet features are fleet structure and fleet size. Fleet structure represents the number of different aircraft types in the fleet; thus, it could be single fleet (only one type of aircraft) and multi fleet (more than one aircraft type in the fleet). In case of single fleet, maintenance costs and cost of flight crew are lower in comparison to multi fleet. On the other hand, different aircraft types in the fleet enable airlines to match demand and supply more closely, make high passengers' load factors and increase their income. Therefore, it is very important to plan the fleet structure according to airline's needs. Fleet size represents the number of aircraft by different types and the total number of aircraft in the airline's fleet, and it also

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needs to be determined according to the airline's requirements. Number of aircraft larger than required means lower fleet utilization, which further induces increase of costs. Number of aircraft lower than required means spill of the demand, i.e. reallocation of passengers to competitor's flights and missing out on the opportunity to earn money. Both fleet structure and fleet size must be determined properly in order to enable the airline to realize the planned schedule and generate a profit.

In order to retain its market position, an airline need to manage its fleet, which means that it should permanently monitor the fleet and decide how many aircraft and when would be acquired (bought or leased) and retired. The existence of a large number of different aircraft types, which would have certain mission and purpose and which could operate markets that have different air travel demand and characteristics, emphasizes the complexity of aircraft type selection problem. Aircraft should be chosen to be used in the future and to meet air travel demand in given market conditions (price and competition). In order to select appropriate aircraft type, planners very often have to balance multiple, usually conflicting criteria. Interests of both the airline and passengers must be considered, as well as operational requirements. In order to provide a satisfactory choice while dealing with multiple criteria, planners can apply some of the multiple criteria decision-making (MCDM) methods as an aid to decision making. Since the last decade has been very turbulent for the global airline industry, airlines - as one of the players - are faced with the inability to respond to market and demand changes adequately. Different infectious diseases, volcanic eruptions and terrorist attacks had direct impact on air travel demand. Since the airline industry is one of the main pillars of global economy, it was directly affected by the world financial crisis which has further resulted in job reduction, losses and bankruptcies. Therefore, certain airlines could still go bankrupt and could be replaced by new ones, while others could have an opportunity to confirm their market position. For all airlines, either new ones or airlines that are well positioned in the market, fleet planning and aircraft type selection are very important and always actual problems, which have motivated the authors to research them.

This paper proposes three different MCDM methods for the aircraft type selection: Analytic Hierarchy Process (AHP), Fuzzy Analytic Hierarchy Process (FAHP) and Even swaps method (ESM). According to [13, 14], AHP and FAHP are applied to various problems, and could be considered as widely used methods (over 150 papers are cited in each paper). Considering their application in different areas and their frequencies of appearance in the relevant literature we have been found reasonable to choose them for comparison. Furthermore, the AHP and FAHP are MCDM methods based on pairwise comparisons, while the ESM is a method that belongs to a group of so-called dominance methods, which is not widely used. It was interesting to compare these three methods due to their diversities. Sometimes it is possible to use each of the techniques, but sometimes the technique is determined on the basis of the data availability. The main contribution of the paper is that it indicates methods suitability depending on the data availability. Our goal is to show that different MCDM methods can be used as an effective solution for the same problem.

The introduction and review of the relevant literature are followed by the main issues related to aircraft type selection, pointing out the criteria that should be considered. After appropriate criteria selection, three MCDM methods - Analytic Hierarchy Process (AHP), Fuzzy Analytic Hierarchy Process (FAHP) and Even swaps method (ESM) - are applied to the same problem of regional aircraft type selection and their applicability is illustrated through a hypothetical airline case study.

2 Literature Review

Many researchers consider aircraft type selection problem in different ways. Papers related to aircraft selection/evaluation problem are given in chronological order in Table 1. Multi-attribute decision making based on hypothetical equivalents and inequivalents is used to establish a fleet with one type of aircraft to serve the routes on major cities among Asia Pacific countries and the United States [17]. Three criteria are used in order to choose an aircraft. The authors have neglected to consider the most important criteria related to economic and financial issues. In the study that presents the model for aircraft selection in the case of a Saudi Arabian airline with the base in Jeddah and Madniah [9, 10], specific aircraft types are chosen for consideration based on air travel demand and aircraft performance parameters for given route network. Cost efficiency is calculated using Excel application, and results are low seat mile cost and low trip cost per sector, which could help airline planner to choose the right aircraft. A systematic evaluation model is proposed for selection of an optimal training aircraft for Air Force Academy, mainly from the perspective of pilot drillmasters and trainees [19]. This is the single paper which threats military aviation. New fuzzy group MCDM approach is proposed for aircraft selection problem faced by Taiwan's domestic airline for its major routes [23]. The Analytic Network Process (ANP) is suggested to help choosing a middle range aircraft for Turkish Airlines [15]. Costs, time and physical attributes and others are considered as the main criteria. The three groups of criteria (financial, logistics and quality) in the multi-criteria decision aiding method named NAIADE (Novel Approach to Imprecise Assessment and Decision Environments) are proposed for the aircraft selection problem in regional charter flights in Brazil [7]. Four criteria and eight sub-criteria are selected to support aircraft evaluation using hybrid approach based on AHP and fuzzy set theory in final ranking [3]. As aircraft type selection is recognized as multi-criteria decision making, the AHP and ESM are applied [4, 6], and further compared [5] to research their solution sensitivity to different changes. The robust three-stage model developed in [6] involves approximate fleet composition (number of aircraft types), fleet sizing (number of aircraft per each type) and aircraft type selection (specific types of aircraft) based on fuzzy logic, heuristic and analytic approaches, and multi-criteria decision making, respectively.

Considering cited literature and Table 1 it can be seen that most of researchers employ different MCDM approaches. Ranking of alternatives is usually offered as result [3, 4, 5, 7, 15, 19, 23].

Table 1. The problem of aircraft type selection in the literature

Authors (year)	Approach	Parameters	Technique	Output
See et al. (2004) [17]	Multi-attribute methodology	Speed, range, number of passengers (pax)	Method of the hypothetical equivalents and inequivalents	Single robust optimal alternative (aircraft – a/c)
Harasani, W.I. (2006) [9], Harasani, W.I. (2008) [10]	Five step approach based on number data analysis	Number of pax per route, a/c performance parameters, cost efficiency (DOC) including fuel cost, maintenance cost, annual insurance rate, annual salaries paid, traffic allocation and scheduling	No specific technique	Opt. efficiency a/c - low seat mile cost and low trip cost per sector
Wang, T-C, Chang, T-H. (2007) [19]	MCDM approach/group decision	A/c performance parameters (power plant, stalling speed when flameout, max operating speed, max G limits and fuel capacity)	TOPSIS with a fuzzy environment	Ranking of the seven military aircraft
Yeh, C-H, Chang, Y-H. (2009) [23]	Fuzzy group MCDM approach	Technological advance (maintenance, pilot adaptability, a/c reliability, max range), social responsibility (passenger preference, noise level), economical efficiency (operational productivity, airline fleet economy of scale, purchasing price, DOC, consistency with corporate strategy)	New fuzzy MCDM algorithm	Ranking of the five aircraft
Ozdemir et al. (2011) [15]	MCDM approach	Cost (purchasing, operation and spare, maintenance, salvage), time (delivery time, useful life), physical attributes and others (dimensions, security, reliability, suitability for service quality)	Analytic Network Process (ANP)	Ranking of the three aircraft

(*continued*)

Table 1. (*continued*)

Authors (year)	Approach	Parameters	Technique	Output
Gomes et al. (2012) [7]	Fuzzy stochastic approach	Financial (acquisition cost, liquidity, operating cost), logistics (range, flexibility, cruising speed, replacement parts availability, landing and take-off distance), quality (comfort, avionics availability, safety)	NAIADE method	Ranking of the eight aircraft
Dožić, S, Kalić, M. (2014) [4]	MCDM approach	Price of aircraft, payment conditions, total cost per available seat miles (CASM), seat capacity, total baggage, MTOM	AHP	Ranking of the seven aircraft
Dožić, S, Kalić, M. (2015) [6]	Three stage approach with MCDM	Air travel demand, distance; airline schedule; aircraft seat capacity, price of aircraft, luggage per passenger, MTOM, unit trip costs	Fuzzy logic, heuristics and Even swaps method	Fleet structure, fleet size, the most appropriate aircraft
Dožić, S, Kalić, M. (2015) [5]	MCDM approach	Price of aircraft, payment conditions, total cost per available seat miles (CASM), seat capacity, total baggage, MTOM	AHP and Even swaps method	Ranking of a/c and single, the most appropriate a/c
Bruno et al. (2015) [3]	Hybrid approach with MCDM	Economic performance (operative costs/(range*seats), aircraft price), technical performance (speed, autonomy), aircraft interior quality (seat comfort, cabin luggage compartment size), environmental impact (environmental pollution, noise)	AHP and Fuzzy Set Theory	Ranking of the three aircraft

It is interesting to note that fuzzy set theory is used in three papers [3, 6, 19], but in different ways and in different stages of modelling. In the given papers a variety of criteria/sub-criteria are used, as well. These criteria generally could be recognized as airline, passengers or environmental oriented. In this research, we keep the criteria from previous work [4, 5] that are the most relevant from the airline's perspective. Considering the literature mentioned above, we find out that none of the paper compares three MCDM methods, therefore, we decide to investigate this topic, and contribute by giving comparison based on the problem of aircraft type selection. Hence, AHP and FAHP which have found significant and successful applications in different fields [13, 14] are employed to help airline planners when choosing appropriate aircraft type. In order to learn the advantages and disadvantages of different MCDM methods and possibilities of their application depending on the data that are available, we compare AHP, FAHP and ESM. Considering the difference among the MCDM methods, the sensitivity analysis is carried out in different ways. In the AHP and FAHP, the sensitivity of alternative ratings with respect to different pairwise/fuzzy pairwise comparisons of the alternatives is analyzed, while in the ESM the objective ranking across alternatives is varied in order to learn solution sensitivity.

3 Main Issues in Aircraft Evaluation Process

Whereas profitability of an airline depends on the aircraft type selection, it is necessary to make right decision in the right time following a defined procedure that involves all relevant aspects and factors. Hence, aircraft's purpose and mission in the market (cargo, training or commercial passenger aircraft, for charter, low cost, regional or full service airline), should be examined and the aircraft should be evaluated accordingly. Thus, different issues that may affect aircraft type selection problem can be identified. According to [22], aircraft evaluation process includes five areas: consideration of design characteristics, physical performance, maintenance needs, acquisition costs, and operating economics.

Consideration of design characteristics includes aircraft's dimensions, weights, fuel capacity, type of power plant, systems, seating configuration, containers and pallets, bulk volume, and total volume. These characteristics may predetermine the set of airports that could be operated by a specific aircraft type due to the physical characteristics that an airport has (runway length, runway capacity, apron capacity, etc.) and characteristics that the aircraft needs to perform operations safely. Maximum Take-Off Mass (MTOM) of an aircraft is the maximum mass at which the take-off is allowed, due to structural or other limits. At the same time, it is the main unit for calculation of airport and navigation fees. Airport charges dependent on MTOM at Belgrade Airport Nikola Tesla are calculated based on price list in 2016, for different regional aircraft (Fig. 1). It is very important to emphasize that different fees based on MTOM are calculated so that each started ton is calculated as a whole ton.

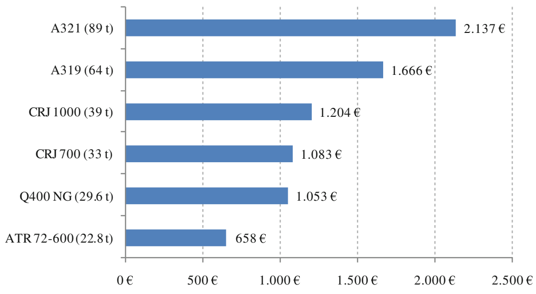

Fig. 1. Airport charges dependant of MTOM for the summer of 2016, Belgrade Airport

Total baggage (including overhead bins) and baggage per passenger are indicators that show how much space is available for cargo, which is not a negligible source of revenue for an airline. Depending on route types and categories of passengers that prevail on the route (business or leisure passengers) different volume of space is required and evaluated differently.

Physical performance includes payload-range diagrams, take-off and landing data, different speeds, runway requirements and noise performance, which could be limiting factors for operations at a particular airport as well. Aircraft range defines the maximum distance between take-off and landing which could be flown without refueling. Thus, depending on the aircraft range, the set of corresponding airports that could be served is defined (Fig. 2).

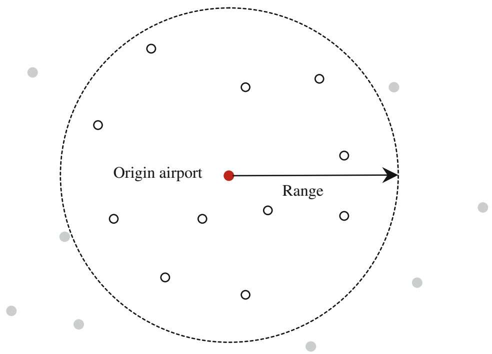

Fig. 2. Aircraft range and airport servicing area

Maintenance needs include spare parts availability, fleet commonality, product support, technical record keeping, and training support. According to [11], fleet commonality represents a concept introduced in order to enable airlines to minimize the number of aircraft types in the fleet and to adjust the fleet to route network at the same time. This concept brings advantages with regard to fleet flexibility in training and rostering of aircrew and maintenance personnel (reduction of training costs and number of pilots), and also flexibility in spares and other equipment (single pool of spares and equipment for the aircraft family). Fleet commonality influences flight operations (lower number of reserve crew and flexible swaps), maintenance (less spare parts, lower costs, lower labour costs), aircraft servicing (standardized ground handling equipment, more cost-efficient), and aircraft capital (lower price for ordering several same type aircraft) [2].

Acquisition costs include the cost of aircraft with spare parts, ground equipment needed, maintenance and flight training and costs of money itself. Since airline costs can be divided into different cost categories, the costs relevant for fleet planning and aircraft selection could be categorized as acquisition costs (capital costs) and direct operating costs [11]. Capital costs, as shown in Fig. 3, include total investment needed to put an aircraft into operation. Therefore, these costs include aircraft price as well as any other costs and conditions related to the first appearance of the aircraft in the service. Bearing in mind that acquisition of a new aircraft requires a huge investment (aircraft produced by Airbus[1] 74–428, aircraft produced by Boeing[2] 80–400, and regional aircraft cost USD 20–50 millions), it is evident that a small savings of a few percent is not negligible for an airline. Although costs of acquiring an aircraft represent large capital expenditures for an airline, these costs are very often lowered by the appearance of used and attractive aircraft leasing options. Direct operational costs are dependent on aircraft type, distance and block time, therefore they affect aircraft type selection.

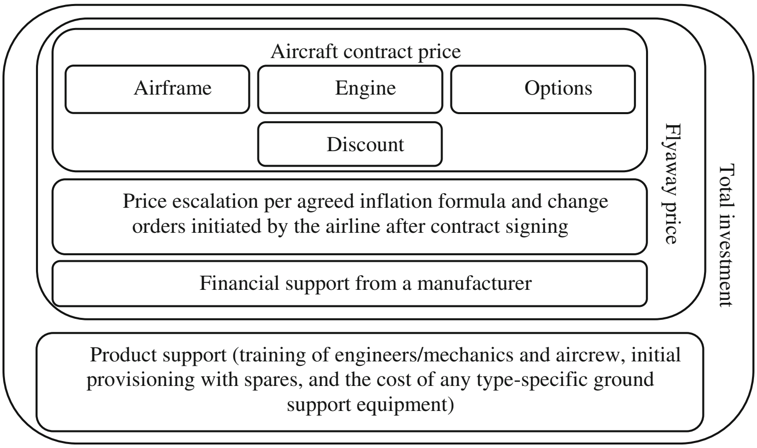

Fig. 3. Total investment for specific aircraft configuration

1 http://www.airbus.com/presscentre/pressreleases/press-release-detail/detail/new-airbus-aircraft-list-prices-for-2015/, May 2016.

2 http://www.boeing.com/company/about-bca/#/prices, May 2016.

Maintenance costs are an important factor in the cost structure. Aircraft should be permanently maintained in order to keep it safe for operations. Aircraft maintenance and monitoring of maintenance costs could be drivers for decisions related to aircraft replacement or retirement.

In order to compare operating costs from one airline to another, unit costs per available seat miles (CASM) are used. CASM are the cost of flying one aircraft seat for one mile [18] and may be calculated for a variety of costs, such as operating costs, total operating costs, or any other cost combination. Moreover, CASM may be calculated for an airline, or for an aircraft type operating on a specific distance. For example, total trip costs per available seat miles for regional aircraft vary from 13.5 c/ASM to 17 c/ASM [1].

Operating economics includes potential aircraft's contribution to the company's profitability (related to network structure, traffic flow and composition, existing traffic volumes, potential future growth, seating density, load factors and utilization). When it comes to operating economics, specific relations should be mentioned. Aircraft seat capacity (the number of seats offered by an airline to passengers on a certain flight represents a measure of potential income) is closely connected to costs. When average unit costs decrease with an increase in the quantity being produced, it can be said that economy of scale is achieved. Airlines offer capacity in line with the expected demand. The smaller the gap between capacity and expected demand is, the greater the load factor is. Greater load factor combined with appropriate revenue management and pricing policy offers airlines an opportunity to have a successful business. Therefore, it could be said that greater load factor is closely connected to greater profitability, as well. Finally, large capacity can be offered only if it is accompanied by high load factor. Airlines aim to reach as high load factor as possible, therefore it is very important to match offered capacity and rising demand.

Considering the above-mentioned issues that affect aircraft evaluation, one should choose criteria for aircraft type selection to reflect airlines' as well as some of passengers' perspectives. The most commonly considered criteria are related to technical and operational characteristics of the aircraft type, which could limit aircraft operations; hence it is reasonable to consider them as mandatory.

In the next section, we will describe different MCDM methods that will be applied for the same problem, in the case of a hypothetical airline.

4 Methods and Data

4.1 Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is an MCDM approach which divides the problem into a hierarchy of issues which should be considered [16]. It uses both quantitative and qualitative data translated into numbers and presents a theory of measurement through pairwise comparisons made using a scale of absolute judgments that represents the domination measure of one element over another with respect to a given attribute. In order to compare alternatives and criteria, a fundamental scale which indicates the intensity of importance on an absolute scale is introduced [16]. The scale consists of verbal judgments of preference ranging from equal to extreme (equal, moderate, strong, very strong, extreme importance) with corresponding numerical judgments (1, 3, 5, 7, 9), and intermediate values between the two judgments, as well. Numerical judgments in the pairwise comparison matrix satisfy the reciprocal property: if an activity i has one of the above nonzero numbers assigned to it when compared with an activity j, then j has the reciprocal value when compared with i ($a_{ji} = 1/a_{ij}$). Pairwise comparison matrices for criteria and alternatives enable computing of local and global priorities as well as ranking of alternatives. Priorities from pairwise comparisons are calculated using eigenvector method.

4.2 Fuzzy Analytic Hierarchy Process

Criteria importance over each other cannot always be precisely express, and decision makers usually have to deal with uncertainty. Therefore we found a possibility to use fuzzy numbers in the AHP method, i.e. to apply Fuzzy Analytic Hierarchy Process (FAHP). Although there are different ways to derive priorities from fuzzy pairwise comparison matrix, one of the newer methodologies, the logarithmic fuzzy preference programming (LFPP) method [21], is applied in this paper. Table 2 shows the conversion of linguistic scale into triangular fuzzy scale.

Table 2. Triangular fuzzy conversion scale for pair of elements i and j

Linguistic scale	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Just equal	(1, 1, 1)	(1, 1, 1)
Equally important	(1/2, 1, 3/2)	(2/3, 1, 2)
Weakly important	(1, 3/2, 2)	(1/2, 2/3, 1)
Strongly important	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Very strongly important	(2, 5/2, 3)	(1/3, 2/5, 1/2)
Extremely preferred	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

It should be mentioned that there are different triangular fuzzy scales in the relevant literature [12], and we decide to use scale according to [20]. The pairwise comparison matrix is filled out with fuzzy judgments instead of precise judgments. Fuzzy judgments reflect the vagueness and imprecision of human thought related to the problem considered. When comparing two criteria, i and j, the exact numerical ratio a_{ij} can be approximated with a fuzzy ratio “about a_{ij}”, which is represented by the fuzzy number $\tilde{a}_{ij}$. It means that criterion i is between l_{ij} and u_{ij} times as important as criterion j with m_{ij} being the most likely times. Therefore, the fuzzy pairwise comparison matrix is given by (1):

$$\tilde{A} = (\tilde{a}_{ij})_{n \times n} = \begin{bmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}) & \cdots & (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{21}, u_{21}) & (1,1,1) & \cdots & (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & \cdots & (1,1,1) \end{bmatrix} \tag{1}$$

The elements of the matrix $\tilde{A}$ satisfy the reciprocal property, which means that $l_{ij} = 1/u_{ji}$, $m_{ij} = 1/m_{ji}$, $u_{ij} = 1/l_{ji}$ and $0 < l_{ij} \leq m_{ij} \leq u_{ij}$ for all i, $j = 1,\ldots, n$; $j \neq i$. Once the matrix is built, crisp priority vector using the LFPP method proposed by [21] can be computed.

4.3 Even Swap Method

Even swaps method (ESM) is an MCDM method which provides a reliable mechanism for making trade-offs [8]. It is based on the fundamental principle of decision making: if all alternatives are rated equally for a given objective, then that objective can be eliminated when choosing among the alternatives considered. The first step in this method is to create a consequences table in such a way that all defined criteria are listed down the left side, and possible alternatives along the top. The ESM enables description of criteria both in quantitative (by numbers) and qualitative terms (by words) in consequences tables. The next step is to create a ranking table where each criterion is ranked across the alternatives. The ranking table enables one to compare an alternative by all criteria and to find the alternative which is worse on some objectives and not better on all other objectives in comparison with the other alternatives - the dominated alternative. It can be eliminated from further consideration, which reduces the number of alternatives in the set of alternatives. Practical dominance (an alternative is worse or equal on some criteria and better in only one criterion) could also results in decrease of the number of alternatives, again, if it is possible. The alternative practically dominated can be eliminated as well, if the worse criterion is not of crucial importance, in the decision makers' opinion. When there are no more dominated or practically dominated alternatives, swaps can be made. ESM provides an opportunity to decrease the value of one of the criteria, while another one must increase by the equivalent value. In this way, different criteria could be adjusted in order to make its value equal across all alternatives, and finally, to eliminate it from further consideration. Progressive simplification of the problem is made using the dominance or practical dominance to eliminate alternatives and using trade-offs to equalize performances on a selected criterion allowing the elimination of that criterion. The objectives and alternatives are eliminated until one alternative dominates all others, or only one criterion for comparison of alternative remains.

4.4 Data

AHP, FAHP and ESM are used to choose the most suitable aircraft type from the set of aircraft considering selected criteria. These methodologies are applied to the case study of a hypothetical airline presented in previous researches [4–6]. In this paper, the focus is on the set of routes covered by small aircraft with capacity up to 100 seats [4, 6]. The determined set of aircraft consists of regional jets ERJ190, CRJ700, CRJ900 and CRJ1000, as well as turboprops ATR72-500, ATR72-600 and Q400NG [4–6].

Considering the main issues in the aircraft evaluation process, mentioned in the previous section, and bearing in mind that aircraft will operate short, regional routes, it has been found reasonable to use the same criteria as in earlier authors' researches. Therefore, we considered aircraft seat capacity, aircraft price, total baggage, MTOM, payment conditions (advantages offered by manufacturers or leasing companies) and total cost per available seat miles – CASM [4–6]. All aircraft from the selected set are ranked with regard to the chosen criteria. The most suitable aircraft is the one the capacity of which best meets the estimated number of passengers per flight. Whereas airlines endeavor to lower their costs, it is expected that the lowest price of an aircraft and acceptable payment conditions are the most acceptable, while the highest price is not desirable. The more baggage per passenger is available, the more suitable the aircraft type is. In terms of MTOM, it is evident that the airline prefers lighter aircraft to heavier ones. Lower unit costs expressed by cents per available seat mile (ASM) make aircraft type more preferable for an airline.

Table 3. Pairwise comparison matrix for the first level and domination measures

	Seat capacity	Price	Total baggage	MTOW	Payment conditions	CASM
Seat capacity	1	0.25	3	0.5	0.25	0.25
Price	4	1	5	5	1	1
Total baggage	0.333	0.2	1	0.5	0.2	0.2
MTOW	2	0.2	2	1	0.2	0.2
Payment conditions	4	1	5	5	1	1
CASM	4	1	5	5	1	1

Domination measure of one aircraft over another with respect to seat capacity

	ATR72-500	ATR72-600	ERJ 190	Q400 NG	CRJ 700	CRJ 900	CRJ 1000
ATR72-500	1	1	4	2	1	3	4
ATR72-600	1	1	4	2	1	3	4
ERJ190	0.25	0.25	1	0.333	0.25	0.5	1
Q400NG	0.5	0.5	3	1	0.5	2	3
CRJ700	1	1	4	2	1	3	4
CRJ900	0.333	0.333	2	0.5	0.333	1	2
CRJ1000	0.25	0.25	1	0.333	0.25	0.5	1

Domination measure of one aircraft over another with respect to payment conditions

	ATR72-500	ATR72-600	ERJ 190	Q400 NG	CRJ 700	CRJ 900	CRJ 1000
ATR72-500	1	1	4	2	3	3	3
ATR72-600	1	1	4	2	3	3	3
ERJ190	0.25	0.25	1	0.333	0.5	0.5	0.5
Q400NG	0.5	0.5	3	1	0.5	0.5	0.5
CRJ700	0.333	0.333	2	2	1	1	1
CRJ900	0.333	0.333	2	2	1	1	1
CRJ1000	0.333	0.333	2	2	1	1	1

Tables 3 and 4 present the input data for the first hierarchy level and importance of alternatives with respect to seat capacity and payment conditions, for AHP and FAHP, respectively. Importance of alternatives with respect to other criteria is not presented due to the space limitation. Pairwise and fuzzy pairwise comparison matrices are created according to the authors' expert knowledge and experience as well as to the verbal (informal) conversation with the people from the airline industry. The fuzzy judgments (Table 2) are used in accordance with numerical judgments used in the AHP, as much as possible. The consistency ratio of matrices is checked, therefore all matrices are consistent.

Table 5 refers to data needed for ESM. In the first part of the Table 5 one can see real numerical data (taken from the manufacturers' official web sites). On the other hand, linguistic data related to payment conditions are assumed, due to unavailability of this kind of data.

Table 4. Fuzzy pairwise comparison matrix for the first level and domination measures

	Seat capacity	Price	Total baggage	MTOW	Payment conditions	CASM
Seat capacity	(1,1,1)	(1/3,2/5,1/2)	(1,3/2,2)	(1/2,2/3,1)	(1/3,2/5,1/2)	(1/3,2/5,1/2)
Price	(2,5/2,3)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(1/2,1,3/2)	(1/2,1,3/2)
Total baggage	(1/2,2/3,1)	(1/3,2/5,1/2)	(1,1,1)	(2/3,1,2)	(1/3,2/5,1/2)	(1/3,2/5,1/2)
MTOW	(1,3/2,2)	(1/3,2/5,1/2)	(1/2,1,3/2)	(1,1,1)	(1/3,2/5,1/2)	(1/3,2/5,1/2)
Payment conditions	(2,5/2,3)	(2/3,1,2)	(2,5/2,3)	(2,5/2,3)	(1,1,1)	(1/2,1,3/2)
CASM	(2,5/2,3)	(2/3,1,2)	(2,5/2,3)	(2,5/2,3)	(2/3,1,2)	(1,1,1)

Domination measure of one aircraft over another with respect to seat capacity

Seat capacity	ATR 72-500	ATR 72-600	ERJ190	Q400NG	CRJ700	CRJ900	CRJ1000
ATR 72-500	(1,1,1)	(1/2,1,3/2)	(2,5/2,3)	(1,3/2,2)	(1/2,1,3/2)	(3/2,2,5/2)	(2,5/2,3)
ATR 72-600	(2/3,1,2)	(1,1,1)	(2,5/2,3)	(1,3/2,2)	(1/2,1,3/2)	(3/2,2,5/2)	(2,5/2,3)
ERJ190	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1/2,2/3,1)	(1/2,1,3/2)
Q400NG	(1/2,2/3,1)	(1/2,2/3,1)	(3/2,2,5/2)	(1,1,1)	(1/2,2/3,1)	(1,3/2,2)	(3/2,2,5/2)
CRJ700	(2/3,1,2)	(2/3,1,2)	(2,5/2,3)	(1,3/2,2)	(1,1,1)	(3/2,2,5/2)	(2,5/2,3)
CRJ900	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,3/2,2)	(1/2,2/3,1)	(2/5,1/2,2/3)	(1,1,1)	(1,3/2,2)
CRJ1000	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(2/3,1,2)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1/2,2/3,1)	(1,1,1)

Domination measure of one aircraft over another with respect to payment conditions

Payment conditions	ATR 72-500	ATR 72-600	ERJ190	Q400NG	CRJ700	CRJ900	CRJ1000
ATR 72-500	(1,1,1)	(1/2,1,3/2)	(2,5/2,3)	(1,3/2,2)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)
ATR 72-600	(2/3,1,2)	(1,1,1)	(2,5/2,3)	(1,3/2,2)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)
ERJ190	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(2/5,1/2,2/3)	(1/2,2/3,1)	(1/2,2/3,1)	(1/2,2/3,1)
Q400NG	(1/2,2/3,1)	(1/2,2/3,1)	(3/2,2,5/2)	(1,1,1)	(1/2,2/3,1)	(1/2,2/3,1)	(1/2,2/3,1)
CRJ700	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,3/2,2)	(1,3/2,2)	(1,1,1)	(1/2,1,3/2)	(1/2,1,3/2)
CRJ900	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,3/2,2)	(1,3/2,2)	(2/3,1,2)	(1,1,1)	(1/2,1,3/2)
CRJ1000	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,3/2,2)	(1,3/2,2)	(2/3,1,2)	(2/3,1,2)	(1,1,1)

Table 5. Consequences and ranking table for aircraft type choice

Consequences	ATR72-500	ATR72-600	E190	Q400NG	CRJ700	CRJ900	CRJ1000
Seat capacity	68	70	98	74	70	88	100
Price (mil. USD)	21.9	22.7	43	31.67	37	44.5	49.5
Total baggage (m^3)	13.75	15.13	32	17.9	18.3	20.32	23.6
MTOW (t)	22.5	22.8	47.8	29.6	33	36.5	39
Payment conditions	Excellent	Excellent	Poor	Very Good	Excellent	Good	Poor
CASM	16.4	16.4	15.4	15.6	>16.4	14.5	14.5
Ranking	ATR72-500	ATR72-600	E190	Q400NG	CRJ700	CRJ900	CRJ1000
Seat capacity	1	1	4	2	1	3	4
Price (mil. USD)	1	1	3	2	2	3	4
Total baggage (m^3)	6	5	1	4	4	3	2
MTOW (t)	1	1	6	2	3	4	5
Payment conditions	1	1	4	2	3	3	3
CASM	4	4	2	3	5	1	1

Payment conditions are subject to negotiation and can be real and available only when negotiation for ordering of aircraft is in progress. In the second part of Table 5, all alternatives are ranked throughout the six criteria. Ranking table enables decision maker to identify dominated/practically dominated alternatives, make trade-offs and progressively reduce the size of problem in order to reach the final solution.

The next section presents our results obtained by applying EMS, AHP and FAHP to the aircraft type selection problem.

5 Results and Discussion

5.1 Analytic Hierarchy Process

AHP is used [4, 5] to support selection of appropriate aircraft type from the set of seven regional aircraft, considering six criteria stated before. In this subsection we will summarize results from [4, 5]. Thus, the criteria are described by numerical, quantitative values, with the exception of payment conditions, which are defined qualitatively. ATR72-600 is chosen as the most appropriate aircraft in [4, 5]. AHP also gives as a result the final ranking of aircraft types (ATR72-600, ATR72-500, CRJ900, CRJ1000, Q400NG, CRJ700 and ERJ190, Table 6), which is used as the initial solution for sensitivity analysis.

Sensitivity of the solution (rank of alternatives) and consistency ratio in respect to different judgments in comparison matrices for the second level are analyzed in [5]. The sensitivity analysis with respect to the following four criteria was not conducted because CASM varies with the change of sector length (average sector length for the hypothetical airline is 200 miles, and CASM data are related to this sector length), MTOM and total baggage are characteristics of the aircraft which cannot be changed, and finally, lower price is always more desired than the higher one. Therefore, the numerical judgment of payment conditions and aircraft capacity is varied throughout

Table 6. Local and global priority weights

	Seat capacity (0.071)	Price (0.271)	Total baggage (0.043)	MTOW (0.075)	Payment conditions (0.271)	CASM (0.271)	Final priority vector
ATR72-500	0.227	0.250	0.037	0.278	0.263	0.065	0.1947
ATR72-600	0.227	0.250	0.056	0.278	0.263	0.065	0.1954
ERJ190	0.051	0.082	0.347	0.033	0.052	0.172	0.1037
Q400NG	0.134	0.144	0.090	0.176	0.093	0.107	0.1197
CRJ700	0.227	0.144	0.090	0.114	0.110	0.042	0.1082
CRJ900	0.083	0.082	0.148	0.073	0.110	0.274	0.1437
CRJ1000	0.051	0.050	0.232	0.048	0.110	0.274	0.1346

all alternatives because they are subject to changes. For example, for an airline it is possible to negotiate payment conditions with the manufacturer or a leasing company, while the value of aircraft capacity criteria could be more or less close to the demand.

In the initial experiment, excellent payment conditions are offered for the ATRs, very good for Q400NG, good for CRJs and poor payment conditions are offered for ERJ190 [5]. Considering four different categories of payment conditions (excellent, very good, good and poor) as 4 permutations of 4 elements, 24 experiments in total (4!) were carried out for this criterion (the initial one and additional 23 experiments). The 24 experiments carried out show that priority of an alternative in the final priority vector decreases with the decrease of the domination measure of one aircraft over another with respect to payment conditions, for all aircraft types.

Four different aircraft capacities were assumed in the initial experiment [5]. The capacity of ATRs and CRJ700 matches the estimated passenger number best. These aircraft capacities are followed by Q400NG, then CRJ900, and finally CRJ1000 and ERJ900 which do not satisfy the airline needs appropriately. Regarding the aircraft capacity criterion, it is possible to carry out (theoretically) 24 experiments in total, but only the initial experiment and additional 8 experiments are reasonable [5]. Therefore, 9 selected experiments were considered in sensitivity analysis for the aircraft capacity criterion, by changing the judgments for aircraft capacity, while other numerical judgments were kept constant. It is shown in [5] that the increase in demand that requires larger aircraft capacity caused the changes in the final ranking of aircraft. The initial ranking of alternatives is changed, thus the last two aircraft exchange their positions. The most inappropriate aircraft is CRJ700 instead of ERJ190, while the first five aircraft preserved their positions. When the increase in demand requires aircraft of the largest capacity, final ranking of aircraft is as follows: ATR72-500, ATR72-600, CRJ1000, CRJ900, ERJ190, Q400NG and CRJ700.

5.2 Fuzzy Analytic Hierarchy Process

The criteria importance over each other cannot always be precisely expressed, and airline planners in charge of fleet planning usually have to deal with uncertainty. Whereas the FAHP method has found significant and successful applications in different fields [13], the authors decided to employ it for appropriate aircraft type selection. To obtain the initial solution, fuzzy pairwise comparison matrices are created. LFPP method is employed to derive priorities from fuzzy pairwise comparison matrix. We used the Microsoft Excel Solver in order to obtain optimal solution, and measure inconsistency. Whereas the consistency condition is satisfied, the ranking in the initial solution is as follows: ATR72-600, ATR72-500, Q400NG, CRJ900, CRJ1000, CRJ700 and ERJ190 (Table 7).

Table 7. Local and global LFPP priorities

	Seat capacity (0.0960)	Price (0.2368)	Total baggage (0.0839)	MTOM (0.1099)	Payment conditions (0.2368)	CASM (0.2368)	Global LFPP priorities
ATR72-500	0.1921	0.2045	0.0830	0.2129	0.2126	0.1035	0.1720
ATR72-600	0.1921	0.2045	0.0830	0.2471	0.2126	0.1035	0.1758
ERJ190	0.0740	0.0947	0.2602	0.0750	0.0819	0.1482	0.1140
Q400NG	0.1394	0.1567	0.1109	0.1663	0.1542	0.1482	0.1497
CRJ700	0.2219	0.1567	0.1109	0.1138	0.1129	0.0722	0.1240
CRJ900	0.1014	0.0947	0.1990	0.0924	0.1129	0.2122	0.1360
CRJ1000	0.0791	0.0883	0.1530	0.0924	0.1129	0.2122	0.1285

The sensitivity analysis is performed in the same way as in the case of the AHP, for the two criteria. The results are again obtained by using Microsoft Excel Solver, and they are as follows. If aircraft ATR72-500 and ATR72-600 are the aircraft with the most acceptable payment conditions in comparison to other aircraft types, then the ATR72-600 is the best ranked aircraft irrespective of payment conditions for other aircraft (Fig. 4, experiments 0–5). If the most acceptable payment conditions are offered for Q400NG, it will be the best ranked aircraft no matter what payment conditions are offered for the other aircraft (Fig. 4, experiments 6–11).

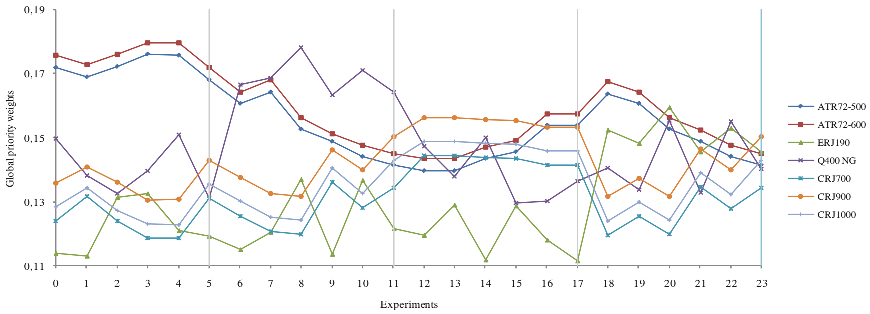

Fig. 4. Aircraft rankings with respect to payment conditions changes

If Bombaridier's CRJs (CRJ700, CRJ900 and CRJ1000) have the highest value of fuzzy pairwise judgment for payment conditions, in the final aircraft ranking the aircraft CRJ900 will be the best ranked aircraft in four experiments (12, 13, 14, and 15).

The most suitable aircraft in the experiments 16 and 17 will be ATR72-600 (Fig. 4, experiments 12–17), in the case when ATRs are in the second place with respect to payment conditions. If aircraft ERJ190 is the aircraft with the best payment conditions, in the final ranking this aircraft will be top-ranking only in the experiment 20, in which ERJ 190 is followed by Q400NG, ATRs and CRJs, respectively, according to fuzzy pairwise judgment with respect to payment conditions (Fig. 4, experiments 18–23). Aircraft ATR72-600 has the best ranking in the experiments 18, 19 and 21, while the top-ranked aircraft in the experiments 22 and 23 are Q400NG and CRJ900 respectively. The three aircraft ATR72-500, CRJ700 and CRJ1000, are not sensitive to changes of fuzzy judgment for single property payment conditions, thus these aircraft are never the final choice. Fuzzy judgment for payment conditions, will affect the final ranking of aircraft, which is expected because payment conditions are one of the most influential criteria (they have the highest priority in the priority vector for the first level, [4, 5]). It can be observed that the aircraft ATR72-600 is the most acceptable aircraft in most experiments (in 11 of 24 experiments).

Regarding the changes in the aircraft capacity, while other fuzzy judgments are kept constant, the initial experiment (denoted by 0) and 8 additional, possible experiments were carried out (Fig. 5). It can be observed that the increase in demand that requires larger aircraft capacity caused the changes in the final ranking of aircraft. The initial ranking of alternatives is changed, thus the first two aircraft are always the first ones, while the other aircraft exchange their positions. The most inappropriate aircraft are ERJ190 and CRJ700 (Fig. 5) which are always the last two.

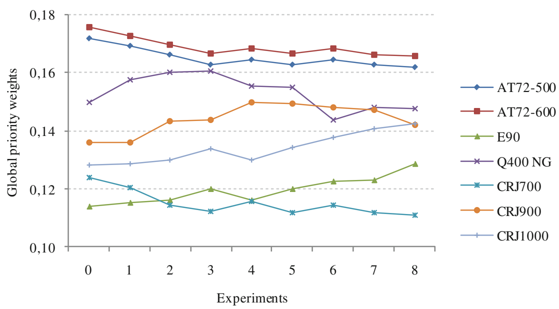

Fig. 5. Aircraft rankings with respect to aircraft capacity changes

5.3 Even Swap Method

Unlike the two previously applied methods, ESM does not rank alternatives, but rather only offers the most appropriate solution. In the case with our example, as it is shown in [5], the aircraft type ATR72-600 appears to be the most appropriate one. The sensitivity analysis performed corresponds to the sensitivity analysis for the second hierarchy level in the case of AHP and FAHP methods. As in AHP, initial experiment was carried out as well as 23 additional experiments, showing that the final solution is not sensitive to changes of payment conditions [5]. The most suitable aircraft type in all experiments was always the same – ATR72-600. Speaking of solution sensitivity when the demand is changing, it is concluded that the ESM is not sensitive to this kind of changes either, and the choice is always ATR72-600 [5].

5.4 Discussion

Considering the chosen methods we show that all three methods can be successfully applied to the problem of aircraft type selection suggesting the same aircraft, ATR72-600, as the most suitable solution in the initial experiments. Considering the three presented MCDM methodologies and sensitivity analysis presented, it can be concluded that they differ in the data they require. Moreover ESM is suitable for cases when decision makers have complete data and can rank all alternatives across selected criteria. When decision makers are not able to make rankings and when only the pairwise comparison is available, AHP befits better. Finally, when decision makers do not have precise pairwise comparisons, FAHP is the appropriate method. Thus, ESM requires the most specific data, AHP needs pairwise comparison of the data, while FAHP can use imprecise pairwise comparison.

With regards to sensitivity analysis presented in this section, we demonstrate that solutions offered by the AHP and FAHP are sensitive to the changes of payment conditions. The solution's sensitivity to changes in demand can be observed, but only in aircraft ranking, not for the top ranked aircraft. The ESM is not sensitive at all to any kind of changes, and always gives the same solution. However, this conclusion that regards sensitivity of the solution refers to presented example and maybe would be changed in different one. It could depend on the airline policy (goals and priorities that could influence alternatives and criteria selection) and people involved in the process of decision making.

It should be mentioned that MCDM includes a certain level of subjectivity and decisions could depend on decision maker experience. In that sense, trade-offs which are made in the ESM, as well as pairwise comparison matrices in AHP and FAHP could be influenced by experience of decision maker.

6 Conclusion

This paper applies the three MCDM methodologies - AHP, FAHP, and ESM, to the same problem under the same conditions with the identical sets of alternatives and criteria, offering the same solutions (chosen aircraft type). The paper also presents a sensitivity analysis, underlining the rank of alternatives' sensitivity to the changing importance of aircraft types with respect to different criteria. The initial experiment and additional 23 experiments were carried out applying AHP, FAHP and ESM, by changing the criterion of payment conditions. It is shown that the AHP and FAHP are sensitive to this kind of change, while the ESM is not sensitive at all. The solutions obtained by AHP, show that the final priority weight for specific aircraft type decreases with the decrease of the domination measure of one aircraft over another with respect to payment conditions, for all aircraft types.

Influence of changes in travel demand, which further affect the required aircraft capacity, is also presented in this paper through the experiments conducted by applying the AHP, FAHP and ESM. The initial experiment and 8 additional experiments are analyzed and it is concluded that the changes in the required aircraft capacity influence the final ranking of aircraft types derived by AHP and FAHP. On the contrary, the most suitable aircraft according to the ESM is always ATR72-600.

The three methods, the AHP, FAHP and ESM, can be successfully used for aircraft type selection problems. The great advantage of these methods is that each of them can use both quantitative and qualitative data. With regards to data required, it can be seen that ESM requires the most specific data, AHP needs pairwise comparison of the data, while FAHP can use imprecise pairwise comparison. Having in mind that selection of final, the most appropriate aircraft is not dependent on the chosen method, decision makers have an opportunity to choose the method according to his own preferences or with regards to practical issues.

Decision making related to aircraft selection is process which involves people from different department in airlines that have different points of view. In order to encompass this diversity in thinking influenced by positions in airline as well as by educational background, group decision making could be employed in the future. It would include different opinion concerning fuzzy scale, as well. The interviews could be conducted with people involved in aircraft selection problem to get pairwise/fuzzy pairwise comparison matrices based on airline representatives' expert opinions. Different fuzzy numbers could be used as well, in order to learn sensitivity of solutions with regards to this kind of changing.

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