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TWO-STAGE AIRLINE FLEET PLANNING MODEL

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***Abstract**: Fleet planning is a process of strategic importance for an airline. Airlines have a tendency to match their capacities and passenger demand for corresponding market conditions, which has a direct impact on airline profitability and costs. It is necessary to consider many different factors in order to make a good fleet plan. This paper proposes the sequential two-stage model for fleet planning. The first stage refers to determination of an approximate fleet mix in terms of aircraft size which is obtained by fuzzy logic. The outputs from this stage are two sets of routes: one presenting routes covered by small aircraft and another one presenting routes covered by medium size aircraft. At the same time, these outputs represent inputs for the second stage in which the fleet sizing problem is solved using heuristic procedure. The sequential two-stage model is exemplified with the incumbent airline with its base at Belgrade Airport.*

Keywords: *airline fleet planning, fleet mix, fleet sizing, fuzzy logic.*

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1. INTRODUCTION AND LITERATURE REVIEW

One of the main goals of an airline is to match its capacity and passenger demand for corresponding market conditions, which has a direct impact on the increase of airline profitability and reduction of airline costs. Since acquisition of a new aircraft requires a huge investment, it is evident that a small savings of a few percent, is not negligible for an airline. In order to achieve even such a small savings, adoption of an appropriate methodological approach is essential.

Generally, fleet planning process is very complex for an airline. It is necessary to consider many different factors, such as aircraft economies, commonality, aircraft performances, finance, market evaluation, etc. With regard to time perspectives in fleet planning, it is obvious that the market and environment in which an airline operates are predictable for a relatively short time and uncertainty increases with time. Strategic planning is fundamental to overcome the gap between the growing flexibility of resources and growing uncertainty of the market.

Many authors have dealt with the fleet planning problem in different ways. Most of them research the close connection between airline frequencies and aircraft size considering more or less similar factors. The factors that have influence on airline flight frequencies and aircraft size on US airline routes taking into consideration market demographics, airport characteristics, airline characteristics and route characteristics are commented in [8]. Regression analysis is used [2] to point out that route characteristics, such as distance, level of demand and competition, strongly influence the selection of aircraft size, while airport characteristics (number of runways, hub or not hub) do not influence aircraft selection. A nested logit model is developped [10] in order to investigate influence of aircraft size, frequencies, seat availability and fare in airlines' demand and market share in duopoly markets. They demonstrate that an airline achieves greater market share by increasing frequencies rather than increasing seat availability per flight. The paper [7] focuses on operating effects of leasing rather than financial effects. It indicates that an airline which needs additional capacity in short time period may not reach advantageous agreements with manufacturers (higher prices and waiting for delivery), while large leasing company can provide aircraft from manufacturers in shorter time period and at lower prices. They can lease aircraft from a leasing company in order to adjust the airline's capacity and demand. Dynamic programming in decision-making process related to the number of aircraft to be bought, leased and retired is proposed in [4]. [3] indicates the environmental implications with regards to airlines' selection of aircraft size.

They mention the importance of frequency for preserving the airline position on the market and the fact that airlines prefer increasing frequency to increasing aircraft capacity, especially on short routes. It can be observed that the baseline in most of the papers written on this topic is travel demand.

In this paper, the authors try to help planners by proposing a sequential, two-stage model which could be used during the airline fleet planning process. The output of the first stage is the input for the second one. The model should offer a solution for an assumed route network – an approximate fleet mix from the first stage and fleet size from the second stage, which fit the market conditions and airline requirements. Passenger demand and distance are the inputs to the first stage in order to get approximate fleet mix in terms of aircraft size. Small or medium-size aircraft are assigned to each destination according to the index of preference obtained from fuzzy logic system. The outputs are two sets of routes: one set presents the routes covered by small aircraft and the other one presents routes covered by medium-size aircraft. The number of small and medium aircraft depends on weekly frequencies and airline schedule. With splitting the set of planned flights into subsets, the problem transforms into two independent fleet sizing problems. The solution to these problems obtained by heuristic procedure should answer the following question: How many small and medium aircraft does the airline need in order to implement the planned flight schedule?

Models developed are exemplified by the incumbent airline with its base at Belgrade Airport which should replace existing one on the established market. The paper has 4 sections. After the introduction and literature review, the first stage of the sequential model for approximate fleet mix determination is presented (Section 2). The third section presents the heuristic procedure for fleet sizing problem. The last section gives concluding remarks and further research directions.

2. MODEL FOR APPROXIMATE FLEET MIX

The main assumption in the model for approximate fleet mix determination is that all aircraft can be classified into two categories – small and medium size aircraft. A small aircraft is an aircraft with capacity of 50 to 100 seats, while a medium size aircraft has the capacity of 101 to 200 seats. Each of these categories comprises different types of aircraft which differ in capacity, technical characteristics, dimensions, noise generation level, take-off or landing runway length. Taking into consideration passenger demand on selected routes and distance between origin and destination airport, a fuzzy system is created in order to help an airline planner to make a decision whether to use small or medium size aircraft. Based on the past experience, it has been decided to use trapezoid fuzzy sets as follows. The membership functions of fuzzy sets *Small* (SYD), *Medium* (MYD) and *Large* (LYD) are related to yearly demand (Fig. 1a), while the membership functions of fuzzy sets *Short* (SD), *Medium Short* (MSD) and *Medium* (MD) are related to distance (Fig. 1b).

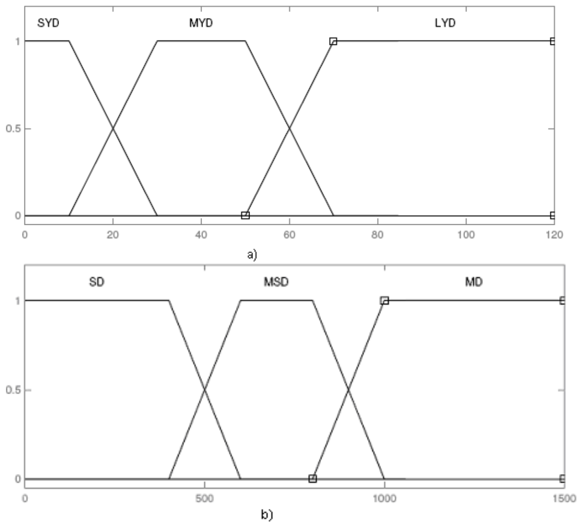

Figure 1. Membership functions of fuzzy sets (a) Small, Medium and Large yearly demand; (b) Short, Medium Short and Medium distance

When selecting an aircraft for a given route, an airline has a certain preference for selection of the aircraft that will operate; therefore, strength of preference may be "stronger" or "weaker". Let us denote with p_s the index of preferences for using small aircraft and with p_m the index of preferences for using medium aircraft. Their values can range from 0 to 1, and their sum is always equal to 1.

Bearing in mind that sum of those indexes is 1, in following text, only the index of preference for operating small aircraft (p_s) will be used. The value of p_s is equal to 1 when an airline has an absolute preference for using small aircraft on the considered route. The value of the p_s decreases with the decrease of airline's strength of preference, so the airline will use medium aircraft in cases when p_s is equal to 0. Airline's strength of preference for operating small aircraft may be described by using triangle fuzzy sets *Very Small* (VS), *Small* (S), *Medium* (M), *High* (H) and *Very High* (VH) strength of preference (Fig. 2).

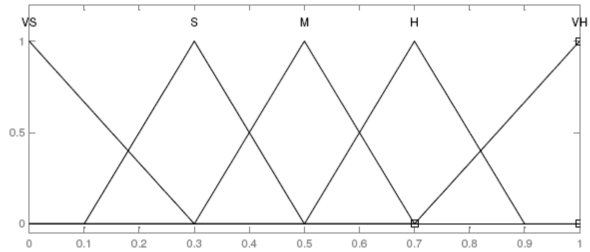

Figure 2. Membership function of fuzzy sets *Very Small*, *Small*, *Medium*, *High* and *Very High* strength of preference

Index of preference for operating small aircraft is calculated on the basis of historical data used on selected routes. Data are taken from the Belgrade Airport's timetables for the period winter 2001 to winter 2012. Estimated index of preference (p_{se}) represents the ratio between the number of small aircraft used and the total number of aircraft used on the considered route in the selected period, and its value, as aforementioned, varies from 0 to 1. The lowest value of p_{se}, equal to 0, means that small aircraft have never been used on the considered route, while the highest value 1 indicates that small aircraft are always used. Values of p_{se} for all destinations in the airline network assumed (consisting of 27 routes) are given in Table 1. It should be noticed that the network presents network defined in [5] and [6] extended to some new routes. Fuzzy rule base to determine the strength of preference consists of 9 rules.

For known yearly demand and distance between origin and destination airports, strength of preference for operating small aircraft can be determined for all routes by using the approximate reasoning rule base. The indexes of preference for operating small aircraft (p_{sf}) are obtained by applying MAX-MIN fuzzy reasoning and defuzzification by centre of gravity.

Strength of preference to use small aircraft by applying fuzzy logic will not be determined for all destinations. Sometimes, it is known in advance. For example, if an airline is a new one on the market, it is evident that small aircraft will be in service for the beginning. If an existing airline introduces a new route, small aircraft will operate it due to the uncertainty of demand. When the value of p_{se} is not greater than 0.05, the route will be operated by medium aircraft, while small aircraft will operate the route for which the value of p_{se} is not smaller than 0.95. These cases will not be considered in the fuzzy logic system starting with these assumptions. Routes from Belgrade to Thessalonica and Ljubljana will be excluded from further consideration (p_{se} = 1) and small aircraft will be assigned to them. Also, routes to Paris (p_{se} = 0.02), Amsterdam, Stockholm, Gothenburg, London, Moscow and Monastir (p_{se} = 0) will not be considered and medium size aircraft will operate these routes. Thus, there are 19 routes for p_{sf} determination by fuzzy logic system. Comparative review of p_{se} and p_{sf} for 2012 and 2015 is given in Table 1, as well as relative errors.

Table 1. Index of preference (estimated and obtained by fuzzy logic) and relative errors

Destination	p_{se}	p_{sf}		Relative errors	
		2012	2015	2012	2015
Vienna	0.66	0.64	0.55	0.04	0.17
Brussels	0.07	0.10	0.10	0.38	0.38
Copenhagen	0.07	0.10	0.11	0.43	0.56
Athens	0.53	0.28	0.28	0.46	0.47
Rome	0.22	0.30	0.30	0.36	0.36
Milan	0.38	0.43	0.43	0.12	0.12
Munich	0.48	0.47	0.36	0.01	0.24
Frankfurt	0.12	0.11	0.10	0.08	0.19
Stuttgart	0.43	0.34	0.35	0.21	0.20
Düsseldorf	0.27	0.10	0.10	0.64	0.63
Berlin	0.08	0.11	0.12	0.38	0.45
Prague	0.32	0.70	0.64	1.19	0.99
Skopje	0.61	0.79	0.53	0.30	0.14
Zurich	0.19	0.17	0.17	0.09	0.09
Sarajevo	0.91	0.90	0.90	0.01	0.01
Istanbul	0.4	0.29	0.29	0.27	0.27
Tivat	0.78	0.90	0.90	0.16	0.16
Podgorica	0.73	0.90	0.90	0.23	0.24

Let us assume that upper boundary for the p_{sf} is 0.5. Routes with the value greater than 0.5 will be operated by small aircraft, otherwise - by medium size aircraft. The outputs from this stage are two subsets of routes: the first subset presents routes covered by small aircraft and the second one presents routes covered by medium size aircraft. Destinations from Belgrade to Vienna, Prague, Skopje, Sarajevo, Tivat and Podgorica, together with Thessalonica and Ljubljana are covered by small aircraft, while routes to Brussels, Copenhagen, Athens, Rome, Frankfurt, Düsseldorf, Berlin, Zurich, Istanbul, Milan, Munich, Stuttgart (from fuzzy logic system), Paris, Amsterdam, Stockholm, Gothenburg, London, Moscow and Monastir (known) are operated by medium size aircraft.

Relative errors (Table 1) are acceptable for all destinations, except Prague and Athens. This exception can be explained by the fact that there have been no flights between Belgrade and Prague in recent years, so use of a small aircraft is expected on newly opened routes.

In order to determine the required number of small and medium aircraft, it is necessary to determine flight frequencies (weekly) and define a timetable (departure times) for the assumed route network. The earlier research indicates a close link between flight frequency and aircraft size, [11], [9], [8]. An airline should make decisions related to flight frequencies and aircraft size for the observed route, while estimated traffic for known demand on some route depends on market conditions (competition, passenger profile, distance, airports, etc.). The estimated demand, previously determined aircraft size (small or medium aircraft) and existing frequencies (partially) will be considered for flight frequency determination due to the fact that a new airline is entering the established market. Some assumptions are introduced: minimal weekly frequency is 2, while maximal frequency is 28. Maximal frequency limit is introduced because of the fact that the airline is not large, so higher frequency would not be reasonable in the observed competitive market.

Forecasted total passenger flows from Belgrade Airport to the selected countries are obtained by multiple linear regressions, while flows by airports are results of historical data, market conditions and expert opinion [6]. Average weekly number of passengers and adopted frequencies are given in Table 2.

According to [1] recommended passenger load factor of 75% is acceptable for an airline. Therefore, minimal and maximal frequencies for 75% load factor are calculated as the average value of minimal values for 2012 and 2015, and maximal frequencies are calculated as the average value of maximal values for 2012 and 2015. The adopted value of frequency for the selected route (Table 2) in most cases is the maximal value if it is an even number (for routes to Brussels, Copenhagen, Paris, Rome, Milan, Munich, Stuttgart, Berlin, Ljubljana, Sarajevo, Istanbul, Tivat and Podgorica) or the first smaller if it is an odd number (Vienna, Amsterdam, Frankfurt, Düsseldorf, Stockholm, London, Prague, Moscow, Zurich and Monastir).

Route to Gothenburg has the adopted frequency equal to 2, because this value is set as a minimal weekly value. There are some exceptions in the case of route from Belgrade to Thessalonica and Skopje. For these routes, the minimal value of frequency will be adopted, due to the fact that Athens and Thessalonica could be considered as one, Greek, market, while the air market of FRY Macedonia (Skopje) has good connections to Serbia by road transport.

Table 2. Weekly frequencies on route network

City	Weekly passenger demand		Adopted frequency
	2012	2015	
Vienna	940	1208	28
Brussels	147	189	2
Copenhagen	267	343	4
Paris	1469	1887	22
Athens	846	1087	12
Thessalonica	470	604	6
Amsterdam	360	462	4
Rome	646	830	10
Milan	129	166	2
Munich	417	536	6
Frankfurt	1143	1469	16
Stuttgart	245	315	4
Düsseldorf	998	1282	14
Berlin	817	1049	12
Stockholm	206	265	2
Gothenburg	69	88	2
London	1293	1661	18
Prague	176	226	4
Ljubljana	382	491	12
Skopje	1028	1321	16
Moscow	1557	2001	22
Zurich	1360	1747	20
Sarajevo	588	755	18
Monastir	214	275	2
Istanbul	661	849	10
Tivat	727	934	22
Podgorica	516	662	16

3. FLEET SIZING MODEL

The fleet sizing model refers to a minimal number of aircraft which an airline needs to operate a planned flight schedule. The number of small and medium aircraft is determined separately, using simultaneous and sequential heuristic approach. The simultaneous heuristic algorithm consists of the following 5 steps:

Step 1: Make a list of all flights planned for one week, sorted according to the departure time and day in the week (start with the flight with the earliest departure time in the first day in the week, and finish with the last flight in last day in the week).

Step 2: Assign the first flight to the aircraft 1.

Step 3: Consider the next flight from the list. Assign it to some of the already introduced aircraft if time (departure time is after the arrival time of the previous flight) and space (departure airport is actually the arrival airport of the previous flight) constraints are satisfied. Otherwise, introduce a new aircraft.

Step 4: If the flight can be assign to more than one aircraft, choose the aircraft which is available in the earliest time. If there is more than one aircraft with the same time when they are available, choose arbitrarily between one of them.

Step 5: If there are no unassigned flights on the list, end the algorithm. Minimal number of aircraft is the number of introduced aircraft. Otherwise, go to the Step 3.

The second approach is the sequential heuristic procedure which consists of the following 4 steps:

Step 1: Make a list of all flights planned for one week, sorted according to the departure time and day in the week (start with the flight with the earliest departure time in the first day in week, and finish with the last flight in the last day in the week).

Step 2: Assign the first flight to the aircraft 1. Then go through the list assigning to this aircraft the next flight which has the earliest possible departure time, until the end of the list, considering time and space constraints, and the fact that departure airport in the first day must be the same as the arrival airport in the last day in the week.

Step 3: Take the first flight from the list which is not assigned to any aircraft and introduce a new aircraft repeating the procedure from the Step 2.

Step 4: If there are no unassigned flights on the list, end the algorithm. Minimal number of aircraft is the number of introduced aircraft. Otherwise, go to Step 3.

The algorithm is applied day by day considering space constraints (aircraft must start new flight from the airport where it is finished previous flight) and aircraft balance (it is necessary that required number of aircraft is available at each airport).

The planned flight schedule of the incumbent airline is the existing one (existing airline's), extended to some new routes and frequencies. It consists of 304 flights in total, 184 operated by medium aircraft, and 122 operated by small aircraft. Algorithms are applied day by day, separately for small and medium aircraft. Both give the same solutions – the same number of aircraft by day. Difference between solutions obtained by these two algorithms represents the balanced flight hours in the solution obtained by the simultaneous approach compared to the sequential approach, where the firstly introduced aircraft operate much more flights than the lastly introduced aircraft. Minimal daily required number of small is equal to 3 during the whole week, except for Sunday, when it is equal to 4. The airline needs 9 aircraft three days per week (Tuesday, Wednesday, and Thursday), and 8 medium size aircraft four days per week.

Now, the question is how many aircraft the airline should order? Is the answer 4 small and 9 medium aircraft, or 3 small and 9 medium aircraft, or 3 small and 8 medium, or something else? These are some of the possibilities that may be adopted by the airline. The decision depends on the planned flight schedule and demand. Schedule could be designed in such a way so that some small aircraft could operate flights to which medium aircraft is assigned, and vice versa, and demand could also allow this change in aircraft size. In the case of the incumbent airline presented, the minimal required number of small aircraft is 3, because flight schedule allows one of the medium size aircraft to operate flights assigned to the fourth small aircraft.

Moreover, an airline could try to adjust its flight schedule, by changing departure time of some of the flights, day of operation or reducing the frequency so as to enable reduction of the minimal number of aircraft.

Another solution is to find an appropriate proportion of acquired to leased aircraft. According to [7] an optimal share of leased aircraft within the total fleet is 40%. Their conclusion is based on the data of 23 leading airlines. As the airline described in this paper is not a leading one, additional research is required to determine this share.

4. CONCLUSION

This paper presents the two-stage fleet planning model consisting of fleet mix and fleet sizing models. Fuzzy logic approach in determination of approximate fleet mix within the fleet planning process is introduced and it presents the main contribution to the literature. The input data in this stage are based on passenger demand on route and route distance. The outputs from this stage are a set of routes operated by small aircraft and a set of routes operated by medium size aircraft. At the same time, the abovementioned outputs are input for the second stage. The heuristic algorithm with two approaches is developed to determine a minimal number of aircraft which an airline needs to implement a planned flight schedule.

Fleet planning is a process of strategic importance for an airline that has a tendency to match their capacities and passenger demand for corresponding market conditions. Good fleet plan has a direct impact on airline profitability and costs. Thus, when choosing aircraft for fleet, both the interests of the airline and passengers must be taken into consideration. The airline is interested in carrying out the planned traffic with the least possible number of aircraft, the lowest possible operating costs and the highest aircraft block time and passengers load factor. Passengers are interested in high flight frequencies, large number of non-stop flights, small connecting time, etc. These conflicting interests need to be harmonized. Airline planners in charge of strategic planning very often have to make certain decisions dealing with uncertain and approximate values of input parameters. Huge experience of airline planners is incorporated in fuzzy logic system presented in this paper in order to make easier decision making related to approximate fleet mix.

The advantage of the model is that it could be applied in the case of cargo airlines with minor adjustment related to specific caracteristics of air cargo transport. Depanding on freight demand and distance airline will choose medium or large aircraft in the approximate fleet mix model, while fleet sizing model could be applied without changes.

Further research can focus on improving the solution in fleet sizing model in terms of a more balanced number of flight hours by aircraft. Another possibility to extend this research is to make additional analysis in order to consider leasing/buying share of aircraft in a fleet. Finally, with regard to decision making related to aircraft acquisition (aircraft types), this research could go further with deeper analysis of aircraft types, aircraft prices, fleet commonality and other factors that may influence aircraft selection.

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