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MULTI-OBJECTIVE OPTIMIZATION APPLIED FOR PLANNING OF REGIONAL EUROPEAN AIRLINE

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Abstract: *Fleet planning is very important elements in the airlines planning process. Fleet planning should answer the question which types of aircraft are required and how many of them are required taking into account the current and future transportation needs. Decision-making in the field of operations has a character of engineering. This process requires consideration of many factors, dependencies and criteria. The article presents the decision problem formulated in the form of a multi-objective mathematical model. This work preliminarily determines the structure of the transportation system which performs carriages on the local routes.*

Key words: *regional air transport, aircraft fleet planning, multiple objective optimization*

1. Introduction

Context and background: Europe is one of the Earth's most densely populated areas. In 2012, approximately 9.5 million IFR flights were performed in Europe and the forecast for 2017 assumes 21 per cent increase in the number of IFR flights, which is an equivalent to 11.5 million take-offs, and the same number of landings, in European airports [10], [11]. As much as 44 per cent of the total air traffic is concentrated on only 25 largest European airports [11]. That results in a very high air traffic density in the largest European airports and in their vicinity. But on the other hand some parts of Europe have a poorly developed road and motorway network, as well as railroad and air routes [9]. Then Europe has a huge partly unused potential of airports and landing grounds [5] which can be the basis for creating a competitive travel offer around Europe by light passenger aircraft using less busy airports and adjusted and re-qualified landing grounds. One of the ways leading to improvement of the transport situation is the development of local aviation services. Air transportation as a part of the passenger carriage sector is characterized by a much higher average speed of transportation, which proves its undoubted advantage in relation to other means of transport. The infrastructural requirements are limited mostly to the airports as their isolated infrastructure. In order to use the mobility and potential of transportation performed by aircraft to the full, it is necessary to determine possible available places to perform take-offs and landings, i.e. operational-technical data, possibility to use them etc. The cost of creating a system enabling correct functioning of local aviation services, in spite of common opinions, is not quite high. Thus, creating a network of airports accessible within less than 20 to 30 minutes from each point of the country does not require a significant expenditure in comparison to the sums of money allocated to the development of other transport infrastructure. Small and medium airports can become a basis for creating competitive travelling offers around Europe using light commercial aircraft and less busy airports as well as relevantly adjusted and re-qualified landing fields addressed to those travelling by passenger airplanes so far. In the integrated system of communication of Europe aviation has a chance to perform a substitution role in the places where the road or rail infrastructure is poorly developed and its modernization and extension will demand significant financial costs.

Development perspectives: it can be expected that the direction of development of local service aircraft of the new generation will continue in the future. The conclusions following from the research programs speak for this fact. The following programs have been developed in the USA: Small Aircraft Transportation System (SATS) or Advanced General Aviation Transport Experiments (AGATE) [24]. In Europe the first works concerning the local transportation systems using light aircraft were commenced by professor J. Rohacs introducing the notion of Personal Air Transportation System in the frames of the PATS project [27]. These works were continued by a group of professor J. Rohacs as well as within the program financed by the European Committee: the European Personal Air Transportation System (EPATS). About the majority of the problem indicates the fact that one of the main initiatives proposed in Clean Sky 2 is Small Air Transport (SAT), which represents the R&T interests of European manufacturers of small aircraft used for passenger transport (up to 19 passengers) and for cargo transport, belonging to EASA´s CS-23 regulatory base [8]. The main aim of the development of the Regional Small Aircraft Transportation System is to increase the "door-to-door" travelling speed (e.g. four times in AGATE [24]) in comparison to average speeds obtained when travelling by car on a motorway. This system should win the travellers travelling between cities located 200 to 1400 km from each other. Passenger carrying aircraft should meet the following requirements: high factor of safety, easy operation, compliance with the ecological norms, guarantee of comfort to the travelers, high flying speed (up to 550 km/h), the range of about 1500 km, competitive costs of operation in comparison to travelling by car over the distance exceeding 500 km.

<u>Selecting the area of functioning</u>: the European Union is an economic and political union of 28 democratic European states. Despite the Schengen Agreement, the passenger flow in the EU territory is determined by territorial division. It can be assumed that transportation needs on regional routes concern mainly a single state. The state where the development of the regional transportation with the use of light transport aircraft is the most appropriate is Poland. Poland has a poorly developed infrastructure of roads, motorways, railroads and airport network [9]. Undoubtedly, the necessity to develop a transportation infrastructure (especially motorways and airport networks) is the result of the fast economic development. The existing motorway stretches due to their disunity do not guarantee long-range international services. The planned extension of the motorway network and some airports would not solve the transport problems in Poland. At the same time Poland is said to be one of the European countries with the largest density of airports. There are 38 airports with man-made runways and 80 landing fields and places to perform take-offs and landings of light aircraft. 70% of the population lives within 30 minutes by car from the nearest airport [5].

2. Fleet planning

Fleet planning is one of the most important elements in the airlines planning process. Fleet planning should actually answer the question which types of aircraft are required and how many of them are required taking into account the current and future transportation needs. This work preliminarily determines the structure of the transportation system which performs carriages on the local routes. It was assumed that the analyzed transportation system would compete mainly with the road transport over the distance exceeding 200 km for business trips.

Among the factors having a significant influence on the choice of the type or types of aircraft we should distinguish technical, economical and exploitation parameters, parameters concerning airports, expenditures and costs, volume of transportation needs and others. The following values depend on the technical parameters of an aircraft: selection of the flying speed, annual utilization in flight hours, period between overhauls, distance flown and at last selection of a proper aircraft to the needs of the line. This work also assumes the value of the offered weight usability factor and the same quantity of annual operation hours of comparable types of aircraft.

Economic and operational parameters characterize the aircraft during its work and allow comparing the operation results of different aircraft. Among these factors it is possible to distinguish: passenger-distance (e.g. pkm), payload-distance (e.g. tkm), block distance (e.g. km), block speed (e.g. m/s) and block time (e.g. hour). This measuring allows establishing the unit-per-hour output of the aircraft, i.e. determining the value of transportation work per block hour.

In order to estimate the optimal choice of the aircraft in terms of investments, the purchase price of the aircraft, spare engines and spare parts for the airframe, the engines and radio navigational devices should be taken into consideration. Comparative evaluation can be made on the basis of the direct operating costs increased by the take-off and landing costs [30].
One of the most important characteristics of air transportation is a large span of unit costs which depend on the type of aircraft and its selection to a particular line. That is why the aircraft selection planning requires a detailed forecast of the transportation needs on certain lines. In other branches of transportation this factor also exists but it is less distinct. The problem is complex, because it is better for a service company to have as few types of aircraft as possible. That is why this work presents a division of the lines according to the size of the predicted transportation and similar block distances; heavy aircraft types were selected for these established groups. The frequency of flights was determined assuming the necessity to meet all transportation needs most efficiently [6].

3. Aircraft selection

It was assumed that the basic criterion when selecting the best aircraft is satisfying the traffic needs defined uniquely by the tasks set.

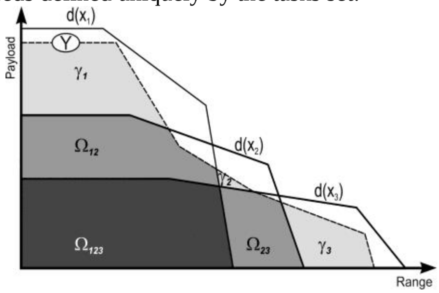

Fig. 1. Aircraft fleet transport potential [4]

Satisfying the traffic needs requires the use of different types of aircraft with different characteristics and different efficiency. These aircraft make a fleet whose efficiency depends on the efficiency of specific types composing it. Cooperation of the aircraft within the fleet reveals in the fact that the capabilities of different aircraft, as a rule, are partially covered. Thus, alternative fields are created Ω_{12}, Ω_{123}, Ω_{23} (Fig. 1) to cover which two or more types of aircrafts are used [4].

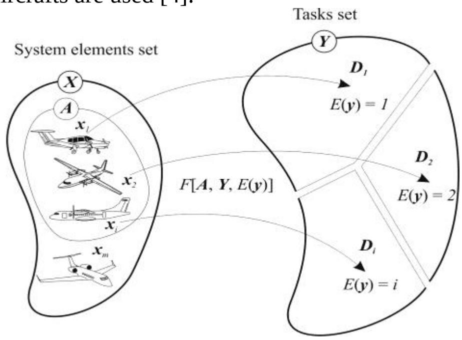

Fig. 2. Task division between aircraft within a fleet

The task of selecting the aircraft can be reduced to task division between the aircraft of the system (Fig. 2) determining the number of types and the quantity of each type, which will guarantee the highest efficiency of performance of all transportation tasks. The task of finding the optimal fields of specialization ($\boldsymbol{D_i}$) of the aircraft which are an integral part of the system in multi objective optimization (MOO) terms can be solved using a special algorithm [21], [22].

4. Problem formulation

The fleet (multitask system) consists of a certain finite number m of elements which make up set $\boldsymbol{A}$ called a set of system elements. The set of all elements x_i, which can potentially enter the system structure, is determined by $\boldsymbol{X}$, i.e.

$$\boldsymbol{x_i} \in \boldsymbol{X} \quad for \quad i = 1,\dots,m, \tag{1}$$

and set $\boldsymbol{A}$ is defined as:

$$\boldsymbol{A} = \{\boldsymbol{x_i}\} \subset \boldsymbol{X} \quad where \quad i = 1,\dots,m, \tag{2}$$

It is supposed that set $\boldsymbol{Y}$ will be a set. The integral function $E(\boldsymbol{y})$ was determined in this set which takes values $1, 2, ..., m$ – it is called the distribution function. The field of specialization $\boldsymbol{D_i}$, of the element $\boldsymbol{x_i} \in \boldsymbol{A}$ for $i = 1,..., m$, will be called a subset of the set $\boldsymbol{Y}$ in points of which the distribution function has values equal to i:

$$\boldsymbol{D_i} = \{\boldsymbol{y} \in \boldsymbol{Y} : E(\boldsymbol{y}) = i\} \quad for \quad i = 1,\dots,m, \tag{3}$$

The fields of specialization must fulfil two criteria [4]:

- the fields of specialization for different elements cannot have common parts,

$$\boldsymbol{D_i} \cap \boldsymbol{D_k} = \varnothing;\ \forall\, i, k = 1,\dots,m;\ i \neq k\ , \tag{4}$$

- the sum of all the fields of specialization must be equal to the external multitude $\boldsymbol{Y}$

$$\bigcup_{i=1}^{m} \boldsymbol{D_i} = \boldsymbol{Y}\ , \tag{5}$$

Three main elements of the presented model $<\boldsymbol{A}, \boldsymbol{Y}, E(\boldsymbol{y})>$ are called the multitask system [4]. The vector of quality of the multitask non-vector system can be defined as follows:

$$F = F\left[\boldsymbol{A}, \boldsymbol{Y}, E(\boldsymbol{y})\right]\ , \tag{6}$$

Putting the mathematic multitask system into the notion of the local quality function $f\ [\boldsymbol{x}, \boldsymbol{y}, \mu(\boldsymbol{D})]$ of the field of specialization $\boldsymbol{D}_i$ of the aircraft $\boldsymbol{x}_i \in \boldsymbol{A}$, it is possible to express the coefficient of the multitask system quality (6) in terms of its values in particular fields of specialization $\boldsymbol{D}_i$ of certain elements $\boldsymbol{x}_i \in \boldsymbol{A}$:

$$F\left[\boldsymbol{X}, \boldsymbol{A}, \boldsymbol{E}(x)\right] = \sum_{i=1}^{m} \sum_{y_j \in D_i} f\left[x_i, y_j, \mu(\boldsymbol{D}_i)\right]\ , \qquad \boldsymbol{Y} = \bigcup_{i=1}^{m} \boldsymbol{D}_i \tag{7}$$

where: $\mu(\boldsymbol{D}_i)$ – field of specialization measure $\boldsymbol{D}_i$.

The desire to take into consideration when estimating the effectiveness of the multiplicity of the solutions and heterogeneity of their traits and performance properties leads to different criteria and as a result to heterogeneous estimation of the efficiency. It leads to the vector optimization task which takes into account several criteria expressed by the MOO problem formulation which can be regarded as a generalized single objective optimization problem. In recent years all over the world a lot of methods of solving the MOO problem have been discussed. Among them it is possible to distinguish: Weighted Objectives Methods [2], Hierarchical Optimization Methods [32], Trade-Off Methods [20], Global Criterion Methods [14], Distance Functions and Min-Max Methods [25], Goal Programming Method [16] and more willingly unconventional approach to MOO is used using Evolutionary Algorithms [7], [13], [23].

The quality of solution $\boldsymbol{x} \in \boldsymbol{X}$ will be estimated by a certain set element n of the scalar factor which is usually interpreted as a certain vector of objective function values $\boldsymbol{F}$. It is necessary to choose in the accepted set $\boldsymbol{X}$ the best in some respects variant $\hat{\boldsymbol{x}}$. It is known that the mathematical vector optimization model corresponds to this formula

$$F(\boldsymbol{x}) = \underset{\boldsymbol{x} \in \boldsymbol{X}}{opt}\left(F(\boldsymbol{x})\right), \quad F = \{f_1, \dots, f_n\} \tag{7}$$

where: opt – is the operator of optimization of the vector of the objective function values which determines the principle of preference of the solution variants. For the purpose of a single-valued choice of the solution an additional principle (a rule or hypothesis) is introduced to the analysis which determines the compromise scheme between the factors $f_1, \dots, f_n$. This principle in the mathematical view is given by the functional of the components of the vector of the objective function values (i.e. the component synthesis method)

$$F = \varphi\left[f_1, \dots, f_n\right] \tag{8}$$

The introduction of the principle of the synthesis φ converts the vector of the objective function values into a scalar functional and brings the process of the solution choice to the case of scalar optimization. The most widely known method of synthesis is linear synthesis of the components $f_1, \dots, f_n$ to the scalar criterion of the function

$$F(\boldsymbol{x}) = \sum_{i=1}^{n} w_i f_i(\boldsymbol{x}) \tag{9}$$

where: w_i – weights which model the accepted system of the preferences fulfilling the conditions:

$$\sum_{i=1}^{n} w_i = 1, \quad w_i \geq 0, \quad i = 1, \dots, n \tag{10}$$

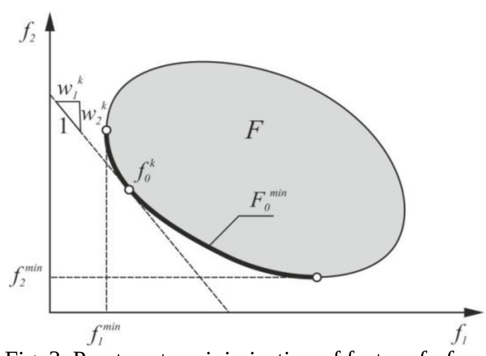

Fig. 3. Pareto set - minimization of factors f_1, f_2

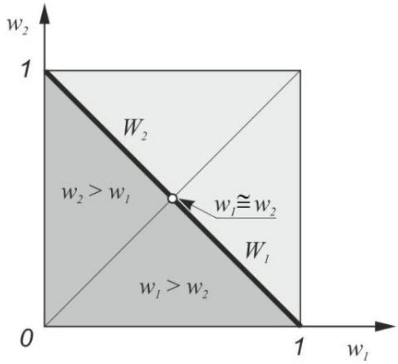

Fig. 4. Sets W_1 and W_2 for 2 criteria [4]

These conditions highlight in the zone of the weights a certain area ***W*** which will be interpreted as a set of uncertainty. Figure 4 on the subspaces w_1, w_2 presents sets $\boldsymbol{W_1}$ and $\boldsymbol{W_2}$ for the cases $w_1 > w_2$ and $w_2 > w_1$ correspondently. Point $w_1 \cong w_2$ reflects the situation of preference equivalence. The weights w_1 and w_2 determines the slope of this line and establishes the essence of the compromise between the elements f_1 and f_2 (Figure 3). The solution in this case leads to the choice of the certain values of $w_i \in [0, 1]$ made by a group of experts, and the principle φ separates the set of possible ratios for the uncertainty of the efficiency estimation. In many tasks it becomes necessary to establish the desirable value limits of the factors themselves.

$$f_i \in \left[f_{i\,\min}, f_{i\,\max} \right], \quad i = 1,\ldots,n \tag{11}$$

For example, for the aviation multitask system, these are limits to the aero-technical, manoeuvrability, aerodynamic and weight values and other characteristics of the aircraft parameters. On this basis it is possible to determine the limits to the weight values

$$w_i \in \left[w_{i\,\min}, w_{i\,\max} \right], \quad i = 1,\ldots,n \tag{12}$$

Thus, the question of taking into account the uncertainty in the efficiency estimation and the choice of a relevant solution leads to construction of the weights set and summing of products $w^T \cdot f(x, y)$.

5. Optimization criteria

Literature analysis [4], [26], [30], [31] helps to distinguish some of the criteria of aircraft performance evaluation with different ranges of their use and capability. Simple technical criteria – is the technical criteria which describe performance and bulk characteristics of the aircraft. The following values can act as criteria: maximum speed, maximum rate of climb, service ceiling, range, take-off distance, landing distance, payload weight and gross weight. Complex technical criteria [4] connect some simple characteristics of the aircraft and give more “meaningful” estimation of the quality, however limited, to a selected aircraft category with not so distant technical features. These criteria have relative character. Economic criteria – originally appeared for the needs of airlines (transport companies) [30], [31]. They are used to optimize the aircraft fleet as well as setting rational (and competitive) traffic tariff rates. Simple technical criteria do not allow analysing the influence of design parameters on the user parameters of the aircraft, they are important from the point of view of transport efficiency. Economic criteria require, however, the knowledge of the structure and the method of performing the tasks. In order to avoid the complex modelling problem of the aircraft functioning in the transportation system, it was decided to choose two criteria: specific transport efficiency (13)

$$STE = \frac{m_{PAYLOAD}}{m_{TO}} V_{CRU} \tag{13}$$

and Direct Operating Cost (DOC). The first one describes the amount of fuel needed to carry one passenger at a unit distance. The second one (DOC) express the cost of a time unit of operation of a given type of aircraft [30]. The DOC is a sum of costs directly connected with performing an aviation task. It consists of flight costs (fuel, personnel salaries, amortization, repairs, airport charges, navigation, etc.) which fall on each aircraft and calculation unit.

6. Aircraft characteristics

A computational model in terms of content describes: physical properties of the aircraft, requirements to fulfill a certain task (perform a certain task) by the aircraft and functioning of the aircraft aimed at achieving a certain effect. In algorithmic terms, the model is a system of equations (or relations), which establish the correlation of technical parameters describing the aircraft and its transport properties.

The computational model is mostly based on the methods described at [1], [3], [12], [17], [26], [28], [29], [30], [31]. The weight breakdown was concentrated on the weight prediction of the aircraft's main parts that included the power unit, which was modified by changing the bypass ratio. The power unit model is essential to estimate the thrust characteristics and fuel consumption characteristics of the engine and is dependent upon the height, flight speed and power level. The aircraft performance was estimated taking into account the limits, which follow from the requirements concerning the current procedures of the aircraft take-off in accordance with the flight operational procedures [1], [12]. Then the methods of defining the aircraft performance in different phases of the flight using the conventional equations of motion were used.

7. Problem description

It was assumed that the air transport will be more attractive to passengers if the block time of travelling by plane will be three times shorter than travelling by car. It means that when performing the flights over short distances the aircraft must fly relatively fast. Thus, it was assumed that only turboprop aircraft will be taken into consideration with the cruising speed not less than 400 km/h.

Table 1. Aircraft data

Aircraft type	b [m]	S [m^2]	P_{max} [kW]	W_{TO} [kg]	n_{pax}	V_{Max} [km/h]	Lz [km]	C_{km} [kg/km]	DOC [$/km]
Single-engined									
TBM 850	12,68	18,00	634	2 938	5	504	3 739	0,1918	1,555
GM-17 Viper	13,04	31,30	560	3 102	6	414	1 083	0,2467	1,915
Ae 270 Ibis	13,82	21,00	634	3 785	9	456	3 205	0,2097	1,670
PC-12	16,23	25,81	1 197	4 738	9	556	2 739	0,3465	1,803
T 101	18,20	43,63	706	5 648	9	336	1 674	0,5012	2,603
Explorer 500T	14,43	18,36	447	3 017	9	335	2 412	0,2905	1,968
Cessna 208	15,88	25,96	503	3 659	9	389	3180	0,2931	1,765
Twin-engined									
King Air C90B	15,32	27,31	410	4 226	6	452	3 553	0,2729	2,014
BN2T	14,94	30,19	298	3 579	8	412	1 445	0,3379	2,015
King Air 200	16,61	28,15	634	4 904	9	552	3 855	0,3523	1,839
P 180 Avanti	14,04	16,00	1 107	4 970	9	748	1 152	0,6595	1,533
King Air 350	17,65	28,80	783	5 374	10	589	2 969	0,4297	1,802
Cessna F 406	15,08	23,48	373	4 531	12	476	3 426	0,2335	2,044
Evektor EV-55	16,10	25,29	400	5 004	14	450	2 902	0,2987	2,292
Beechcraft 1900	17,65	28,80	954	7 448	19	599	3 057	0,5187	2,050
Dornier 228	16,97	32,00	533	5 818	19	459	4 071	0,3946	2,397
Harbin Y-12	17,24	34,27	462	5 208	17	431	3 054	0,3289	2,427
PZL M28	22,06	39,72	820	7 937	19	514	1 083	0,8622	2,284

Where: b-wing span, S-wing area, P_{max}-one engine power, W_{TO}-take-off weight, n_{PAX}-number of passengers, V_{Max}-maximum speed, Lz-range, C_{km}-fuel consumption per kilometre, DOC-direct operating cost.

On short distances, the high cruising speed of jet aircraft does not translate into a higher block speed in comparison to turboprop aircraft. The costs of purchasing and operation of a jet aircraft is, however, much higher. Aircraft with a piston engine reach too little block speed on short distances and do not give a possibility to make the flight block time three times shorter. Table 1 shows data of analysed aircraft, received with use of published information [19] and calculation model.

The air transport's domain is traffic to the distance over 200 km. Calculation of the passenger traffic volume for certain lines was made on the following basis: supposition that the distance cannot be less than 200 km, demographic forecast for Poland to the year of 2020 (prepared on the basis of current demographic data [15] and [9]), traffic forecast of substitution branches of transport and their percentage share according to the distance zones [9], country's citizen mobility factor for the traffic exceeding 200 km.

Twenty-two airports were chosen for Poland (more or less one in each region) on the basis of which a planned network of communication serviced by light transport aircraft was created (Fig. 5). Among all the communication only those whose distance is more than 200 km were selected, and the block speed of the aircraft is three times higher than the block speed of the car covering the same distance (between the centres of the biggest cities). The aircraft block speed was determined for an established traffic model assuming extremely short time a passenger spends at the airport (20 min) and time to access to and from the airport to the city centre (determined for a real distance of the airports and cities). The block time of the car traffic was determined for each pair of cities with the use of the automotive navigation system.

There is a lack of forecast regarding the percentage share of the traffic of certain branches of transport in Poland according to the distance zones. Assuming that the structure of this traffic will be close to the existing one, it was supposed that the travels performed over the distance more than 200 km on business purposes will be 3 % of all carriages. It agrees with the assumptions accepted by the EPATS project. The Isard method [18] was used to determine the traffic volume in one direction in the passenger traffic on each analyzed route. Estimated annual number

	EPBK	EPBA	EPBY	EPRU	EPGD	EPKM	EPKA	EPKO	EPKK	EPSW	EPLL	EPOD	EPKN	EPPI	EPPO	EPRA	EPRZ	EPSC	EPTO	EPBC	EPWR
EPBA	13																				
EPBY	7	14																			
EPRU	13	0	15																		
EPGD	10	21	0	22																	
EPKM	5	0	6	0	9																
EPKA	14	16	17	0	26	12															
EPKO	6	14	0	15	6	7	14														
EPKK	4	0	5	0	7	0	0	3													
EPSW	13	24	19	25	27	17	0	10	21												
EPLL	7	16	9	0	18	8	0	7	17	17											
EPOD	5	14	5	15	0	8	14	3	13	14	11										
EPKN	6	0	7	0	10	0	7	4	0	11	6	7									
EPPI	16	26	0	0	17	19	27	0	30	31	24	14	19								
EPPO	10	14	0	13	13	11	13	4	17	17	10	10	9	0							
EPRA	8	15	11	0	17	9	0	6	11	0	0	9	12	9	28						
EPRZ	9	14	13	18	19	8	0	6	0	0	16	12	13	10	34	5					
EPSC	7	15	7	17	11	9	15	0	14	17	14	8	11	0	17	7	13				
EPTO	5	11	0	11	0	6	10	2	11	11	0	0	8	0	0	5	10	6			
EPBC	0	37	23	29	37	27	0	14	40	0	0	19	27	20	56	0	34	32	18		
EPWR	14	16	13	0	23	0	21	7	19	26	17	16	0	10	0	10	21	15	11	46	
EPZG	5	10	5	11	9	5	11	3	9	12	9	6	6	4	0	5	9	4	4	23	0

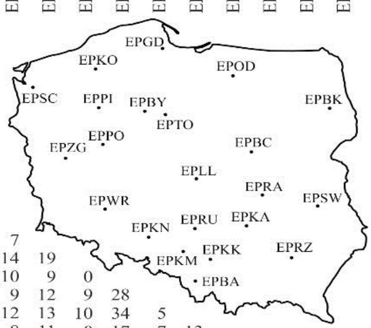

Fig. 5. Air connections specification with passenger flow rates per day (EPBK-Białystok, EPBA-Bielsko-Biała, EPBY-Bydgoszcz, EPRU-Częstochowa, EPGD-Gdańsk, EPKM-Katowice, EPKA-Kielce, EPKO-Koszalin, EPKK-Kraków, EPSW-Lublin, EPLL-Łódź, EPOD-Olsztyn, EPKN-Opole, EPPI-Piła, EPPO-Poznań, EPRA-Radom, EPRZ-Rzeszów, EPSC-Szczecin, EPTO-Toruń, EPBC-Warszawa, EPWR-Wrocław, EPZG-Zielona Góra)

of passengers travelling with use of regional air transportation system in Poland is 755 000. This work does not take into account the influence of different factors on the attractiveness of the air traffic such as attraction of the region for tourists, the administrative or industrial size or activity, etc. However, the influence of the factors decreasing the traffic attractiveness was taken into account by comparing the block time of travelling by air with the real time of travelling by car. Another factor which influences the choice of the aircraft as a means of transport is the frequency of flights on a given route. It was supposed that the period between the flights must be such so that passengers would not go by alternative means of transport. It means that the aircraft should travel faster. In this case we obtained a minimal number of flights on each route which fulfill the established assumption. It was also assumed that a day number of flights cannot be less than 2 (one flight in one direction and one return flight).

8. Results

On the basis of the carried out analysis, using the algorithm described in [21] and [22] the tasks were distributed between the aircrafts of the transport system and aircraft of the most suitable transport class were selected for each line. However, as the world market possesses a great number of aircraft of a required transport category, the choice of a specific type is made using the algorithm of the optimal task division between competing aircraft. As the basic criterion of the selection a direct operational cost was used, however, the additional criterion is the transport qualitative efficiency.

The calculations were made for a net of 182 air communications of the characteristics presented on Fig. 5. On the basis of the established categories some aircraft with a turboprop engine were selected (Table 1) for which the transport tasks were divided. The results are shown on Fig. 6 and 7.

Fig. 6 shows a set of compromise solutions. For the chosen weight factors (w_i) a compromise solution can be obtained depending on the accepted system of preferences. If both criteria are equivalent, the optimal type of aircraft is F406 Caravan II carrying 12 passengers. For weight factor $w_1 = 0$ the result is obtained with taking into consideration only one criterion – transport efficiency. In this case are preferred two types of aircraft. The first is a single- engined TBM 850 carrying 5 passengers.

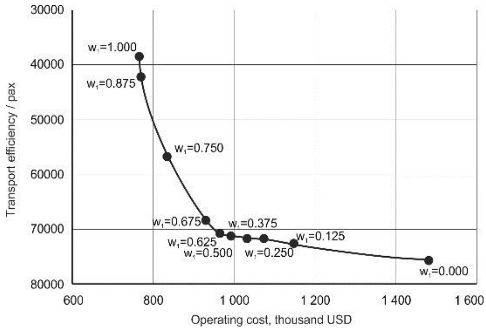

Fig. 6. The envelope of the best values of the analysed criteria (Pareto set) for different weight factors

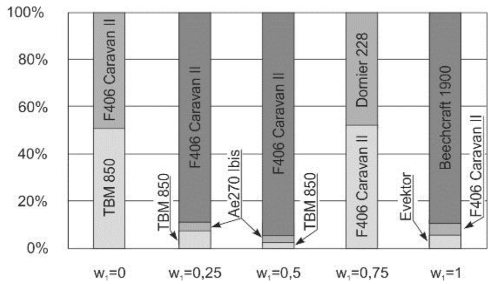

Fig. 7. Aircraft share in task realization for different weight factors

The second one is F 406 Caravan II. For weight factor $w_1 = 1$ the result is also obtained with taking into consideration only one criterion – operating cost. In this case, the optimal aircraft is Beechcraft 1900, the biggest one, with a small share of smaller aircraft (Evektor and F406). If transport efficiency is more important ($w_2 > w_1$) the smaller aircraft are preferred, for cases when costs are more preferred, larger types of aircraft are justified. If transport efficiency is more important ($w_2 > w_1$) the changes of weight factors influence slightly to transport efficiency criterion, but cost changes in large range. If direct cost is more important ($w_1 > w_2$) the changes of cost are lower than changes of transport efficiency with weight factors changes. Direct cost preference gives change of weekly cost of transport from

990 549.5 [USD] to 765 619.3 [USD]. Equivalent variant ($w_1 = w_2 = 0{,}5$) gives loss of transport efficiency in 5,79% and in cost of 33,4%.

9. Conclusions

One of the problems of designing the transport system is determining the structure of the aircraft fleet in order to achieve the set goals. This task is called fleet planning. This work focuses on the selection of the aircraft types for the transport system using light aircraft. The system will create a net of local communication in a European country with a relatively poor developed transport infrastructure. It was assumed that the aircraft should efficiently compete with cars on the distances exceeding 200 km due to shorter travelling times and acceptable level of costs. In order to complete this task, such airports in the territory of Poland were selected which are the most attractive from the point of view of developing the transport system using light aircraft. Air communication characterized by the most foreseen passenger traffic and time of travelling by air at least three times shorter than travelling by car on the same route was determined. The minimal daily frequency of flights was determined on the basis of the assumption that the time period between the flights must be such so that the passengers will not use alternative means of transport (for instance, the car). The categories of heavy aircraft which meet the transport needs at specific routes were determined. In order to identify the transport categories, some types of existing aircraft were selected which can potentially make up a fleet whose main goal will be satisfying the estimated traffic needs. Optimal division of the transport tasks was made between the aircraft which enabled the selection of aircraft types and their number minimizing the costs of performing the tasks and maximizing the transport efficiency. The obtained results should be treated as a partial solution to the problem of a light aircraft fleet optimization carrying passengers over short distances in Europe. Choosing Poland as the model country was dictated by extremely beneficial conditions for the development of the system of transportation using light aircraft transportation (poor transport infrastructure, dense airport network). The obtained results can be generalized for other European countries with a similar logistic system.

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