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Demand Analysis Models for Passenger Air Transportation

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ABSTRACT

Analysis of demand for air transportation is a key business process around which each airline develops strategic and operational plans. Based on the demand forecast, strategic plans for development of the airline's route network are developed, as well as budgeting, financial planning, sales and marketing plans, aircraft fleet planning, risk assessment and plans to overcome their consequences. Demand analysis also facilitates important management activities, such as decision-making, performance evaluation, and reasonable allocation of resources in specific and uncertain conditions for development of the air transport system.

Based on the specific requirements of the airline or in relation to a specific airline, an individual demand forecasting model can be developed. Such a model is an extension or a combination of various qualitative and quantitative methods for forecasting demand. The task of developing a custom model is often iterative, highly detailed, and driven by expert knowledge and can be accomplished by introducing suitable demand management software.

The task stated in the article is not a staging task for building a model, but only offers to study the available theoretical material for the analysis of demand for air transportation based on the most famous models for forecasting demand for transportation.

The method of scientific research of the problem posed in the article is the method of scientific analysis of existing models. Offer and demand for air transport services are reciprocal but asymmetric. Although the realized demand for transportation cannot take place without an appropriate level of supply, an air transport service can exist without appropriate demand. This is often found in projects that are developed with a margin that meets the expected level of demand, which may or may not be realized, or it may take several years to be realized. Regular air transport services form a supply that exists even if demand is insufficient. Several models presented in the article emphasize the conditions in which there is supply saturation, and on the other hand, the models in which demand is formed due to the mutual attractiveness of the entities that form demand are considered.

Keywords: *transport, demand for air transportation, forecasting, macroscopic model.*

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To analyze the demand for air transportation, we can proceed from the fact that the demand for air transportation between two cities or two regions depends on:

• socio-economic characteristics of the regions;

• characteristics of the transport system.

These two factors are interconnected. In general, the characteristics of the transport system of Russia show that in 2018, according to the Federal State Statistics Service: transport turnover in Russia grew by 2,8 % compared to 2017 and amounted to 5640 bln t • km. The growth was recorded for all modes of transport, except sea (-10,3 %), air (-0,7 %) and inland water (-6,8 %) transportation. The freight turnover of the railway transport increased by 4,2 %. The share of railway transport in the total structure of freight turnover amounted to 46,1 % (by 0,7 percentage points higher than in 2017). The share of railway transport in total transport freight turnover (excluding pipelines) amounted to 87,4 % (0,6 percentage points above the level of 2017). In 2018, passenger turnover in Russia increased by 6,6 % compared to 2017, to 531,9 bln passenger-km [1].

Passenger turnover of certain modes of transport amounted to: railway – 129,5 bln passenger-km; road – 114,8 bln passenger-km; air – 286,9 bln pass.-km. The increase in the passenger turnover of public transport occurred due to the increase in passenger turnover in air transport (by 10,6 %). Within the structure of passenger turnover of public transport, air transport accounted for 53,9 % (+1,9 percentage points to the level of 2017). Passenger turnover of railway transport increased by 5,2 % compared to 2017, but its share in the structure of passenger turnover decreased to 24,4 % (by 0,3 percentage points). The share of road (bus) transport in passenger transportation by public transport was 21,6 % (-1,6 percentage points to the level of 2017), and passenger turnover decreased by 1 % [1].

Models for assessing demand for air transportation most often evaluate:

• number of potential passengers;

• number of passenger kilometers that can be achieved;

• expected number of take-off and landing operations;

• seat occupancy rate.

The process of forecasting the demand for transportation most often consists of the following steps:

• trip generation;

• travel distribution;

• modal differentiation;

• destination of the trip [2].

When building a demand model, one should consider whether the model includes competitive modes of transport. Therefore, we can consider models that are independent of the characteristics of alternative modes of transport and multimodal models [3].

Aviation is the predominant mode of transport on many long-distance routes. Therefore, demand for air transportation on long-haul routes should be evaluated independently of other modes of transport.

Multimodal models are mainly used to estimate demand for air transportation along short-haul routes.

Demand for air transportation on shorter routes is usually assessed simultaneously with assessment of demand for other modes of transport.

Classification of models of demand for air transportation:

• macroscopic model;

• microscopic model [4].

Macroscopic models are used to assess the level of development of air transportation in a particular country or region:

• number of passengers;

• number of flights;

• number of passenger kilometers.

Assessment of microscopic models:

• demand for transportation between two cities;

• passenger flow at the airport;

• number of passengers on a particular route;

• number of passengers in each class [5].

In the macroscopic model: demand is a function of time, factors affecting the number of passengers are not taken into account

The model is described as follows:

$$y = kt + m, \tag{1}$$

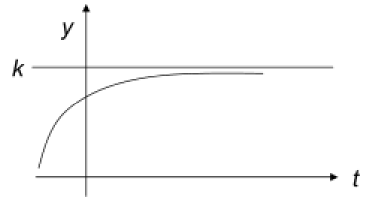
where t – time;

y – number of air passengers that changes over time;

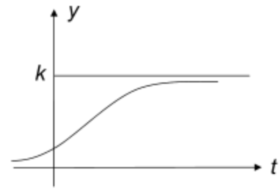
k, m – parameters.

Calibration of the model can be carried out by the least squares method.

In practice, when modeling various processes – in particular, economic, physical,



Pic. 1. Graphical view of a model [5].



Pic. 2. Gompertz curve [14].

technical, and social ones – various methods of calculating approximate values of functions from their known values at some fixed points are widely used [6].

Such problems of approximation of functions often arise:

• when constructing approximate formulas for calculating the values of the characteristic values of the process under study from tabular data obtained as a result of the experiment;

• in numerical integration, differentiation, solving differential equations, etc.;

• when it is necessary to calculate the values of the functions at the intermediate points of the considered interval;

• when determining the values of the characteristic values of the process outside the considered interval, in particular when forecasting [7; 8].

If, to simulate a certain process specified by the table, we construct a function that approximately describes this process on the basis of the least squares method, it will be called an approximating function (regression), and the task of constructing approximating functions will be called the approximation problem [9; 10].

Model as an exponential function:

$$y = a \cdot b^t \quad (2)$$

Logarithmic form:

$$logy = loga + t \cdot logb. \quad (3)$$

When using polynomials of various degrees, the trend control parameters are estimated using the least squares method (LSM) [11] in the same way as the parameters of the regression equation are estimated based on spatial data. The levels of the dynamic series are considered as a dependent variable, and the time factor t, which is usually expressed by a series of natural numbers 1,2, ..., n, is considered as an independent variable.

Model in the form of a modified exponential curve (see Pic. 1):

$$y = k + a \cdot b^t, \quad (4)$$

where $a < 0$, $b < 1$, k – fixed level of saturation.

Forecasting of socio-economic phenomena based on growth curves (saturation curves) has been used relatively recently. These methods were first used at the beginning of 20th century to forecast the growth of biological populations. However, growth curves have worked well in forecasting socio-economic phenomena. Their use in this case requires compliance with certain conditions:

1. The initial time series should be quite long (30–40 years).

2. The initial time series should not have jumps, and the trend of such a series should be described by a fairly smooth curve.

3. The use of growth curves in forecasting socio-economic phenomena can give fairly good results if the saturation limit is determined relatively accurately [12].

It should be noted that the growth curves reflect cumulative increase up to a predetermined maximum limit.

A feature of the growth curves is that absolute increments decrease as they approach the limit. However, the growth process goes to the end.

The significance of growth curves as methods of statistical forecasting of socio-economic phenomena lies in the fact that they contribute to the empirically correct reproduction of the development trend of the studied phenomenon.

The most common growth curves used in statistical forecasting practice are Gompertz growth curve and Pearl-Reed growth curve.

Both curves are, in general, similar to each other and graphically depicted as an *S*-shaped curve.

A feature of the equations of these curves is that their parameters can be determined by the least squares method only approximately. To calculate the parameters of these curves, a number of artificial methods are used, based on dividing the initial series of dynamics into separate groups [13].

Gompertz curve (see Pic. 2) [14]:

$$y = k \cdot a^{b^t}. \qquad (5)$$

Logarithmic form:

$$logy = logk + b^t \cdot loga. \qquad (6)$$

When log $a < 0$, $b < 1$, k – saturation level.

Logistic curve or Pearl-Reed curve (see Pic. 3):

$$y = \frac{k}{1 + b \cdot e^{-at}}. \qquad (7)$$

The least squares method cannot be used to estimate parameters of:

• modified exponential curves;
• Pearl-Reed curve;
• Gompertz curve.

In the macroscopic model, demand is a function of socio-economic characteristics.

Dependent variable:

• number of passengers;
• number of flights performed;
• number of passenger kilometers.

The independent variable is selected from the socio-economic characteristics and the characteristics of the transport system, most often these are socio-economic characteristics:

• population;
• national income;
• personal consumption;
• trade volume;
• number of tourists;
• characteristics of the transport system;
• transportation cost;
• speed and travel time.

In general, the model takes the following form:

$$y_t = a \prod_{t=1}^{m} S_{it}^{bi} \prod_{j=1}^{n} T_{jt}^{cj}, \qquad (8)$$

where m – total number of socio-economic characteristics;

n – total number of characteristics of the transport system;

y_t – number of air passengers during time t;

S_{it} – value of the i-th socio-economic characteristic at time t;

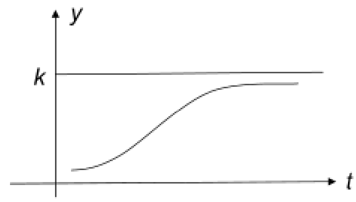
T_{jt} – value of the j-th characteristic of the transport system at time t;

a; b_i; c_j – parameter.

Logarithmic form:

$$logy_t = loga + \sum_{i=1}^{m} b_i \cdot logS_{it} + \sum_{j=1}^{n} Cj \cdot logT_{jt}, \qquad (9)$$

where a; b_i; c_j – estimates of parameters.



Pic. 3. Pearl-Reed curve [14].

Models of trip distribution

When the total number of trips that a region can generate is established, trips are then distributed.

Trip distribution sets the number of trips between individual zones.

Commonly used models:

• entropy model;
• gravity model (analogy with Newton's law of gravity):

$$f_{ij} = k \frac{A_i \cdot B_j}{d_{ij}^2}, \qquad (10)$$

where f_{ij} – number of trips between the cities i and j;

k – constant;

A_i – «size» of the city i;

B_j – «size» of the city j;

d_{ij} – distance between the cities i and j;

A_i, B_j most often taken as the number of departures or arrivals.

Problems in the initial gravitational model: are not satisfied with the following flow conservation equation:

$$\sum_{j=1}^{n} f_{ij} = a_i, \sum_{i=1}^{m} f_{ij} = b_j. \qquad (11)$$

Modified gravitational model:

$$f_{ij} = k_i \cdot a_i \cdot k_j \cdot b_j \cdot f(d_{ij}), \qquad (12)$$

where k_i, k_j – coefficients related to the number of departures and arrivals;

$f(d_{ij})$ – function of distance, it may be distance, travel time, etc., or a combination of various variables.

In this way:

$$\sum_{j=1}^{n} f_{ij} = a_i, \qquad (13)$$

$$\sum_{j=1}^{n} k_i \cdot a_i \cdot k_j \cdot b_j \cdot f(d_{ij}) = a_i, \qquad (14)$$

$$k_i = \frac{1}{\sum_{j=1}^{n} k_j \cdot b_j \cdot f(d_{ij})}. \qquad (15)$$

Thus:

$$\sum_{i=1}^{m} f_{ij} = b_j, \qquad (16)$$

$$k_j = \frac{1}{\sum_{i=1}^{n} k_i \bullet a_i \bullet f(d_{ij})}. \quad (17)$$

Entropy model

«As in the case of the gravitational approach, the idea of constructing an entropy model was suggested by physics, namely, the second law of thermodynamics, which states that any closed physical system seeks to achieve a stable equilibrium state, which is characterized by a maximum of entropy of this system» [15; 16, p. 12]. The use of the entropy model, as well as the gravitational one, is due to similarity with processes in physics, i.e., simplicity of understanding their essential nature. The actual distribution of the flow is associated with distribution of flows obtained by maximizing the entropy function. The entropy function parametrically depends on the desired state of the system for all elements. Maximizing the weighted entropy allows to find not just an equilibrium state, but to determine the state that is closest to the real situation, which could have developed taking into account the preferences of individuals. Measuring the entropy of a system is important for determining the dynamics of a system. An important task of the air transport system is the ability to assess changes in the entropy of the system. An indicator that the entropy of the system is growing, can be revealed through a constant increase in the price of air transportation of passengers and (as a result of this process) a gradual decrease in demand.

These models have proven themselves in convergence of simulation results with the results of field surveys.

Conclusion.

Demand forecasting models can be applicable both for studying individual characteristics of formation of demand for transportation, and for studying development of traffic flows, especially in anticipation of a sharp increase in transportation, which, for example, occurs during large sporting events, such as the Olympic Games or the World Cup.

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