Mathematical Techniques and Approaches to
Forecast Passengers' Demand for
Transport Services to Provide Sustainable Development

E.S. Osetrov
Dubna International University for
Nature, Society and Man, Russia

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Abstract

In the present work application of mathematical techniques and approaches to forecast passengers' demand for transport services is considered. Scientific approaches to determination of demand for types of transport, the description of economical and power approach for providing a sustainable development of transport system is submitted, and also application of linear model and the discrete analysis to forecast passengers' for transport services are considered.

Keywords: transport demand, mathematical methods of forecasting of passenger traffics, sustainable development, transport system

1 Introduction

Transport is the one of the general conditions for development of economy and society, and its influence on the life of a certain country is diverse and multidimensional. Transport promotes progressive geographical and structural shifts in placement of production and population, growth of labor productivity, and higher standard of living. Favoring international division of labor, mass tourism, and cultural exchange, transport causes large changes in economy and culture.
As far back as 1987, following the recommendation of the UN, the absolute majority of the states accepted the basic principle of sustainable development of society according to which the Civil Society and the State take the responsibility to provide opportunity to satisfy requirements of both the present and future generations [6].

Now forecasting of growing population’s demand for transportation and special requirements of stable communication of settlements with the main transport network and affordable prices for socially important transport services remains a crucial scientific problem.

2 Determination of the demand for transport services using the economic and energy approach

For providing transport services to the population the transport system must spend a particular amount of not only time but also energy (cost of servicing). We will designate this theoretical minimum of energy consumption for the j-th transport service as \( g_j(t) \). The actual energy consumption for rendering the j-th transport service will be designated as \( b_j(t) \).

The ratio of the theoretical energy consumption minimum to the actual energy consumption in rendering the j-th transport service will be referred to as technology perfection coefficient [2, 4]

\[
\eta_j(t) = \frac{g_j(t)}{b_j(t)}.
\]  

(1)

The total energy consumption of the transport system as a whole can be represented as a sum of all rendered transport services.

If the j-th service demands the actual energy consumption \( b_j(t) \) and the number of units of these transport services leaving the j-th production is \( k_j(t) \), the energy consumption for this service is \( N_j(t) \). When \( b_j(t) \) is determined in kilowatt-hours and the amount of transport services is determined in an hour, the power will be expressed in kilowatts.

In this case, the amount of the j-th service can be written as

\[
k_j(t) \cdot b_j(t) = N_j(t),
\]  

(2)

where \( k_j(t) \) is the amount of the j-th service rendered in 1 hour; \( b_j(t) \) is the actual energy consumption in rendering the j-th services; \( N_j(t) \) is the actual power in kilowatts consumed for rendering the j-th service.

Making the amount of rendered transport services in a socioeconomic system in general, we obtain the amount of the provided public service per hour or a gross product of the transport system per hour:

\[
P(t) = \sum_j k_j(t) \cdot g_j(t) = \sum_j N_j(t) \cdot \eta_j(t).
\]  

(3)

At the same total energy consumption it is possible to increase the volume of rendered transport services per unit time due to the growth of technology perfection coefficient.
If the amount of the rendered $j$-th service surpasses the rate of its consumption, the consumption rate ratio to the amount of the service rendered per unit time gives numerical value the transport demand forecasting quality. Thus, the balance equation of satisfaction of demand for transport services can be presented in the form

$$F(t) = \sum_{j} k_j(t) \cdot g_j(t) \cdot \epsilon_j(t) - \sum_{j} N_j(t) \cdot C_j(t) \cdot \epsilon_j(t),$$

where $F(t)$ is the satisfaction of transport service needs per unit time; $C_j(t)$ is the transport technology perfection coefficient, and $\epsilon_j(t)$ is the demand forecasting quality coefficient for the $j$-th transport service.

Inadequate quality of the transport service demand forecasting in an economic system can result in both deficit of transport services (including availability and quality) and its overproduction. Thus, the increase in quality of the transport service demand forecasting is one of the most important tasks in ensuring the transport and economic balance.

Estimates of sensitivity of passengers’ needs to various factors (to socioeconomic, financial, qualitative characteristics of transport, infrastructure) are part of forecasting of the transport service demand [3].

2 Determination of the transport service demand based on a change in the transport mobility of the population

We will consider the use of a multiple-factor linear regression model and obtaining of sensitivity coefficients and expected values for internal transportation. For each correspondence in each type of transport the following model is proposed:

$$ \Delta M_i = \beta_0 + \beta_1 \cdot \Delta GRP_i + \beta_2 \cdot \Delta GRP_i^{no} + \beta_3 \cdot \Delta t_i + \Delta \epsilon_i, $$

where $\Delta M_i$ is the change in the mobility (passenger traffic) from transport region $i$ for a concrete type of transport at time $t$ in relation to time $t-1$;

$\Delta GRP_i$ is the change in the gross regional product (GRP) in the transport area from which there is a passenger traffic at time $t$ in relation to time $t-1$;

$\Delta GRP_i^{no}$ – is the change of GRP in the transport area to which there is a passenger traffic to $t$ time-point in relation to $t-1$ moment;

$\Delta t_i$ - is the change in the tariff index for a type of transport at time $t$ time-point in relation to $t-1$;

$\beta = (\beta_0, \beta_1, \beta_2, \beta_3)$ are the estimated model coefficients;

$\Delta \epsilon_i$ is a random error of the model.

To obtain the estimate $\beta$, it is necessary to know the passenger traffic gain ($\Delta M_i$) for a concrete correspondence in a concrete type of transport in the form of a vector $Y$ and factors (GRP gain and tariff index) and to create a matrix $X$ in which their values of factors are located in columns.
Substituting the above data into the expression (5)

\[ \hat{\beta} = (X^T X)^{-1} X^T y, \]  

we obtain the estimates of the sensitivity coefficients.

For obtaining forecasts of the demand for transport services, the expected values of the factors (in this case two gains of GRP and the tariff index) are also necessary in addition to the sensitivity coefficients (set exogenously or found as described above). Substituting them into equation of the model (5), we obtain forecasts of passenger traffic for the years for which there are expected values of the factors. From the gains we easily find the amounts

\[ M_{t+1} = M_t + \Delta M_{t+1}, \]

where \( M_t \) is the known passenger traffic for the last period (that is, this procedure should be carried out beginning with the first expected value when the actual passenger traffic for the last year is known); \( \Delta M_{t+1} \) is the resulting expected value of an increase in the number of consumers; \( M_{t+1} \) is the desired expected value of an increase in the number of consumers.

3 Change in the demand for transport services due to the induced transportations resulting from a change in the transport infrastructure

The second component of the change in \( t \)-th demand for transportation is the induced demand resulting from a change in the infrastructure. It is supposed that the passenger traffic limits the inadequate level of infrastructure connectivity [3].

To obtain forecasts of the induced demand transport from region \( i \) to region \( j \) using the gravitational model, it is necessary to have the following initial data: the actual passenger traffic from transport region \( i \) to transport region \( j \); population of the transport area from which there is a passenger traffic \( (P_i) \) and to which there is a passenger traffic \( (P_j) \); the weighted average travel time between transport regions \( i \) and \( j \) \((t_{ij})\). To find the increase in the demand for transport services from transport region \( i \) to transport region \( j \) due to the induced demand \( (\Delta PT_{ij}) \), we substitute the data into the following expression:

\[ \Delta PT_{ij} = A_n \frac{PP_{ij}}{IS_{ij}} - PT_{ij}, \]

where \( A_n \) is the coefficient on the basis of the training group of pairs of areas "saturated" with infrastructure and similar to the pair of transport regions of \( i \) and \( j \) in remoteness \((ts)\); it is defined as the coefficient average over the passenger traffic volume.

The forecast should be calculated only if improvement of infrastructure for a concrete correspondence is planned (for a concrete type of transport). Otherwise, the increase in the given component is zero.
4 Change in the transport demand due to the switching of passengers’ needs between types of transport

In this model of the discrete analysis a key factor of making a choice of a type of transport is the cumulative cost of a trip consisting of the cost of the ticket and the cost of the spent time which can be expressed by a formula

\[ C_g = C + h, \] (9)

where \( C \) is the cost of the ticket, \( h \) is the travel time cost, \( C_g \) are the cumulative transport expenses.

The ratio of the needs for transport type \( n \) to the needs for transport type \( m \) is equal to the ratio of the cumulative expenses:

\[ \frac{P_n}{P_m} = \frac{c_{g-n}}{c_{g-m}} = q, \] (10)

where \( P_n \) is the transport type \( n \) passenger traffic, \( P_m \) is the transport type \( m \) passenger traffic, \( c_{g-n} \) are the cumulative expenses of one passenger on transport type \( n \), and \( c_{g-m} \) are the cumulative expenses of one passenger on transport type \( m \).

Therefore, the fraction of the passenger traffic switched over from transport type \( m \) to transport type \( n \) will be

\[ P_n = \frac{q}{q+1}, \] (11)

where \( q \) is the ratio of the cumulative expenses on transport types \( m \) and \( n \).

Fig. 1. Dependence of the travel cost on the distance for various types of transport
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It is evident from figure 1 that the fixed specific tariff determines a more rapid growth in the price of the ticket for the high-speed rail with increasing travel distance in comparison with other types of transport and successfully competes in price with the airlines over distances up to 1000 km [5].

The model for forecasting needs of passengers for transport services should allow for the fact that the larger the difference in tariffs between types of transport, the higher the influence of the price on the passenger traffic switch-over. Dependence of the switch-over on the ticket price should be nonlinear. The elasticity coefficient can be expressed as:

$$\alpha = \frac{C_n}{C_m}. \tag{12}$$

An additional factor determining the nonlinearity of the dependence of the passenger traffic switch-over on the cumulative travel costs is travel comfort elasticity. The greater the difference in comfort between types of transport, the greater the importance of the term $h$ in (9).

The coefficient $\beta$ consists of three quantitatively measurable travel comfort criteria: $a$ - standard passenger density in the compartment (people/sq.m); $b$ - the noise pollution in the compartment; and $c$- the punctuality (%) calculated as an average increment of the travel duration.

The integral estimate of comfort is the average of the three indicators

$$v = \frac{1}{3}(a + b + c), \tag{13}$$

where $a$ is the passenger density, $b$ is the noise level in the compartment, and $c$ is the punctuality.

Considering formulas (9-13), we obtain the following equation for the calculation of the passenger traffic switching between transport types $m$ and $n$:

$$\frac{P_n}{P_m} = \frac{C_m^\alpha + (h_m T_m)^{\beta \alpha}}{C_n^\alpha + (h_n T_n)^{\beta \alpha}}, \tag{14}$$

where $P_n$ is the initial passenger traffic by transport type $n$ between settlements $i$ and $j$; $P_m$ is the passenger traffic between settlements $i$ and $j$ by transport type $m$; $C_n$ is the cost of the ticket for the travel by transport type $n$ between towns $i$ and $j$; $C_m$ is the cost of the ticket for the travel by transport type $m$ between towns $i$ and $j$; $T_n$ is the time of travel by transport type $n$ between towns $i$ and $j$; $T_m$ is the time of travel by transport type $m$ between towns $i$ and $j$; $h_m$ is the cost of time for passengers choosing transport type $m$; $\alpha$ is the price elasticity coefficient; $\beta$ is the comfort elasticity coefficient.

Equation (14) can be separately applied to passenger transport by railway, urban transit, air, sea, and river.

5 Conclusion

In the article has been shown the dependence of the gross domestic product of the transport system with the level of energy consumption. In the work
has been shown the correlation of rate of technology excellence, and received the balance equation to meet the demand for transport services, which is determined by a numerical value of the quality of forecasting traffic demand.

Applications received in the scientific article balance equation to meet the demand for transport services using advanced mathematical modeling techniques will improve the management efficiency of the transport sector, including at the stage of pre-investment project development, as well as provide savings in time and money in the transportation industry.

The field of application is the work of professionals working in the transport industry and to forecast growing demand of the population for transport services depending on social and economic factors (gross regional product (GRP), population, income, etc.).

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References


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