Determination of factors that influence public transport

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Abstract

This paper proves that modelling of the public transport route network in Lithuanian towns is very important. It is the new way for planning public transport services in Lithuania under market-conditions, in order to reach harmonious interaction between public transport and the needs of citizens.

An empirical statistical method was used for finding indicators that mostly have influence on public transport flows. The used data included data from public transport research in Vilnius and theoretical research on public transport's accessibility and its economic indicators. The empirical model of Vilnius public transport was developed with the help of statistical analysis software Statgraphics. Statistical means were used to choose the most characteristic indicators that have impact on the demands for public transport and to formulate models of polynomial regression. These factors were analysed in 50 Vilnius transport districts and its suburbs on the grounds of the last comprehensive research on passenger flows of public transport carried out in 2002 and on the theoretical research of public transport services (accessibility, route density, frequency) and economic indicators (passenger transportation price).
Keywords: transport system, public transport, influence comparison, intermodal network, market segmentation.

1 Standpoint of a planner

In the process of urban development a social and physical division of cities has been continuously increasing. The citizens are distributed in different regions – to live, work and serve. For example, today it is quite usual for a person to live in one district, to work in another district and to go to the third district for spending

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his leisure time. Such a city division into districts makes the residents dependent on the transport system. It is necessary to take into consideration that the inhabited territories are also divided by social classes, ethnic and cultural differences. According to the Vithlani [1], who have studied the urban transport systems, the main cause for the demand for public transportation is a territorial dispersion of objects satisfying the interests of residents, enterprises and companies.

The best indicator characterizing the urban transport system is a distribution of travel mode. A large demand to improve the volume of citizen transportation is mostly noticeable when trying to change the selection of travel mode in favour of public transport (PT). Public faced such problems as traffic congestions, air pollution or limited accessibility. Broadly speaking, these problems are directly related to various aspects of quality of life and to the conception of sustainable transport system [2]. Modal distribution in the European cities (Figure 1) shows that, if compared to other cities, residents of the Vilnius city use public transport more than some others, however Vilnius has least bicycle trips (1 %) [3].

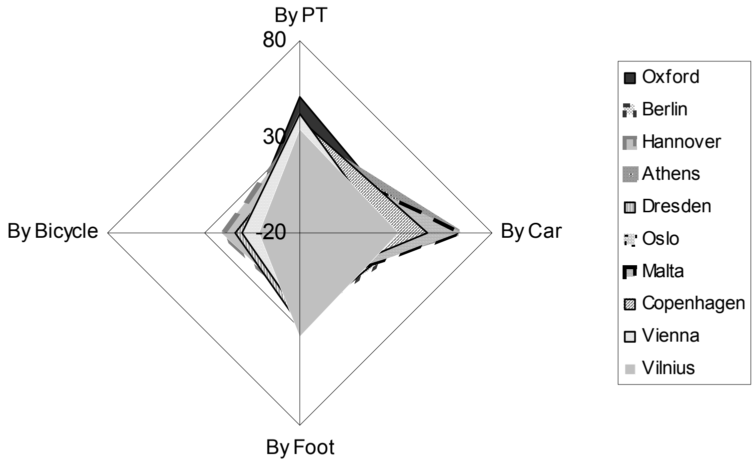

Figure 1: Distribution of travel modes in the European cities, 2002.

From the studied cities, the best ratio between the trips made by environmentally-friendly vehicles and cars has Vilnius, Vienna and Hannover. In these cities the percentage of car trips varies from 25 % in Vienna to 31 % in Vilnius. The largest amount of citizens (more than 60 %), travelling by car, is in the cities of Malta and Athens.

Shifftan et al [4] and Huwer [5] pointed out five main aspects that influence the use of public transport in the cities:

1. Planning of land use on which the following depend: size and density of built up territories; size and dispersion of industrial areas; distribution of attraction objects intended for recreation and in the result - the demand for public transport.

2. Governmental policy. Government exerts influence on all transport solutions that in turn have influence on the level of public transport services, starting with land-use and ending with transport management. Strong relations between PT operators and the government representatives make the public transport system look more attractive for a user.
3. Size of economic sources. Larger financial sources ensure a comprehensive research of public transport, more substantiated planning, wider and more frequently serviced network of public transport routes.
4. Installation of technologies. New technologies exert influence on the vehicle itself and its speed.
5. Social trends. Mobility and the choice travel mode depend on social groups of people living in the city.

The effect of transport and its accessibility within a changing city structure was acknowledged as a priority field in the city planning process, Zhu and Liu [6] and Wu and Hine [7]. In a well-sustained transport system of large and densely populated city, public transport must be well-developed and accessed both in residential as well as industrial territories [8, 9].

2 Standpoint of a passenger

When talking about the quality of public transport the following elements are mentioned by the passengers: regularity, reliability, stop infrastructure, condition of vehicles and comfort, accessible information about public transport in stops, at home and at work [2].

In Poland passengers are very much interested in travel time, i.e. walking time from (to) the stop, waiting time at the bus stop, the speed of vehicle depending on the environment and having a direct influence on the travel time, transfer time, installation of stops, also: paying system, vehicle condition and comfort, the level of safety.

Research, carried out in Sweden, showed that by only increasing vehicle standards and raising requirements for information systems, passenger satisfaction with the public transport system will not be ensured, and in order to improve this indicator and attract as many passengers as possible, it is necessary to optimize a routing scheme of public transport [10].

Having generalized the results of passenger surveys, carried out in Europe and USA, the authors determined the criteria that influence the use of PT and suggest dividing them into 5 groups [11]:

1. Convenience - mentioned by most respondents. It covers the optimally chosen routes, sufficient frequency of routes and good accessibility to public transport routes.
2. Comfort - also among the top criteria as indicated by the residents when speaking about the improvement of the public transport system. It also covers convenient and high-speed vehicles, well-installed stops.

3. Accessibility - the third important criterion mentioned by the respondents. Detailed information on the network of public transport routes and its timetables, set tariffs providing a possibility of using public transport even for low-income people.
4. Safety was not very often mentioned among the respondents, probably because it is in a good state at present. Low number of accidents related to public transport, safety assurance for people waiting at the stops (especially in a peripheral zone of the city).
5. Environmental protection - a rarely mentioned criteria; it is more a social duty than a factor that raises passengers' concern. It covers a lower environmental pollution by vehicle emissions and traffic-generated noise, less loaded city centre.

A current situation of public transport raises a question – how, with the limited financial resources, to plan and develop the public transport system in order to make it attractive for the citizens and guests. The key challenge lies in planning the transport system.

3 Identification of indicators that influence public transport

Transport planning is inseparably related to social, demographical and economic interests of inhabitants, thus, when planning transport system in the city, it is necessary to carry out the analysis of these interests. Division of the planned territory into transport districts gives a possibility to more detailed analyze and assess situation in different parts of the city. When preparing transport plans the main attention is being paid to the determination of characteristics of street network and PT system. The demand for public transport depends not only on the distribution of working, learning or leisure places and their transport mobility, but also on the public transport infrastructure and transport supply, vehicle characteristics [12].

In order to conclude an empiric model for factors that have influence on the passenger flows of public transport, the programme Statgraphics was used, in which all the dependency models were assessed with the reliability of 95% – 99%. These factors were analysed in 50 transport districts of the Vilnius city and its suburbs, based on the latest comprehensive research on passenger flows of public transport, carried out in 2002, and on a theoretical research of public transport services (accessibility, route density, frequency) and economic indicators (passenger transportation price) [13, 14].

By using the Statgraphics programme a statistical analysis was carried out of the indicators on which public passenger flows could depend. The analysed indicators can be divided into 4 groups: urban structure, use of a transport mode, public transport services and economic group (table 1).

The group of urban structure indicators covers the density of inhabitants and working places, making the effect on the total mobility of inhabitants, which in the studied districts varies from 0,01 working places/ha to 217,2 working

Table 1: Description of the studied indicators.

Group	Indicator	Abbreviation
Group of urban structure indicators	Population density, inhab./ha	*PD*
	Work place density, inhab./ha	*WPD*
	Street density, km/km^2	*SD*
	Car ownership level, cars/1,000 inhabitants	*COL*
Group of indicators of transport mode use	Flows of bus passengers, passengers/h	*FPb*
	Flows of trolley-bus passengers, passengers/h	*FPt*
	Flows of passengers on private passenger transport, passengers/h	*FPp*
	Total flows of passengers, passengers/h	*FP*
	Maximum flows of cars, cars/h	*MFc*
Group of indicators of public transport services	Accessibility of bus routes, %	*Ab*
	Accessibility of trolley-bus routes, %	*At*
	Accessibility of private passenger transport routes, %	*Ap*
	Total accessibility of routes, %	*A*
	Bus route density, km/km^2	*Db*
	Trolley-bus route density, km/km^2	*Dt*
	Density of private passenger transport routes, km/km^2	*Dp*
	Total route density, km/km^2	*D*
	Frequency of buses, veh./h	*Fb*
	Frequency of trolley-buses, veh./h	*Ft*
	Frequency of private passenger transport, veh./h	*Fp*
	Total frequency of transport, veh./h	*F*
	Number of transport modes for travelling, pcs.	*NTm*
Group of economic indicators	Passenger transportation price on buses, LT/passenger km	*TPb*
	Passenger transportation price on trolley-buses, LT/passenger km	*TPt*
	Passenger transportation price on private passenger tr., LT/passenger km	*TPp*
	Total passenger transportation price on buses, LT/passenger km	*TP*

places/ha (in the centre). The indicators also include the street density of the district and the level of the car ownership. This group of indicators shows the demand for public transport in the studied transport district of the Vilnius city.

The indicators of transport mode use, describing the attractiveness of public transport mode, are as follows: separate passenger flows in buses, trolley-buses and mini-buses, the total flow of public transport passengers and cars. The passenger flows of public transport in different transport districts of the Vilnius city varies: in buses – from 40 pass./h to 983 pass./h, in trolley-buses – from 300 pass./h to 1 869 pass./h, in mini-buses – from 4 pass./h to 467 pass./h. These indicators show which mode of the public transport is preferred by the passengers in a certain region.

The indicators of public transport services, which describe accessibility indices of public transport routes, include the accessibility to public transport routes, their density and frequency in a transport district. These indicators are very different in each of the studied transport districts; in the central and middle part of the city they ensure a high level of public transport service, while in a periphery - only the indispensable service level, and this is also confirmed by the number of transport modes in the district.

The group of economic indicators, which up to now have not been used in Lithuanian practise for a regression analysis, is comprised by a minimal price of passenger transportation in different transport districts by bus, trolley-bus, mini-bus and by public transport in general.

4 Determination of polynomial models

A polynomial linear regression model is created by searching for a statistical relationship between the dependent variable y – passenger flow of public transport and independent variables x_1, x_2, ...x_m, eqn (1).

$$y = \alpha + \beta_1 x_1 + \beta_2 x_2 + ... \beta_n x_m + \varepsilon \ , \tag{1}$$

where α – constant, $\beta_1, \beta_2, ...\beta_n$ constants of a regression model, and ε – random error. In solving the question the change of which indicator tend to be associated with the change in the others, the Pearson‘s sample correlation coefficient R was used, eqn (2):

$$R = \frac{\sum xy - m\overline{x}\overline{y}}{\sqrt{\left(\sum x^2 - m\overline{x}^2\right)\left(\sum y^2 - \overline{y}^2\right)}} , \tag{2}$$

where $\overline{x}, \overline{y}$ - arithmetical mean of variables x and y. To determine the relationship between more than two variables in a multiple regression the sample multiple coefficient of determination - r^2 was used, eqn (3):

$$r^2 = \frac{\Sigma(\hat{y} - \overline{y})^2}{\Sigma(y - \overline{y})^2} . \tag{3}$$

A multiple correlation coefficient indicates a fraction of the total variation of y, determined by a regression equation - $r = \sqrt{r^2}$. Significance of correlation coefficient is tested with *t-statistics*, eqn (4):

$$t = r\sqrt{\frac{n-2}{1-r^2}} , \tag{4}$$

where *r* – estimated value of correlation coefficient; *(n–2)* – degrees of freedom of the Student‘s distribution.

Reliability of a regression curve is evaluated by testing the probability P of the null hypothesis (that variables are independent), based on which the hypothesis is accepted or rejected. The significance level α shows the impossibility of the event. A computer-based data analysis estimates the lowest level of significance - p-value, at which a true null hypothesis in a study case could be rejected.

When the probability of erroneous solution is equal to α, the probability of a true solution is (1–α), usually expressed in percent. If the p-value is rather low, the null hypothesis is rejected.

Polynomial regression of bus passenger flows. As it was described in Section 2, during the passenger surveys it was indicated by the respondents that the choice of public transport is predetermined by the frequency of public transport and the possibility to directly reach the destination point.

Polynomial correlation regression equation was obtained, taking into consideration the dependency of the volume of bus passenger flows on the density of bus routes and working places, frequency of bus routes and maximum flows of cars. This reveals that the level of public transport services is the key influencing factor with respect to the bus passenger flows.

$$PF_a = -29{,}25 + 30{,}19 * D_a - 2{,}25 * WPD + 14{,}21 * F_a + 0{,}04 * MF_c \qquad (5)$$

The obtained coefficient of determination 0,78 shows that the linear regression model explains 77,68 % of dispersion of the studied factors with respect to the bus passenger flows. The corrected correlation coefficient equals to 0,75. Reliability level of a regression equation model – 99 %.

Polynomial regression of trolley-bus passenger flows. The factors that could possibly influence the trolley-bus passenger flows could not include the number of transport modes for making trips, since all the transport districts, served by the trolley-bus routes, are provided with a maximum number of transport modes.

The trolley-bus passenger flows are influenced by the trolley-bus route density, showing that the waiting time in a trolley-bus stop is very important for the passengers, and by the maximum flows of cars on the studied route, showing the general trends in citizen transportation, eqn (6):

$$PF_t = 399{,}62 - 2532{,}13 * TP_t + 11{,}99 * F_t + 0{,}09 * MF_c\,. \qquad (6)$$

A regression model of trolley-bus passenger flows revealed that the passenger flows depend on the price of passenger transportation, trolley-bus route density and maximum flows of cars. Based on this equation, the lower the transportation price, the greater the flows of passengers. This is more an inverse relationship since the transportation price is calculated per 1 passenger kilometre, i.e. the more passengers, the less the price.

The obtained coefficient of determination 0,57 shows that the linear regression model explains 57,05 % of dispersion of the studied factors with respect to trolleybus passenger flows. Reliability level of a regression equation model – 95 %.

Polynomial regression of private passenger transport flows. When carrying out a polynomial regression of private passenger transport flows a large attention is being paid to such factors as density and frequency of private passenger transport routes [13]. These are the already earlier observed indicators, having a higher or lower influence on the passenger flows of all modes of public transport. Also, attention should be paid to such indicators as accessibility of routes, number of transport modes for making a trip.

The obtained polynomial regression equation revealed that private passenger transport flows depend on the density of private passenger transport routes, density of inhabitants, maximum car flows and are inversely proportional to the density of working places, eqn (7). As mentioned before, a possibility to directly reach the destination point exerts influence on the choice of public passenger transport due to a negative attitude towards the time wasted during a transfer.

Dependency on the density of inhabitants and maximum flows of cars shows the correspondence of private transport to the general travel directions of inhabitants. Inverse dependency on the density of working places is affected by a large density of working places in industrial districts, where people with lower income live and work, when the tariffs for the tickets of private passenger transport are nearly double.

$$PF_p = -4{,}47 - 1{,}41 * WPD + 0{,}64 * PD + 0{,}03 * MF_c + 12{,}17 * D_p \,. \qquad (7)$$

The obtained coefficient of determination 0,72 shows that the linear regression model explains 71,88 % of dispersion of the studied factors with respect to private bus passenger flows. Reliability level of a regression equation model – 99 %.

Polynomial regression of total flows of passenger transport. Taking into consideration the attitude of the planners and the passengers, the indicators, that have influence on the passenger flows of public transport, were selected, such as frequency, accessibility and density of routes, social indicators.

The obtained polynomial regression equation reveals the dependency of total public transport passenger flows on the price of passenger transportation, frequency of public transport routes, number of transport modes chosen for the trip and maximum flows of cars, eqn (8).

$$PF = -274{,}17 + 1{,}54 * F + 0{,}04 * MF_c - 38{,}60 * TP + 135{,}16 * NTm \,. \qquad (8)$$

Inverse dependency of passenger flows on the transportation price shows that when reducing the transportation price the passenger flows will increase, however, this is true only until a certain level, since the lower transportation price the more loaded are public vehicles and the overloaded passenger vehicles force the passenger to choose another travel modes [13, 15].

The obtained coefficient of determination 0,81 shows that the linear regression model explains 80,46 % of dispersion of the studied factors with respect to total passenger flows. Reliability level of a regression equation model of total passenger flows – 99 %.

The frequency of transport routes has the influence on all passenger flows, except private passenger transport, the service frequency of which is too large not to make a negative impact on a passenger when he chooses a travel mode. The flows of bus passengers and private transport passengers are also influenced by the density of routes, based on which the existing public transport system was created. Today the routes of public transport are artificially thickened in the central city districts, where the routes serving the suburbs, run. Thus, the passenger flows in these districts are artificially increased, since, at present the city centre serves the transit function for the passengers with the possible destination point in the suburban districts. Maximum car flows, included in all regression models, as it was mentioned before, reveal the general trends of the citizens in making the trips.

Since the square of the correlation coefficient of all polynomial regression equations is $\geq 0{,}6$, it could be stated that the regression equations include the key factors making the influence on passenger flows.

5 Conclusions

1. From the studied cities, the best ratio between the trips made by environmentally-friendly vehicles and cars has Vilnius, Vienna and Hannover. In these cities the percentage of car trips varies from 25 % in Vienna to 31 % in Vilnius. The trip distribution structure in the Vilnius city becomes a matter of great concern. Since 1993 the trips by public transport has decreased by 1,5 times, by bicycle and on foot – by almost 5 % and the amount of trips made by car in a 12-year period has increased by 3 times. In order to slow down the change in travel distribution it is necessary to as soon as possible improve the public transport system situation and its urban operation.

2. During the surveys, carried out in the European countries and USA, the key factor mentioned by the most respondents and influencing the use of public transport is its convenience showed by the optimally chosen routes, sufficient frequency of transport routes and good accessibility to the public transport routes. These are the main criteria which could become the basis for planning the public transport system in Lithuanian cities; they will allow optimisation of the public transport service by using the current resources, satisfying the needs of inhabitants and meeting the environmental requirements.

3. Polynomial correlation regression equation ($r = 0,78$) was obtained, taking into consideration the dependency of the bus passenger flows on the density of bus routes and working places, frequency of bus routes and maximum flows of cars. However, a regression model ($r = 0,57$) of trolley-bus passenger flows revealed that the passenger flows depend on the price of passenger transportation, trolley-bus route density and maximum flows of cars. The private passenger transport flows depend on the density of private passenger transport routes, density of inhabitants, maximum car flows and are inversely proportional to the density of working places ($r = 0,72$). A possibility to directly reach the destination point exerts influence on the choice of public passenger transport due to a negative attitude towards the time wasted during the transfer. *Reliability level of equations is 95-99%– 99 %.*

4. The obtained polynomial regression equation (*$r = 0,81$, reliability level– 99 %*) reveals the dependency of total public transport passenger flows on the price of passenger transportation, frequency of public transport routes, number of transport modes chosen for the trip and maximum flows of cars. Inverse dependency of passenger flows on the transportation price shows that when reducing the transportation price the passenger flows will increase, however, this is true only until a certain level, since the lower transportation price the more loaded are public vehicles and the overloaded passenger vehicles force the passenger to choose another travel modes.

5. For further modelling of the public transport system, the following indicators, reflected in the regression models, should be taken into consideration: frequency of served routes that have influence on all passenger flows except private passenger transport, the service frequency of which is too large not to have a negative impact on a passenger when he chooses a travel mode; route density that influences the flows of bus passengers and private transport

passengers and based on which the existing public transport system was created, i.e. to ensure for all the citizens that the destination point is reached without any transfers.

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