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Application of Statistical Methods of Scientific Researches in the Surveying of Passengers Flows of Urban Road Transport

The purpose of the paper is to propose scientific and methodological approaches to the generalization of passenger flow survey methods, the formation of the route transport network of the city, the calculation of the required type and number of rolling stock of passenger road transport, the formation of a list of preferential routes.

The paper examines applied aspects of the application of the theory of urban passenger transportation in relation to transportation by means of passenger road transport of the city (PRTC). The main concepts of the theory of urban passenger transport and the issue of interaction between urban passenger transport and the city being served are analyzed on the basis of system concepts. An analysis of the main factors that affect the quality of planning, control and regulation of passenger road transport in the transport systems of cities has been carried out. Aspects of the theory of urban transport systems and design calculations of passenger transport by road are also considered. The research was carried out by the formation of new scientific and methodological approaches and scientific argumentation proposed on the basis of numerous works of domestic and foreign scientists in the field of passenger transportation organization. Research method are mathematical statistics and modeling.

The solution to the tasks of urban transport service is divided into two main complexes: the design of urban transport systems, and the organization of urban transport traffic. To form an optimal or rational route network, as well as to effectively use rolling stock and ensure a high level of passenger service, it is necessary to know the directions, sizes and degree of unevenness of passenger flows, the specific values of which are established during certain surveys. When surveying passenger flows, it is necessary to obtain reliable data in order to use them in solving problems of improving the quality of passenger service. But when choosing a survey method, it is necessary to take into account the complexity of the method and the costs of its implementation.

passengers, transportation, car, transportation, city, statistics, method, passenger traffic

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Justification of the level of competition on urban passenger routes

The components of the market competition of carriers on passenger transport routes of the city transport system are considered. It is shown that the demand for transportation can be presented in the form of matrices of passenger correspondence. Due to its fluctuations within some limits, the main issue is its distribution among the routes that form the urban route network. The essence of the level of competition between carriers, which has a growing tendency, has been revealed. It is proposed to use the Likert method and the results of a sociological survey to build a model of the attractiveness of routes as its assessment. The utility function of the route, the optimization function of Lagrange and the model of the choice of the passenger movement path were constructed. It is taken into account that transport enterprises operate in break-even conditions, and profit is a limitation when solving the task of improving the quality of public service.

level of competition, attractiveness of the route, rolling stock, passenger transportation, mathematical modeling

Formulation of the problem. Sustainable functioning of urban passenger transport is one of the indicators of the quality of life of the population. Road transport plays an important role in meeting the demand for passenger transportation in Ukraine [1]. In recent years, the market economy has significantly changed the operating conditions of passenger road transport and the nature of the city's population's demand for transport services. Population demand has become more diverse in its spatial and temporal characteristics, which are quite difficult to take into account when organizing and managing passenger transportation in cities [2,3]. At the same time, it is appropriate to obtain objective information about passenger flows, the structural composition of passengers and the peculiarities of their consumption of city passenger transport services, their quality, as well as the determination and forecasting of passenger demand for different types of rolling stock.

Analysis of recent research and publications. The construction of models and approaches for assessing the quality of transport services for the urban population was carried out by domestic and foreign scientists: G.A. Varelopulo, V.O. Vdovichenko, A.V. Velmozhyn, P.F. Gorbachev, V.A. Gudkov, A.G. Goldin, N.U. Gulev, V.K. Dolya, M.G. Martynov, E.V. Nagornyi, V.V. Aulin, U.E. Deming, P.P. Dumitrashku, F.B. Crosby, M.S. Filsheson, F.U. Taylor, J.H. Harrington, Y. Tsybulka, and others. It was revealed that the formation of criteria for the effectiveness of the urban passenger transport functioning is usually carried out depending on the specific goal and the tasks to be solved [4-6]. The selected indicators for assessing the quality of the transport service, as a rule, characterize the efficiency of the state and development of individual links of the urban passenger transport system and do not reflect the requirements of passengers for the required level of transport service [7-9].

From the quality indicator of the evaluation of the service for the transportation of passengers by urban route transport, separate transport characteristics are used: the total time spent on movement, the number of transfers, safety of the trip, the filling of the ruddy warehouse, the carrying capacity of the transport, the waiting time of the vehicle at the stops [10-12]. Along with the absolute indicators of the results of passenger transportation services, relative quality indicators are offered, which consist in evaluating the deviation of certain characteristics of the transport process relative to their "ideal" values [13-16]. It was found that most of the existing methods of assessing the quality of transport services reflect the partial consequences of the transport process and do not take into account the degree of importance and significance of individual indicators for users of city routes. In this regard, it is necessary to develop a methodology for assessing the level of the quality of public transport services, taking into account the level of competition of carriers, which should take into account the attitude of users of urban routes to the transport services provided to them [17-19].

Setting objectives. The purpose of this work is the theoretical justification of taking into account the level of competition between carriers on urban passenger routes while ensuring high-quality transport service of vehicles and profitability of serving transport enterprises.

Presentation of the main material. The main task of urban passenger transport in market conditions is the provision of passenger transportation services, the quality of which must meet consumer requirements, provided that the urban passenger transport system is break-even and taking into account the level of competition between transport companies.

Market conditions within the framework of solving the issue of improving the quality of public transport services are taken into account by formalizing the relationship between demand and supply in the city passenger transportation market. Based on this, the market price is formed, but the pricing of city passenger transportation is the prerogative of local authorities, namely the city executive committee, which plays a key role in the relationship between carriers and passengers. Its regulatory actions regarding the operation of routes and the carriers that serve them impose certain restrictions on the interaction between demand and supply, prevent the formation of a situation of full competition between carriers on the market. As the main levers of control on the part of local authorities regarding the volume of transportation on the routes, there are recommendations on the number of rolling stock that should be operated on each of the city routes.

The fare c_m^w affects the income of transport companies serving certain routes. An increase in the tariff leads to an increase in their profit, but the tariff policy in the field of transport services for the population of the cities of Ukraine, despite the market conditions, is the prerogative of the city self-government bodies.

The second component of market competition is demand, which represents the needs of the population in the framework of urban passenger transportation. They are presented in the form of a matrix of passenger correspondence for the studied period of time. The demand may fluctuate within certain limits, but for solving the problems of current planning, an assumption is made about its constancy. The main issue is the distribution of this demand between the routes that form the urban route network. In general, the demand for passenger transport services can be considered constant, i.e:

$$H^k = \sum_{i=1}^{N} \sum_{j=1}^{N} h_{ij} = \text{const}, \tag{1}$$

where H^k – the matrix of passenger correspondence for the studied period, pas.;

h_{ij} – the amount of passenger correspondence between the i-th and j-th transport districts of the city for the calculation period, pas.;

N – the number of transport districts in the city, unit.

It is possible to formalize the offer on the passenger transport market through the transport capabilities of the routes. The data depend both on the parameters of the routes and on the technical and operational performance of the rolling stock on them. However, the main factors that influence the transportation capabilities of the routes are: the number of rolling stock operated on them and their capacity. The carrying capacity of city passenger transport per day can be estimated by the formula:

$$U = \sum_{m=1}^{s} V_{Em} \cdot T_{pm} \cdot \sum_{p=1}^{g} q_{pm} \cdot A_{pm}, \tag{2}$$

where V_{Em} – the average operating speed on the m-th route, km/h;

T_{pm} – operating time of the m-th route, hours;

q_p – the capacity of the p-th type of rolling stock operated on the m-th route, pass;

A_p – the number of units of the p-th type of rolling stock operated on the m-th route, units;

g – the number of types of rolling stock on the route, units;

s – the number of routes in the route network, unit.

As for the level of competition between passenger carriers, it (can be determined) based on the ratio of supply and demand:

$$R_к = \frac{\sum_{m=1}^{s} V_{Em} \cdot T_{pm} \cdot \sum_{p=1}^{g} q_{pm} \cdot A_{pm}}{\sum_{i=1}^{N} \sum_{j=1}^{N} h_{ij} \cdot l_{ij}}, \tag{3}$$

where l_{ij} – the distance between i-th and j-th transport districts of the city, km.

The analysis of this expression shows that under the condition $R_K > 1$ competition will be present among carriers, and as the value of the indicator increases, R_K its level will increase. Since the process of providing passenger transportation services takes place in the field of market conditions, competition among carriers will always be present, that is, the condition should always be used $R_K > 1$.

The level of competition affects the quality of public service on city passenger routes. Its growth, according to the classic laws of economics and marketing, should lead to an increase in the quality of the service. However, it must be taken into account that the increase in the quality of transport services implies an increase in the cost of transportation, which, with fixed tariffs, can lead to unprofitability of passenger road transportation. Therefore, it is necessary to determine such a level of competition R_K that will satisfy both consumers of services and enterprises that provide them.

As part of the work of rolling stock on city routes, one of the indicators of the quality of transport service is the level of comfort during the trip, which is formalized as a dynamic indicator of the use of the capacity of the vehicle. It is defined as the ratio of the actually performed volume of transport work to its possible volume:

$$\gamma_D = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} h_{ij} \cdot l_{ij}}{\sum_{m=1}^{s} V_{Em} \cdot T_{pm} \cdot \sum_{p=1}^{g} q_{pm} \cdot A_{pm}}. \quad (4)$$

Comparing the right-hand sides of expressions (3) and (4), we come to the conclusion that the relationship holds:

$$\gamma_D = \frac{1}{R_K}. \quad (5)$$

It can be seen that the level of competition between carriers is inversely proportional to the level of quality of public transport services. Thus, with effective passenger transportation, it is necessary to determine the balance point between the level of competition and the level of quality that satisfies both participants in the transport process of passengers and carriers.

Along with the indicator of the dynamic use of the capacity of the rolling stock γ_D, which characterizes the comfort of the trip, based on the analytical review of literary sources, it is proposed to use the travel time of t_{ij}^{w} passengers and the fixed cost of their travel to evaluate the quality of transport service c_m^{w}.

In total, the proposed three evaluation characteristics γ_D, t_{ij}^{w}, c_m^{w} of the transport process make it possible to determine the level of quality of transport service in the conditions of competition both between the same and between different types of urban passenger transport. Each of these indicators needs to be evaluated by passengers, since it is impossible to formalize the level of influence on the quality of transport services without taking into account the opinion of users of urban routes. This is due to the fact that the quality of urban passenger transport is evaluated precisely by the users of the transport service during the realization of the needs for movement, and only on the basis of their opinions and assessments it is necessary to form a quality improvement evaluation system.

In this study, as a method of assessing the impact of selected characteristics of the transport process on the quality of passenger transportation, it is proposed to apply the Likert method (sum method).

The essence of this method is as follows: the respondent must estimate the degree of importance of factors in assessing the quality of service for his transportation needs in points from 4 to 1. According to the selected method, the significance of the factor characteristic, that is, the presence of its influence on the phenomenon under investigation, is determined on the basis of the pairwise correlation coefficient between the sum of the scores on the questionnaire and the difference of scores on the factor to be evaluated. Under the condition $r_{SB} > 0,5$ – a decision is made about the influence of the factor on the resulting feature. This is due to the respondent's indifferent attitude to this factor characteristic and his high score. Studies have shown that within the framework of the solved question, the results of the sociological research differ from the classical formulation of the task of determining the degree of influence of factor characteristics using the Likert method.

This can be explained by the fact that, when evaluating the choice of a travel option among a certain list of alternative routes, in the case of their identical characteristics according to a certain transport parameter, the passenger is satisfied with all travel options. If, on the contrary, one of the alternative routes is characterized by a high level of filling the interior of the vehicle (low level of quality), then this will lead to a high score for this factor.

The results of the sociological survey can be used as a basis for building a model of the attractiveness of routes:

$$П_{ij}^{k} = 4 - \left(a_0 + a_1 \cdot \frac{x_{ijv}}{x_{v\max}} \right), \tag{6}$$

where $П_{ij}^{k}$ – the attractiveness function of the *k*-th routing path;

a_0, a_1 – regression coefficients;

x_{ijv} – the *v*-th factor characteristic that determines the choice of the *k*-th routing path;

$x_{v\max}$ – the maximum value of the *v*-th factor characteristic.

Analysis of formula (6) shows that its constant component is equal to four. This corresponds to the maximum score, according to the proposed methodology for determining the degree of influence of selected characteristics of factors of the transport process on the quality of the passenger transportation service.

It should be noted that the attractiveness function (6) is constructed for each factor characteristic x_{ijv}. The regression coefficients are a_1 determined on the basis of paired correlation coefficients r_{SB}, due to which the relationship between the level of influence of the *i*-th characteristic of the transport process on the quality of transport service and the attractiveness of the *k*-th option of the travel route is maintained.

Using the attractiveness function of the route, it is possible to construct its utility function:

$$W^{l}(c,t,\gamma) = \sum_{v=1}^{f} \left(4 - \left(a_{0v} + a_{1v} \cdot \frac{x_{ijv}}{x_{v\max}} \right) \right) = 12 - \sum_{v=1}^{f} П_v \to \max, \quad l = \overline{1,p}, \tag{7}$$

where W^{l} – the utility function;

l – typological group of passengers;

$П_v$ – variable component of the attractiveness function;

f – the number of factors that determine the attractiveness of the route, $f = 3$ units.

Substituting expression (6) into expression (7), we get:

$$W^{l}(c,t,\gamma) = 12 - \left(a_{0c} + a_{1c} \cdot \frac{c_m^{w}}{c_{m\ \max}^{w}} + a_{0t} + a_{1t} \cdot \frac{t_{ij}^{w}}{t_{\max}^{w}} + a_{0\gamma} + a_{1\gamma} \cdot \frac{\gamma_{Dm}^{w}}{\gamma_{Dm\ \max}^{w}} \right). \tag{8}$$

To find the conditional extremum of the utility function (8), it is advisable to use the method of Lagrange multipliers, according to which the task of finding the extremum $W(x_1, x_2, ..., x_i, ..., x_v)$ on a set of admissible values is realized:

$$D\left[f_k(x_1, x_2, ..., x_i, ..., x_v)\right] = \begin{cases} f_1(x_1, x_2, ..., x_i, ..., x_v) = 0, \\ f_2(x_1, x_2, ..., x_i, ..., x_v) = 0, \\ \dots \quad \dots \quad \dots \quad \dots \\ f_k(x_1, x_2, ..., x_i, ..., x_v) = 0, \\ \dots \quad \dots \quad \dots \quad \dots \\ f_m(x_1, x_2, ..., x_i, ..., x_v) = 0, \end{cases} \quad (k = \overline{1,m}), \tag{9}$$

The task of finding an extremum can be reduced to the task of unconditional optimization of the Lagrange function:

$$L(x, \eta) = W(x_1, x_2, ..., x_i, ..., x_v) + \sum_{k=1}^{m} \eta_k f_k(x_1, x_2, ..., x_i, ..., x_v), \tag{10}$$

where $\eta(\eta_1, \eta_2, ..., \eta_k, ..., \eta_m)$ – a vector of additional variables, the components of which are Lagrange multipliers.

If the vector of factorial features $(x_1, x_2, ..., x_i, ..., x_v)$ is known, then we get:

$$L(x_i, \eta_1, \eta_2, \eta_3) = W(x_v) + \eta_1\left(c_{\max} - \sum_{i=1}^{a} x_i c_i\right) + \eta_2\left(t_{\max} - \sum_{i=1}^{a} x_i t_i\right) + \eta_3\left(\gamma_{D\max} - \sum_{i=1}^{a} x_i \gamma_{Di}\right), \tag{11}$$

where $c_{\max}$ – the marginal value of the fare, hryvnias;

$t_{\max}$ – limit value of movement time, min.;

$\gamma_{D\max}$ – the limit value of the dynamic coefficient of filling the interior of the vehicle.

Taking into account the attractiveness function of the travel path (6), the possibility of building a model for estimating the probability of choosing a travel path has been revealed. At the same time, the principle of building a calibration model was used:

$$p_{ij}^k = \frac{12 - \sum_{v=1}^{f} \Pi_v}{\sum_{y=1}^{q}\left(12 - \sum_{v=1}^{f} \Pi_{vy}\right)}, \tag{12}$$

where p_{ij}^k – the probability of choosing the k-th routing path between i-th and j-th transport districts of the city;

q – the number of routes, among which the probability of choosing a route is evaluated, unit

One of the levers of regulating the quality of public transport services by local authorities is recommendations on the required number of rolling stock. Which should be operated on each of the city routes. This makes it possible to maintain the specified rate of filling of rolling stock with known characteristics of passenger flows. Along with this, in the conditions of market relations, each transport company must function in conditions of break-even. Thus, their profit acts as an additional limitation within the framework of solving the task of improving the quality of public transport services. Revenues of transport enterprises from passenger transportation can be determined by the formula:

$$D_i = \sum_{d=1}^{G} c_{md}^w \cdot (1 - K_\Pi) \cdot A_d \cdot p_{ijd}^k \cdot \sum_{i=1}^{z} \sum_{j=1}^{e} h_{ij}^k, \tag{13}$$

where G – the number of routes served by a certain transport company, units;

$K_{П}$ – the income reduction coefficient, which takes into account the specific weight of the preferential quota in the total volume of transportation;

c_{md}^{w} – tariff on the m-th route of the w-th type of city passenger transport on the d-th route, hryvnias;

A_d – the number of vehicles serving d -th route, units;

N_p – the number of flights performed per day by one route vehicle, units;

h_{ij}^{k} – the number of passenger correspondences that can be served by one route vehicle per flight, pas.

In the city of Kropyvnytskyi, an assessment of the quality of transport service of the routes of the transport system was carried out according to the following characteristics: transportation tariff, travel time and the degree of filling of the interior of the route vehicle. According to the developed methodology, a high correlation relationship between the sum of the scores on the questionnaire and the difference in the scores on the factor sign indicates a low level of quality based on the evaluation factor, since this characteristic of alternative routes encourages the passenger to evaluate the travel option. According to the results of the sociological survey, the correlation coefficients for each factor were calculated, which were the following values: transportation tariff – $r_{SBc} = 0{,}679$, travel time – $r_{SBt} = 0{,}685$, the degree of filling of the vehicle interior – $r_{SB\gamma} = 0{,}933$. Based on the results of the calculations, it can be concluded that the most significant factor affecting the quality of transport service is the dynamic coefficient of filling the interior of the vehicle.

The results of the survey of passenger flows on the route network of the city of Kropyvnytskyi served as the basis for building a model of demand for urban passenger transport services – a matrix of passenger correspondence, which was modeled using the gravity method. To build demand models for transport services, the territory of the city of Kropyvnytskyi is divided into 55 transport districts. The capacities of the transport areas for departure and arrival were determined based on the results of surveys of passenger flows at control sections of the city's route network. Based on the fact that the survey of passenger flows was carried out throughout the day, the construction of four matrices of passenger correspondence was performed, which characterize the demand for movement in the morning peak, evening peak, between the peak period and the evening decline (after the evening peak).

Conclusions.

1. A number of approaches to evaluating and improving the quality of transport services have been identified, however, most of them do not take into account the relationship of transport service users to various characteristics of the transportation process and the degree of competition of carriers on city routes, which does not allow to approach the solution of this problem taking into account the issue of consumer needs . Therefore, a method of improving the quality of passenger service for the urban population is proposed, taking into account the economic indicators of the functioning of transport enterprises to ensure their profitability, the level of competition and the attractiveness of the route for passengers.

2. The method of assessing the quality of transport services for the city population is theoretically substantiated, taking into account the level of competition between carriers and the levers of its regulation by local self-government bodies. One of the main tools for forming a rational level of competition and ensuring an appropriate level of quality is the recommendations for determining the rational number of vehicles that should be operated on each route, taking into account the appropriateness of their capacity and capacity of passenger flows.

3. A method of determining the attractiveness of a route for a passenger has been developed, which is based on the results of a survey of passenger flows on urban routes and the probability of choosing a route taking into account the actual attitude of users of urban routes to the characteristics of alternative options for movement. This makes it possible to carry out the actual distribution of demand for transport services between different types of urban passenger transport in conditions of competition between carriers.

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Обґрунтування рівня конкуренції на міських пасажирських маршрутах

В данній роботі теоретично обґрунтувано врахування рівня конкуренції між перевізниками на міських пасажирських маршрутах при забезпеченні якісного транспортного обслуговування транспортних засобів та рентабельності обслуговування транспортних підприємств.

На прикладі м. Кропивницького розглянуто складові ринкової конкуренції перевізників на маршрутах пасажирських перевезень міської транспортної системи. Показано, що попит на перевезення можливо представити у вигляді матриць пасажирських кореспонденцій. Через його коливання у деяких межах, основним питанням є його розподіл між маршрутами, які формують міську маршрутну мережу. Показано, що в ринкових умовах в межах вирішення питання підвищення якості транспортного обслуговування населення враховується шляхом формалізації співвідношення між попитом і пропозицією. Виявлено, що на взаємодію попиту і пропозиції певні обмеження накладає тарифікація на міські пасажирські перевезення. Отримано вираз для критерію рівня конкуренції, виходячи із співвідношення попитом і пропозицією на міські пасажирські перевезення. Виявлено сутність рівня конкуренції між перевізниками, який має тенденцію до зростання. Запропоновано в якості його оцінки застосовувати метод Лайкерта і результати соціологічного обстеження для побудови моделі привабливості маршрутів. Показано, що рівень конкурентної боротьби між перевізниками впливає на якість обслуговування населення на міських пасажирських маршрутах. Запропоновано вираз для оцінки цього показника. Визначено, що рівень конкуренції між перевізниками знаходиться в зворотно-пропорційній залежності з рівня якості транспортного обслуговування населення. Побудовано функцію корисності маршруту, оптимізаційну функцію Лагранджа та модель вибору шляху пересування пасажирів. Враховано, що транспортні підприємства функціонують в умовах беззбитковості, а прибуток виступає обмеженням при вирішені завдання підвищення якості обслуговування населення. При обстеженні пасажирської транспортної мережі м. Кропивницького була проведена оцінка якості транспортного обслуговування за такими характеристиками: тарифу на перевезення, часу поїздки, ступеню наповнення салону транспортних засобів.

По результатах соціологічного обстеження розраховано коефіцієнт кореляції для кожного із зазначених факторів, які відповідно рівні: 0,679; 0,685; 0,933. Виявлено, що найбільш значущим фактором є динамічний коефіцієнт заповнення салону транспортного засобу.

рівень конкуренції, привабливість маршруту, рухомий склад, пасажирські перевезення, математичне моделювання

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