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IMPROVEMENT OF URBAN TRANSPORT SYSTEM

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Purpose. To improve of the route network of the urban passenger transport by identifying the need for the new rational routes and determining the parameters of the city transport system. The following tasks were determined: to create of a coordinate model of a transport network of a city with the population of 200 thousand inhabitants and to determinate of an initial route scheme. **Methodology.** The procedure of determination of traffic density in different micro-districts of the city is performed by the gravitation method under the condition of limited information. A coordinate model of the transport network in the city of Kremenchuk is created in a 2D coordinate system by indication of the centers of transport districts and their interconnection. **Results.** The measures for improving of the route network are devised on the basis of determination of the city transport system's parameters. For the initial variant of the bus routes scheme the time spent by all the passengers on travel and changes is calculated. The way taking into account the assigned routes with the least time of travel and changes is chosen for every traffic density. A sufficient condition for determination of a through route consists in meeting a natural requirement that the time of passenger's waiting for a bus at the initial point of the route should be shorter than or equal to the time spent at the point of change. **Originality.** For the first time, we have proved that prospective direction of improvement of the transport system of the Kremenchuk city consists in determination of the optimum route network, providing introduction into the basic scheme of three new routes. **Practical value.** The algorithm of solution to the problem concerning the shortest ways (in time) is developed. The new engineering solutions are formulated and calculation of the route network is carried out.

Key words: route network, traffic density, correspondence matrix, city transport system.

УДОСКОНАЛЕННЯ МІСЬКОЇ ТРАНСПОРТНОЇ СИСТЕМИ

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На основі встановлених параметрів транспортної системи міста розроблено заходи щодо удосконалення маршрутної мережі. Сформульовано нові технічні рішення та проведено розрахунки маршрутної мережі. Дослідження пасажиропотоків проведено гравітаційним методом. Для початкового варіанту схеми автобусних маршрутів розраховується час, витрачений всіма пасажирами на слідування і пересадки. При цьому для кожного пасажиропотоку шлях для поїздки вибирається з урахуванням призначених маршрутів з найменшим часом слідування і пересадки. Достатньою передумовою призначення наскрізного маршруту є задоволення природної вимоги, щоб час очікування пасажиром автобуса на початковому пункті маршруту було б менше або дорівнювало часу, який затрачено у пункті пересадки.

Ключові слова: маршрутна мережа, пасажиропотік, матриця кореспонденцій, транспортна система міста.

PROBLEM STATEMENT. Conditions of human activity are related to physiological cycling and sociological features, which causes considerable variation of traffic density in time and direction of the transport network. Account of dynamics of formation of passenger operations in time and space is one of labor consuming problems occurring during transport calculations that are to aim at minimization of variations at the network sections taking a number of organizational measures [1–3]. One of the basic problems of optimization of transport system and rational organization of urban bus transportation consists in determination of the necessity for new routes.

The solution to this problem is in the research of traffic density among different micro-districts of the city and the choice of route schemes meeting needs for travel without changes. Not only economic results of the operation of automobile companies but also indices of the quality of passenger service, i.e. amount of time spent for passengers' waiting for boarding, change, probability of refusal to board passengers, depend on solution to this problem on the whole .

The performed research was aimed at improvement of the route network of the urban passenger transport by determination of the need for new rational routes and detection of the parameters of the transport system.

EXPERIMENTAL PART AND RESULTS OBTAINED. When passenger operations are forecast, the most accurate calculations are obtained by the method of calculation of transport district mutual correspondences based on calculation of population mobility [2-4]. The idea of this method consists in the fact that entire structure of a settlement with a big number of passenger-forming and absorbing correspondences is presented in an enlarged form (transport districts). This method requires taking into account each social group.

The next stage consists in distribution of the traffic density across the network. The following hypothesis is used: distribution of correspondences in the shortest way of travel [2] determined by the travel distance, amount of time spent on the movement, distribution of traffic density across the ways with minimum resistance to movement.

Urban passenger transport is one of the most important factors providing the vital activity of the city, efficiency of its functioning, joining different parts of the aggregation into a single complex entity [8-11].

At present in most Ukrainian cities the structure of the rolling stock according to classes and passengers capacity does not provide the proper level of the quality of transport service of the city population. Under such conditions the problem of balanced and most efficient use and development of urban passenger transport acquires especial topicality and its solution requires the use of up-to-date approaches and methods of research.

Operation under market conditions makes carriers look for ways of costs reduction, maximum use of the rolling stock. Determination of the route needs for rolling stock is one of the basic problems of organization of urban bus transportation. External parameters of the system of bus transportation are the initial data for further calculation and characteristics of this system enable assessment of the efficiency of the obtained results.

Traffic density is the most important factor that must be taken into account during solution of the mentioned problems as it objectively reflects the need of the population for transportation. Apart from timely servicing of the traffic flow, an important component for the choice or distribution of buses among the routes consists in expenditure of the automobile operating company for the route exploitation [6], which depends on the number of buses, their type (passengers capacity) and various technical and operational parameters. Capacity of the rolling stock [8, 9] is determined by its design features. A lot of factors are taken into consideration during the choice of the rolling stock capacity: traffic flow intensity in one direction at the busiest section; unevenness of traffic density distribution at different hours of the day and route sections; expedient interval of vehicles movement at different hours of the day. As well as road conditions of rolling stock movement and streets throughput (in some streets the movement of high-capacity rolling stock may be restricted because of the overall dimensions), transportation costs.

To achieve the posed purpose the following problems were solved:

– to create a coordinate model of the transport network for a city with the population of 200 thousand inhabitants;

– to develop an algorithm for solution of the problem of the shortest ways (in time);

– to determine an initial route system;

– to create methods for carrying out analysis of passengers' movement;

– to check if section routes correspond to the movement intervals.

The procedure of determination of traffic density in different micro-districts of the city is performed by the gravitation method under the condition of limited information according to [5, 6]. A coordinate model of the transport network in the city of Kremenchuk is created in a 2D coordinate system by indication of the centers of transport districts and their interconnection so that the center of each transport district have no less than three and no more than four connections with other centers Fig. 1.

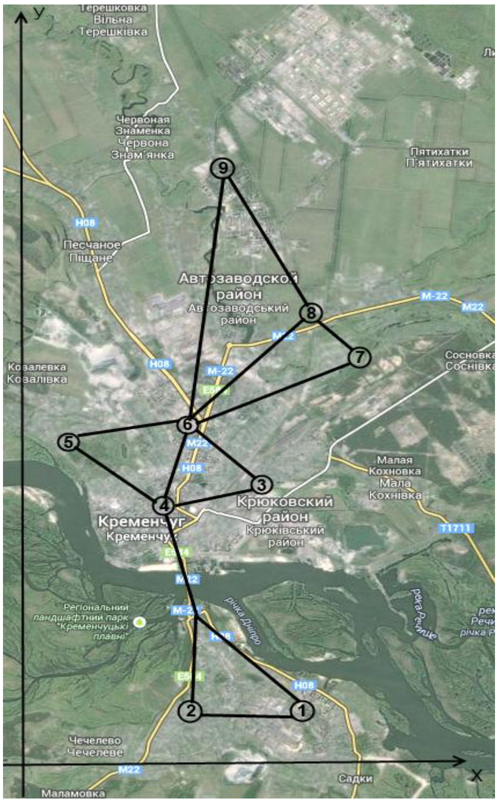

Figure 1 –Transport districts in the city of Kremenchuk: 1 – Rakivka; 2 – Kriukiv; 3 – 1-3 Zanasyp; 4 – Center; 5 – Revivka; 6 – Nahorna chastyna; 7 – Lashky; 8 – Velyka Kokhnivka; 9 – Molodizhnyi

According to the obtained coordinate model of the transport network the length of movement between the districts is determined by way of measurement. The shortest connection among the ones existing in the transport network is chosen.

Resistance to communication between the transport districts (d_{ij}) is determined according to formula:

$$d_{ij} = \frac{1}{t_{ij}}, \quad (1)$$

where t_{ij} – movement time.

Capacity of the transport districts, labor capacity of the districts (number of arrivals) (H_j) are determined on the basis of assumption that during the period of time (rush hour) 80 % of all employees arrive at the district and there are no travels related to cultural and household activities.

Residential capacity of the districts (H_i) (the number of residents of the district or the number of departures from the district) is calculated according to formula:

$$H_i = N_p \frac{\sum_{j=1} H_j}{N_M}, \quad (2)$$

where N_p – number of the residents of the district, people; $N_м$ – population of the city, people.

The matrix of correspondence between the transport districts is calculated by formula:

$$H_{ij} = H_i \frac{H_j d_{ij} k_j}{\sum_{j=1} H_j d_{ij} k_j}. \quad (3)$$

Determination of the value of correspondences between the *i-th* and the *j-th* transport districts is performed with the use of the gravitation model.

Elements of matrix *Y* are determined at the first iteration. The value of the balance coefficient at the first iteration is $\kappa_i=1$.

The conditions of balance of correspondence matrix are verified by formula:

$$\Delta_j = \frac{\left|H'_j - H_j\right|}{H_j}100\% . \tag{4}$$

Condition $\Delta_j \le 10$ is to be true, if it is not met for one of the districts, the balance coefficient is calculated by formula:

$$k_j = \frac{H_j}{H'_j} . \tag{5}$$

If the condition of correspondence of the initial value of labor capacity of district and labor capacity obtained as a result of correspondences distribution according to the gravitational model is not met by all the transport districts, new values of balance coefficient will be calculated and correspondence matrix will be calculated at a new iteration.

The total number of possible routes will be determined by formula [7]:

$$n = \frac{m(m-1)}{2} , \tag{6}$$

where *m* –number of micro-districts. In our case *n* = 36.

Development of the route scheme includes several stages.

Stage 1. Determination of the shortest (in time) ways between the points (micro-districts). The following algorithm of solution to the problem relating to the shortest ways is the most cautious and consists of two steps.

Step 1. Give potential 0 to the initial network node.

Step 2. Look at all links whose initial nodes have potentials and final ones have none. Determine final nodes potentials as a sum of the initial node potential and the time of the bus at the link connecting the initial and the final nodes. Choose the final node with the least potential, write it down beside the node and mark the link with an arrow. Step 2 is repeated till all the nodes are given potentials.

The results of this calculation are written in Table 1, where corresponding boxes in the upper left corner contain points, through which the shortest way passes, and at the bottom – the time of travel between the initial and the final points. Calculation for all the points is performed in an analogous way; each of them is taken as the initial one and the results are written in Table 1 that reveals all the shortest (as to the travel time) routes among all the points of the transport network.

Table 1 – The shortest ways of travel among all the points of the transport system

Points of depart	Points of arrival, passengers									Man-hours
	1	2	3	4	5	6	7	8	9	
1	_	11	^{4} 42,5	30	^{4} 48	^{4} 47	$^{4;6}$ 71	$^{4;6}$ 64	$^{4;6}$ 70	4480,9
2	11	_	^{4} 37,5	25	^{4} 43	^{4} 42	$^{4;6}$ 66	$^{4;6}$ 59	$^{4;6}$ 65	3897,13
3	^{4} 42,5	^{4} 37,5	_	12,5	^{4} 30,5	20	^{6} 44	^{6} 37	^{6} 43	3005,27
4	30	25	12,5	_	18	17	^{6} 41	^{6} 34	^{6} 40	3115,6
5	^{4} 48	^{4} 43	^{4} 30,5	18	_	^{4} 35	$^{4;6}$ 59	$^{4;6}$ 52	$^{4;6}$ 58	5440,32
6	^{4} 47	^{4} 42	20	17	35	_	24	17	23	2659,2
7	$^{4;6}$ 71	$^{4;6}$ 66	^{6} 44	^{6} 41	$^{4;6}$ 59	24	_	^{6} 41	^{6} 47	5291,53
8	$^{4;6}$ 64	$^{4;6}$ 59	^{6} 37	^{6} 34	$^{4;6}$ 52	17	^{6} 41	_	40	4649,28
9	$^{4;6}$ 70	$^{4;6}$ 65	^{6} 43	^{6} 40	$^{4;6}$ 58	23	^{6} 47	40	_	3921,1

Stage 2. Determination of the initial route scheme.

A scheme containing routes meeting a sufficient condition of determination of through direct routes and even section routes not coinciding with any through route is taken as the initial route scheme. A route connecting the centers of three and more micro-districts by the shortest way and the least amount of time spent on the travel is considered to be a through route.

A sufficient prerequisite for determination of a through route consists in meeting the natural requirement that, the time of passenger's waiting for the bus at the initial point should be less or equal to the time spent at the change point, i.e. the following relation should be true:

$$\frac{c \cdot q \cdot T_p}{\rho} \cdot \frac{1}{P_{ij}} \le t_{ni} , \tag{7}$$

where *c* – coefficient of irregularity of passengers' coming to the stop; *q* – capacity of the bus; T_p – length of the calculated period of the day, min.; ρ – coefficient of irregularity of traffic density during one hour; P_{ij} – the number of passengers who travel between final points of a definite route in the direction of the maximum traffic density; t_{ni} – time spent by one passenger on change at point 1 that has maximum duration of the change in comparison with other intermediate points on the way between the initial and the final points of a certain through route in the direction of maximum traffic density.

Routes meeting this condition are included into the initial variant of the bus route scheme.

According to [5], it is proposed to take the coefficient of irregularity of passengers' coming to the stop equal to 0,5. For further calculation a research is carried out to determine this coefficient.

Observation was performed from Monday till Friday (labor travel is of more interest) during the morning rush hour from 7 till 9 at the Rynok stop, where most routes, not only bus routes but also trolley-bus ones, pass; this micro-district also connects a great number of other districts.

An observer counts passengers who come to the stop every 10 minutes not including those who have already been present at the stop.

The examination resulted in determination of explicit periods during the rush hour that correspond to the time when work starts at most enterprises and organizations. Mostly, passengers go to their place of work or study before 8.00, 8.30 and 9.00 a.m. It is caused by the operating schedule of plants, factories, educational establishments. The results of the research are shown in Fig. 2 where one can see two drops of traffic density. For example, if a passenger is to be at work at 8.00, there is no sense to come to the stop at 7.00, so, fewer passengers wait for transport at the stop at that time.

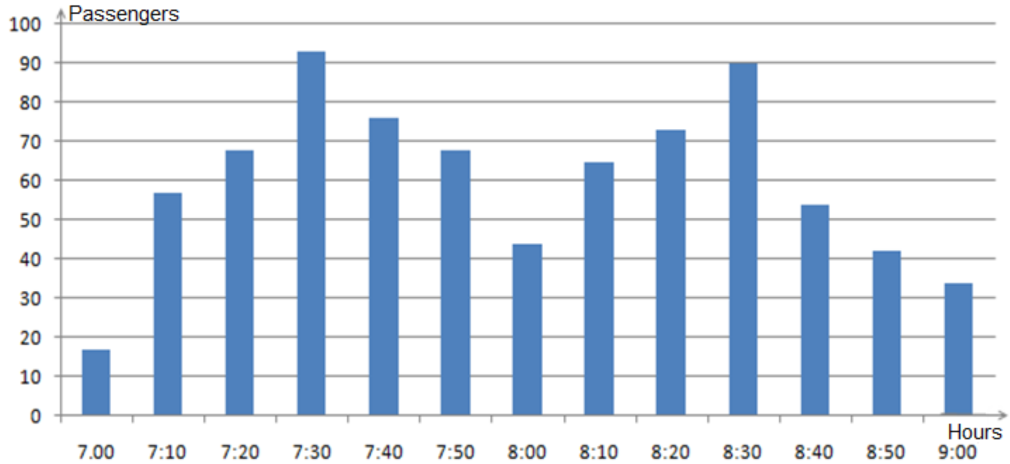

Figure 2 – Results of research of the coefficient of irregularity of passengers' coming to the stop

The coefficient of passengers' coming to the stop is determined by formula:

$$c = \frac{Q_{cp}}{Q_{\max}} \qquad (8)$$

In our case it is 0,63.

We analyze if through routes considered in the example meet the sufficient condition. As to route 1–5 relation (7) obtains the following form $\frac{0,63 \cdot 27 \cdot 120}{1,1} \cdot \frac{1}{102} = 18 \geq 6,2$.

The left side is bigger than the right side, i.e. the time of waiting is longer than the time of change, so this route is not assigned.

The same is observed at route 1–3, where the time of change, equal to two minutes, is taken according to item 4. Thus all other possible through routes are verified.

Stage 3. Verification of the routes correspondence to the traffic interval.

Only section routes that do not coincide with the through ones and pass across the points connected by other possible bus routes are verified. Such section routes include 8–9, 3–6, 4–1, 4–2.

To calculate the interval of bus travel along the route a direction with the highest traffic density is taken. It is seen in the table that for section route 8–9 the maximum traffic density is 3922 passengers, for route 3–6 – 2583 passengers, for route 4–1 – 712 passengers, for route 4–2 – 947 passengers.

For route No. 8–9 an average passenger capacity is found. These districts are connected by route No. 21, where two buses operate, their passenger capacity is 40 people I_{ni} = 1,22 min.

Stage 4. Calculation of purposefulness of assignment of additional through routes. Apart from routes that were present in the initial variant it is possible to assign other intermediate routes, they are assigned only if they meet condition 1 and have intermediate points. It is easy to find them in the table, where for very such route there is a box with at least one number of an intermediate point in the upper left corner. Accordingly, such boxes should be chosen either above or below the diagonal with empty boxes as the table is symmetric. Condition 7 is also to be met. In the considered example these additional routes may include: 1–2, 1–6, 1–9, 2–6, 2–9, 3–2, 4–9, 5–2, 5–6, 5–9, 6–9, 7–2, 7–4, 7–8, 8–2, 8–4.

Let us check if there is traffic flow at these routes. Detection of traffic density at these routes is performed taking into account not only the passenger flow passing from the initial to the final point of this route, but also taking into consideration passengers who may go by this route if there are no other additional routes. To calculate the interval the direction with the highest total traffic density is taken.

The time spent by all the passengers on travel and changes is calculated for the initial variant of the bus route scheme. Moreover, the travel way taking into account the assigned routes with the least time of travel and change is chosen for every passenger flow.

Assume that all combinations of routes meeting the previous conditions are included into the travel scheme. Then to get from point 2 to point 5 it is necessary to change at point 4. As route 2-5 meets the conditions, a direct travel is provided and no time is wasted on travel to point 4. The time reduced from 45 to 34 min.

CONCLUSIONS. The performed research determined an initial route scheme and created a coordinate model of a transport network of a city with the population of 200 thousand inhabitants, an algorithm of solution to the problem concerning the shortest ways (in time) is developed. Methods for examination of passengers' travels are created on its basis and verification of section routes as to correspondence to traffic interval is performed.

As a result it is proved that prospective direction of improvement of the transport system of the Kremenchuk city consists in determination of the optimum route network, providing introduction into the basic scheme of three new routes passing across districts: 1–2–4–6; 1–2–4–3; 2–5–6–4, and a partial change of an existing route, route No. 21 to connect Lashky micro-district with Velyka Kokhnivka and Molodizhnyi. The coefficient of irregularity of passengers' coming to the stop is 0,63.

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УСОВЕРШЕНСТВОВАНИЕ ГОРОДСКОЙ ТРАНСПОРТНОЙ СИСТЕМЫ

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На основании установленных параметров транспортной системы города разработаны мероприятия для усовершенствования маршрутной сети. Сформулированы новые технические решения и проведены расчеты маршрутной сети. Исследования пассажиропотоков проведены гравитационным методом. Для начального варианта схемы автобусных маршрутов рассчитывалось время, затраченное всеми пассажирами на следование и пересадки. При этом для каждого пассажиропотока путь для поездки выбирается с учетом назначенных маршрутов с наименьшим временем следования и пересадки. Достаточным условием назначения сквозного маршрута является удовлетворение естественных требований, чтобы время ожидания пассажиром автобуса на начальном пункте маршрута было бы меньше или равно времени, которое затрачено в пункте пересадки.

Ключевые слова: маршрутная сеть, пассажиропоток, матрица корреспонденций, транспортная система города.

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