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Thesis on the subject: «**Optimization of route networks of urban passenger transport in Taraz city**» for the degree of Doctor of Philosophy (PhD) in the specialty 6D090100 - Organization of transportation, traffic and operation of transport.

ANNOTATION

The relevance of research. The country's economic and social well-being indicators set new standards for urban passenger transport. The most important task for city authorities is to create the necessary conditions to meet the transport needs of the population. Of particular importance in solving the problems of further development of the region's economy is the effective work of the socially important sector, which for state and local authorities is urban passenger transport.

With the high growth rate of cities, a sharp increase in the number of rolling stock on the streets, with the emerging problems of creating new routes, etc. at the present stage, there is a need to use information systems in the management of urban passenger transportation. As a result, the amount of information taken into account and analyzed for making urgent decisions increases significantly. This information scope can be processed only with the help of special programs and computers. Further development of urban passenger transportation is impossible without computer technology.

Solving the problems of transport infrastructure designing and development requires taking into account many factors associated with technical indicators of urban development, the growing needs of enterprises and population, resource opportunities. Taking into account the time dynamics of resource constraints, along with the dynamics of the tasks to be addressed and the needs for transport and road resources, there is an objective need to develop a scientifically based approach allowing optimizing the improvement of major transport links at the urban and regional levels.

The effectiveness of the development and research of these problems is due to the accumulated experience, scientific and methodological work at various historical stages, and regularities of their development. But domestic urban passenger networks cannot be used as an example with the existing rational systems of another state and even other cities. After all, the layout of each city, the mentality of residents, flows with the needs of traffic do not coincide, therefore any city needs planning and organization in accordance with its own peculiarities.

It is obvious that improving the theoretical and methodological foundations of the development and functioning of urban transport systems, in general, and ensuring uninterrupted and safe movement of traffic flows through urban road networks, reducing transport costs in all types of urban transport are among the most relevant today.

The aim of the work is to optimize the public passenger transport network in order to fully, timely and qualitatively satisfaction of the city's residents' demands.

Research objectives:

- analyze the current state of the passenger transport system in Taraz city by quantitative and qualitative indicators;
- to study the modern scientific and theoretical foundations of building efficient networks in the urban transport system;
- develop and research methods for determining the locations of public transport stops;
- to develop an algorithm for optimal passenger routes based on the multi-colonial ant system in the public transport system and the application solution;
- to conduct experimental studies and evaluate the effectiveness of optimization of public passenger transport route networks in Taraz city.

Research methods. Methods of computational mathematics, system analysis, graph theory, probability theory, mathematical statistics, artificial intelligence technologies and new information technologies were used as research methods.

The objects of the study are public transport networks, bus stops, passengers and the quality of services provided in Taraz city.

Theoretical and methodological foundations of the study. The research was carried out by forming new scientific and methodological approaches and scientific argumentation of proposals based on numerous works of domestic and foreign scientists in the field of passenger transportation organization.

Scientific novelty:

- a graph analytic model of transport links of Taraz city has been developed, which allows analyzing route networks and the location of stopping points;
- a criterion for optimizing the route networks of urban passenger transport is proposed, taking into account the interests of all participants in the urban transport system;
- a method has been developed for determining the locations of public transport stopping points, which makes it possible to increase the efficiency of decisions taken to optimize the route networks;
- a method of multicolonial system of ants, allowing to find a solution of generalized optimization at interaction of several colonies, has been proposed;
- the model of optimization of the urban passenger transport network, allowing to take into account the different, sometimes opposite, interests of participants of the urban passenger transport network, has been developed.

The results of the study are of an applied nature and can be used by government authorities in the development of comprehensive programs for the development of urban automotive systems. For this purpose, the following methods are proposed and legalized by the author's certificate: "Method of choosing a passenger public transport network", "Mathematical model for justifying the location of stops based on the theory of dimensions", "Economic and mathematical model of tariffs for urban passenger transportation".

Implementation of the work. The results of the thesis were implemented by the administration of the city of Taraz in the development of the urban passenger

public transport system, and also used in the development of the Taraz passenger transport development program for 2020-2025 years.

Approbation of the work. Highlights of the thesis were reported, discussed and approved at scientific and technical conferences of the Kazakh Academy of Transport and Communications named after M. Tynyshpayev (Almaty, 2019-2021 XLII International Scientific and Practical Conference on the topic: "Innovative technologies in transport: education, science, practice" (Almaty, 2018), XLII International Scientific and Practical Conference on the topic: "Innovative technologies in transport: education, science, practice" (Almaty, 2019), on scientific seminar of the department: "Organization of transportation and operation of transport" and at the meeting of the department: "Transport equipment and technologies".

Publications. According to the subject of the thesis, 5 publications were published. In publications recommended by the Committee for Quality Assurance in Education and Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan: 3 articles in the journal: "Bulletin of the Kazakh Academy of Transport and Communications" of the publishing house: "Academy of Logistics and Transport". 2 articles have been published in international peer-reviewed scientific journals included in the «Scopus» information databases.

Structure and scope of work. Thesis consists of an introduction, four main chapters, a conclusion, a list of references and appendices. The work is presented on 135 pages of printed text, contains 38 figures, 28 tables. The list of references includes 91 titles.

In the introduction, the relevance of the topic of the dissertation research is substantiated, the purpose, objectives, methods and object of research are formulated, the scientific novelty is characterized, and the practical significance of the results obtained is shown.

The first chapter reviews and analyzes the existing passenger flows, route networks and the organization of bus operations on routes, identifies features, indicators, shortcomings and prospects of the development of urban passenger transport organization on the example of the city of Taraz, and also substantiated the problems of the dissertation research.

To assess the existing route network of urban transport in Taraz city, the following main indicators are used: density of the transport network; network coverage coefficient; route coefficient; straightness coefficient of routes.

Analysis of the number of simultaneous routes with more than 15 routes by sections of the city's road network revealed 10 intermediate and 14 final stopping points. At these stops, more than 50% of the busiest routes are UPT (*Urban passenger transport*). The frequency of passenger transport at these stops is 55-79 buses/hour. The high traffic intensity indicates the need to separate the loading of stopping points due to the long stop of the DN (*Density of network*) and poor-quality passenger service at the entrance and waiting for a stop.

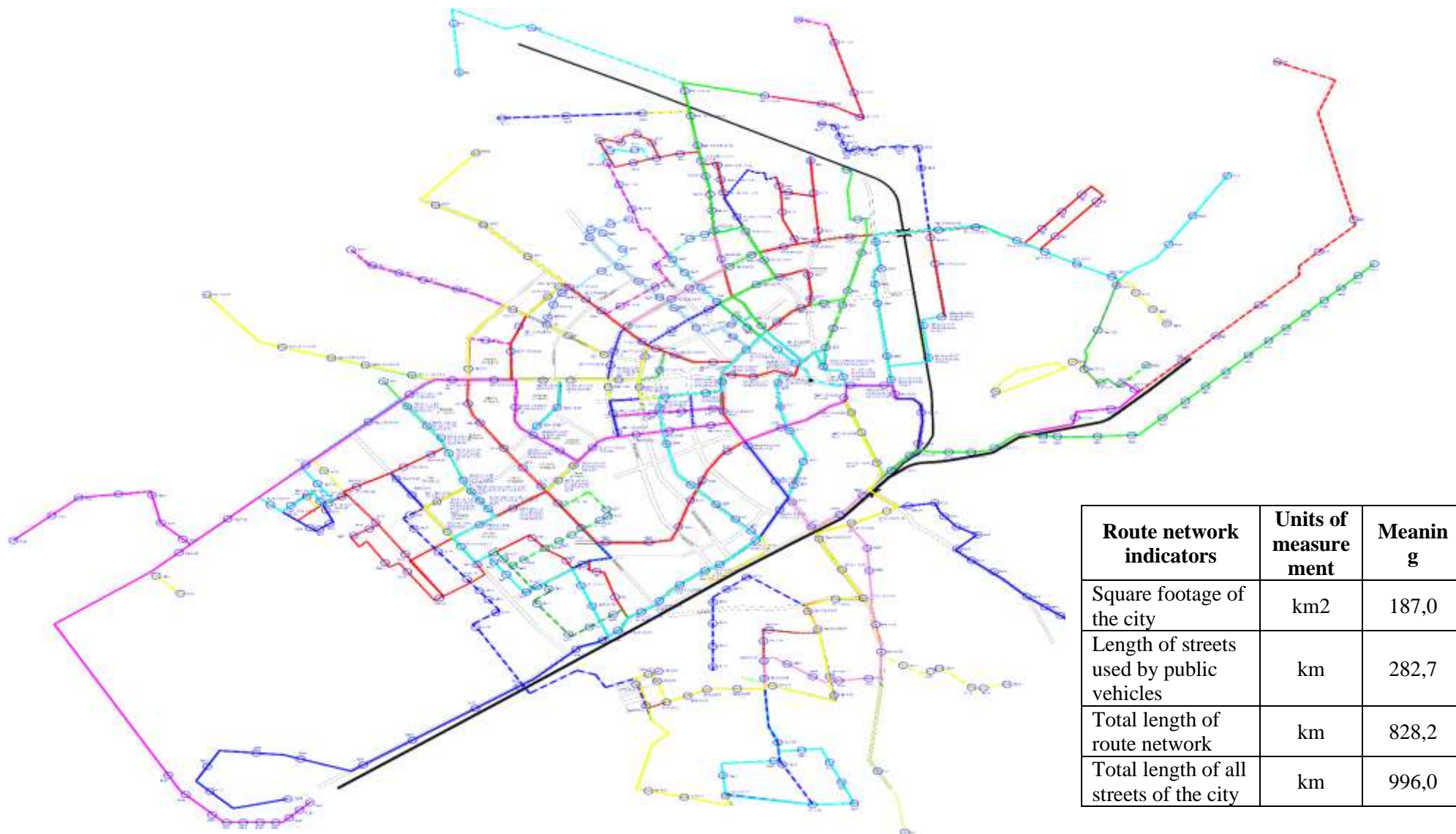


Figure 1 – Route networks in the city of Taraz

The analysis of pedestrian accessibility problems created for residential development areas for some districts of Taraz city showed that in some districts there are areas whose pedestrian accessibility exceeds the standards for urban passenger transport stops. Low level of pedestrian access to urban passenger transport stops in the areas of the Sugar Factory, Baryshansky massif, Karasu, etc.

The beginning of the twentieth century of the Soviet era can be attributed to studies of passenger flows and correspondence, the founders of which are scientists: G.V. Sheleikhovsky, S.A. Andreev. The formation of a route transport network, which is based on the issues of determining passenger flows and correspondence, as well as graph theory methods, allowed us to develop effective methods for organizing passenger transportation in cities. V.V. Konoplin, B.L. Geronymus, D. Dzhumaev, M.V. Khrushchev, V.V. Yavorsky, I.P. Makarov, V.P. Fedorov, N.V. Bulychева, A.P. were engaged in research in this direction. Lopatin, S. Olkhovsky, V.M. Weizman, etc.

The existing methods of organization and management of UPT, applied on the real route network of cities, were prerequisites for analyzing the state and prospects of passenger transportation development on the example of Taraz city.

The second chapter examines the economic essence of the functioning of passenger transport, which is one of the components of urban infrastructure.

The dependence of labor productivity on the time spent by the labor movement creates difficulties for some enterprises located outside the city limits or in areas with poor transport accessibility. The change in the productivity of workers depending on the time spent on the movement of labor, the results are confirmed by the studies presented in Fig.2. Thus, an increase in the duration of work trips by 10 minutes leads to a decrease in labor productivity by 3-4%.

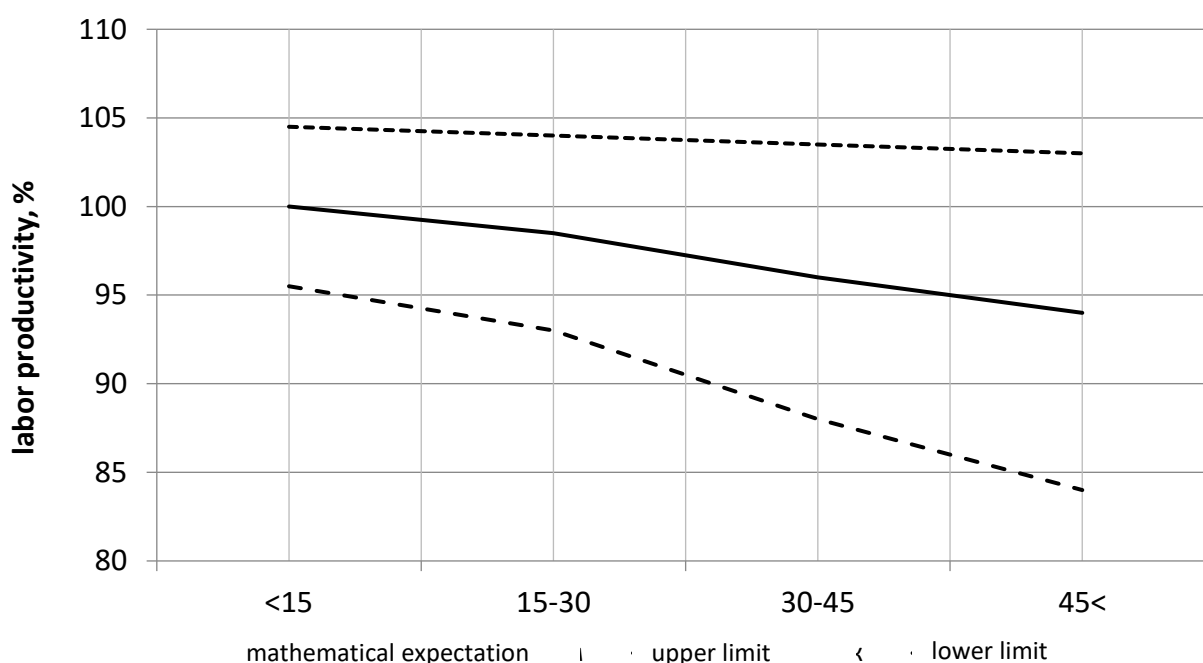


Fig.2. Dependence of labor productivity on travel time.

The thesis reveals an analytical relationship between the time spent on labor movements and labor productivity:

$$E_{\text{өнім}} = 100 - 0,0373T_{\text{жылжу}} - 0,00212T_{\text{жылжу}}^2 \quad (1)$$

where $T_{\text{жылжу}}$ is the time spent on movement;

The main difficulty in determining the time spent on the trip is to determine the numerical values of the components, in particular, the waiting time for the passenger to start the service.

According to the Committee on Statistics, the population, passenger transport, GRP per capita, average per capita income and the number of cars in the city of Taraz have been estimated over the past 13 years. Using linear-type dependence, we use the regression equation to predict the amount of transport mobility of the population.

Links of indicators on the transport mobility of the population:

- the relationship with the indicators of population, GRP per capita and the average per capita income of the population is considered close, (r above 0.9);
- the relationship with the indicator of the level of motorization of the population is considered weak, the value of the correlation coefficient $r = 0.209$;

This means that population growth, along with the standard of living of the population, has recently led to an increase in transport mobility. The increase in the level of motorization of the population indicates the unattractiveness of the use of passenger transport.

The stopping point is an object of transport infrastructure and must be located properly to provide communication with the surrounding areas, thereby ensuring the availability of public transport.

A stop zone located on the territory of Taraz city is considered to be a segment of 500 to 1000 meters in size (Fig.5).



Figure 5 - Division of the city of Taraz city into segments

The division of Taraz city into segments is implemented in the programs of simulation modeling of demand and supply of public transport.

Transport demand provided for the creation of a matrix of inter-stop correspondence. To do this, the entire area of the city is divided into stopping areas, which are the points of origin and repayment of urban passenger traffic. The matrix of inter-stop correspondences was obtained using mathematical modeling (using a "gravity" model in the MATLAB software package).

Based on the analysis of transport routing tasks, additional restrictions were considered that must be taken into account when optimizing the route schemes of the UPT. As an optimization criterion for the UPT system, it is proposed to use the density of passenger traffic on a certain section of the track:

$$D_{AB} = \frac{\sum Q_{AB}}{L_{AB}} \rightarrow \max \quad (2)$$

Analysis of methods for solving transport routing problems has shown that Meta-heuristic algorithms are the most promising today.

In the third chapter, the justification of the location of stops of public transport, the study of preferences of passengers and the development of methods for solving problems of optimization of transit networks of passenger transport based on the formic algorithm are considered.

Thesis identifies the most important factors affecting the availability of stops, and presents the results of the analysis of a priori ranking. Based on a priori information, an a priori rating of factors was compiled, which allows identifying the most significant factors and eliminating factors that have a minor impact.

The a priori rating factor using dimension theory is considered in two stages: pedestrian traffic to a stop and a passenger's trip to a transit stop, and is a theoretical prerequisite for determining the location of public transport stops, taking into account the main indicators of both the distance covered by pedestrians, on the one hand, and the speed of public transport, on the other.

The first stage. According to respondents, the following factors influence the movement of pedestrians to the stop: the distance traveled by a pedestrian to the stop L , the time of approach to the stop t_1 , the pedestrian's speed v and the climatic temperature of the environment θ .

$$t_1 = \left(\frac{L}{v}\right) \cdot f\left(\frac{\theta}{p \cdot Q}\right) \quad (3)$$

The second stage. The following factors affect the passenger's journey to the transit stop: the intensity of public transport J , the speed of transport V_a , the weight of public transport G_a and the travel time in transport t_2 .

$$t_2 = \text{const} \left(\frac{1}{N * t^{-1}}\right) \cdot \varphi\left(\frac{a_a}{a_t}\right). \quad (4)$$

The obtained dependencies can be used in the development and justification of the locations of public transport stops.

This chapter develops a methodology for evaluating the preferences of passengers when choosing a bus line in public transport. The proposed approach is based on a fuzzy logical mathematical apparatus and uses survey data to calculate

the ownership functions that determine the preferences of passengers. To illustrate the methodology developed, the case study of the passenger survey conducted in Taraz city is used.

To evaluate the membership function reflecting the latest preferences of passengers, it is necessary to determine the weighting coefficients for each of the selected attributes. We have determined the values of the weight coefficients as arithmetic averages for all respondents. The preference functions selected according to the survey data were evaluated equally by respondents, although the tariff was evaluated as a somewhat important function.

We defined weights as arithmetic averages for all respondents. Preference functions selected according to the survey data were evaluated equally by the respondents, although the rate was evaluated as a somewhat important function.

Based on the analysis of literature sources indicating the effectiveness of the ant algorithm in solving well-known optimization problems, the choice of its basic principle for the development of a new approach is justified.

The main idea of the proposed method is to use several colonies acting simultaneously, unlike the traditional ant algorithm. To achieve a common goal, colonies make joint decisions at each stage, but at the same time each colony solves its own task.

First, ant groups are formed, which include one representative from each colony. In fact, each of these intercolonial groups will replace a separate ant from the traditional ant algorithm. All the ants in the group consistently form a solution. Ant x belonging to a colony of group k with normalized probability according to the formula:

$$p_{x,i}^k(t) = \frac{[\tau_{x,i}^k(t)]^\alpha \cdot [\eta_{x,i}^k]^\beta}{\sum_{y \in Y} \sum_{j \in J^k} [\tau_{y,i}^k(t)]^\alpha \cdot [\eta_{y,i}^k]^\beta} \quad 5)$$

where: Y – set of colonies;;

J^k – is the set of available vertices for group k ;

$\eta_{x,i}^k$ – is the a priori attractiveness of the alternative, the inverse of the cost of the transition from the vertex of the ant of the colony group x to the vertex i ;

$\tau_{x,i}^k$ – is the a posteriori efficiency of the alternative, determined by the amount of pheromone of the colony at the transition from the vertex of the ant of group x colonies k to vertex i ;

α, β – configurable free parameters of the algorithm

Based on the proposed method, a multi-colony ant algorithm has been developed that allows taking into account various conditions of the task.

The fourth chapter presents the results of experimental studies of the developed algorithm and determines the economic effect of the proposed measures on the example of Taraz city.

To implement the algorithm of the route network optimization methodology, 3 stages are allocated:

At the first stage, the construction of the distance matrix solves the following problem: we consider a graph $G(N,A)$ having N vertices and A arcs. It is required to find the shortest paths on the graph and their lengths from a given vertex i to each separately.

At the second stage, the analysis of the urban transport system is carried out: the correspondence matrix is calculated. The matrix of inter-district correspondence obtained by mathematical modeling using the "gravity" model in MATLAB is transformed into the matrix of inter-stop correspondence $T_{i,j}$.

At the third stage, the selection of optimal routes for passengers in the urban public transport system is carried out according to the criterion of passenger traffic density and effective transfer hubs are determined by the size of passenger traffic. To solve the problem of choosing the optimal direction, a software product in the MATLAB language has been developed.

Optimization of the route network of Taraz city made it possible to improve the quality of passenger transportation. In the process of optimization, passenger traffic has been redistributed in some sections of the street and road network in the city center. As a result, while maintaining all the places of attraction and traffic volumes, the intensity of bus traffic and passenger traffic on the busiest sections of the line decreased.

The total mileage of all buses on the routes of the current route network of the city of Taraz during one working day is 28415 km. The proposed route network has decreased by 25212 km. The passenger capacity is aligned with the PAZ-3205 brand.

It can be concluded that the economic effect in the transition to the new route network of the city of Taraz, obtained with an equal number of passengers transported (as a result of reducing passenger transportation costs), should provide funds in the amount of 208,195 tenge per day or 6,245,850 tenge per month.

Twelve articles have been published on the topic of thesis and 3 author's certificates have been obtained:

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2. Naumov V., Zhamanbayev B., Agabekova D. Zhanbirov Zh. & Taran I. Fuzzy-Logic Approach to Estimate the Passengers' Preference when Choosing a Bus Line within the Public Transport System. Communications - Scientific Letters of the University of Zilina. 2021, 23(3), A150-A157.

3. Жаманбаев Б.У., Бекжанова С. Е., Раимбаев А.Т. Алмаханова Э.А. Қоғамдық көлік аядамаларының орналасуын негіздеу. г.Алматы. Вестник КазАТК, Том 123 № 4, 2022.

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8. Имандосов А.Т., Жаманбаев Б.У., Алмаханова Э.А., Аясқан Ж.Н., Байыс Н.Б., Сәбит М.Б. Қоғамдық көлік жүйесінің әлеуметтік-экономикалық тиімділігі. Научный журнал «Механика и Технологии», Тараз. – 2019. – №2. – С.146-158.
9. Жаманбаев Б.У., Алмаханова Э.А., Имандосов А.Т., Сатаева Ж.Б., Суюнбеков А.Ә., Сәбит М.Б.Қалалық жолаушы көлігінің жүйесін жетілдіру әдістері. Научный журнал «Механика и Технологии», Тараз. – 2019. – №2. – С.159-165.
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12. Жаманбаев Б.У., Мусабаев Б.К., Алмаханова Э.А. Развитие городского пассажирского транспорта г.Алматы: проблемы и перспективы. Материалы XLIII Международной научно-практической конференции «Инновационные технологии на транспорте: образование, наука, практика», 17 апреля 2019 г., г. Алматы, КазАТК им. М.Тынышпаева. том 2, с. 115-118
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