Scientific Journal of Silesian University of Technology. Series Transport
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

Volume 129 **2025**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: https://doi.org/10.20858/sjsutst.2025.129.14

Journal homepage: http://sjsutst.polsl.pl

Article citation information:
Taran, I., Lytvyn, V., Muratbekova, G. Algorithm design for identifying rational parameters of express bus service in urban settings. *Scientific Journal of Silesian University of Technology. Series Transport*. 2025, **129**, 237-259. ISSN: 0209-3324.
DOI: https://doi.org/10.20858/sjsutst.2025.129.14

Ihor TARAN[1], Vadym LYTVYN[2], Gulzhan MURATBEKOVA[3]

ALGORITHM DESIGN FOR IDENTIFYING RATIONAL PARAMETERS OF EXPRESS BUS SERVICE IN URBAN SETTINGS

Summary. In modern urban environments, the efficiency of public transportation systems plays a crucial role in ensuring sustainable mobility and reducing traffic congestion. Among various public transport services, bus systems remain the most flexible and widely used mode of transit. However, growing travel demand and increasing road traffic intensity often lead to delays, decreased service reliability, and reduced passenger satisfaction. One effective solution to these challenges is the implementation of express bus services, which offer limited-stop operations aimed at reducing travel time and improving overall system efficiency. This study focuses on the development of an algorithm for determining the rational parameters of the express mode of bus traffic in urban areas. The proposed approach considers factors such as passenger flow distribution, traffic conditions, and operational constraints to identify optimal solutions that enhance service performance and passenger convenience. The results are expected to contribute to the improvement of urban public transport systems by providing a methodological framework for efficient express service planning and management.

[1] Department of Roads and Bridges, Rzeszow University of Technology, Powstańców Warszawy Ave. 12, 35959 Rzeszów, Poland. Email: i.taran@prz.edu.pl. ORCID: https://orcid.org/0000-0002-3679-2519
[2] Transport Management Department, Dnipro University of Technology, D. Yavornytskoho Ave.19, 49005 Dnipro, Ukraine. Email: litvin.v.v.79@gmail.com. ORCID: https://orcid.org/0000-0002-1572-9000
[3] Department of Organization Air Transportation and Logistics, Academy of Civil Aviation, 44 Akhmetova st., 050039 Almaty, Kazakhstan. Email: muratbekovagulzhan6@gmail.com. https:/orcid.org/0000-0003-4733-2822

Keywords: express mode, rational parameters, transport efficiency, quality of service, bus route, number of stops

1. INTRODUCTION

The expansion of economies around the world is an unprecedented pace hand in hand with the process of urbanization. Based on the UN data, it can be expected that by 2050 about 70% of the world population will live within urban territories. This will create an additional burden on the public transport system in the future. It is predicted that the number of passengers transported within the cities will triple for the specified period. The current stage in the development of passenger vehicles, due to the use of intellectual transport systems (ITS), is characterized by the desire to achieve the extremely high operational characteristics of the road transport vehicles, the need to minimize the loss of time for transportation, and ensure the comfort of passengers' trips. As it is known, one of the effective ways to achieve the above tasks is to use buses on the city routes of the express mode of bus traffic on city routes.

The express mode provides for bus stops only at those points of the route that are characterized by the maximum passenger turnover. A decrease in the number of bus stops helps to increase the bus's speed, reduce passenger's travel time and improves vehicles capacity. The development and implementation of ITS solutions for the express bus services will help to improve the quality of services in public transport networks, thereby increasing their attractiveness. Already now, ITS means playing an important role in the urban environment, optimizing the work of transport, and in combination with artificial intelligence (AI), they will influence the formation of smart cities of the future. A continuous analysis of the collected data, such as the number of passengers, makes virtual modelling of public transport networks for years to come. A decrease in traffic jams and environmental loads will ensure the growth of passenger flow and an increase in carrier income.

The introduction of an express mode of buses movement allows one to achieve significant technological and social effects without the need for additional buses, and under certain conditions, even to release part of the buses without deterioration of basic quality indicators of transport service of passengers. Reducing the number of stops for express buses helps to reduce fuel costs, increasing the profitability of transportation while reducing of harmful emissions into the city's atmosphere [1].

Despite these advantages, the express mode was not widely used in the first place due to the lack of a single methodology by which its rational parameters can be determined.

2. LITERATURE REVIEW AND PROBLEM STATEMENT

The successful operation of express bus services requires the careful selection of operational parameters, such as stop spacing, headways, and routing strategies. Determining rational parameters for express modes involves balancing travel time savings for through-passengers with accessibility needs for those boarding and alighting at intermediate stops. Despite numerous studies on bus operation optimization, there remains a need for comprehensive algorithms capable of adapting to varying urban conditions and travel demand patterns.

In recent years, many studies have been presented in the scientific literature on the optimization of various aspects of the express bus movement. Below is a review of key works reflecting modern approaches and methods in this area. Thus, in the papers [2, 3], methods of optimizing the number and location of stops were considered in order to minimize the time in the path of passengers. In studies [4, 5], approaches to determining the rational intervals of movement and the functioning schemes of express routes in the conditions of alternating passenger traffic and road situation were studied. Models were also developed that take into account the features of the transport infrastructure, the density of the development and the dynamics of the passenger flow throughout the day [6, 7].

To optimize the bus schedule using deep training Ai et al. [8] method of dynamic optimization of the bus schedule based on deep learning with reinforcement (Deep Reinforced learning) was offered, which allows adapting the intervals of movement in real time, depending on the variable passenger flow. Oliveira et al. [9] developed framework for planning the trajectories of autonomous buses, taking into account the characteristics of the urban environment providing safe and efficient movement.

In the study [10], conducted in the high-tech zone of the city of Zhengzhou, an improved algorithm of an ant colony was proposed to optimize existing bus routes, taking into account the features of urban development and passenger traffic. The same algorithm for optimizing route networks of urban bus transport was used by authors [11, 12]. Zhen and Gu [13] have developed models to optimize routes in conditions of spatially heterogeneous demand, which is especially relevant for rapidly developing urban areas. Models take into account variations in the density of the passenger flow, providing an effective connection with the main transport hubs.

The authors [14] presented an asynchronous multiplayer approach to Deep Reinforced learning to reduce the effect of "accumulations" of buses. The model optimizes the strategy for holding buses at stops, given the uncertainty in passenger traffic and road conditions. The study [15] offers the method of optimizing the routes of express buses with a limited number of stops for long-distance passengers. Using the algorithm for solving the routing problem taking into account the landing and disembarkation of passengers, the authors achieve a reduction in time on the way and increase the attractiveness of public transport. A technical and operational assessment of the introduction of the express mode of movement of buses on the city routes of Jizak city (Uzbekistan) is presented in [16]. Wei and Zhu [17] considered the optimization of bus routes in small and medium cities on the example of route No 7 in the city of Jijoyzo. Methods of increasing the efficiency and safety of the route are proposed, taking into account the features of urban infrastructure and passenger flow.

Prediction of passenger traffic is playing a key role in organizing express bus services. Accurate forecasting enables optimization of intervals, the number of stops and the schedule, providing a balanced ratio between the speed of transportation and the availability of the route. Here you can highlight Baghbani et al. [18], Bharathi et al. [19] and Shen et al. [20].

The organization of dedicated lanes significantly increases the efficiency of bus traffic in the conditions of city transport systems. Their implementation reduces delays, increases the speed of routes, and helps to stabilize traffic intervals, ensuring the priority of public transport in overloaded areas of the road network. Studies by Khakimov et al. [21], Chen et al. [22] and Jiang et al. [23] are devoted to the impact of the selected bus lanes on the road traffic.

Separately, the cluster can be distinguished by the control of the psychophysiological state of the driver [24]. Control is necessary to ensure the safety of passenger transportation. Regular monitoring enables timely identification of deviations that increase the risk of emergency situations [25, 26].

And finally, the introduction of the express operating mode of buses helps to reduce emissions of pollutants by reducing travel time and the number of stops [27, 28]. This positively affects the environmental situation in the city, reducing the level of air pollution in areas with heavy traffic [29].

The analysis of the presented studies shows that, despite the variety of approaches and methods, there is a need to develop a complex algorithm that can take into account the dynamics of passenger flow, the features of urban infrastructure, and operational restrictions. Such an algorithm should provide adaptive and effective planning of express bus routes, contributing to the improvement of the quality of service and sustainability of the city transport system.

The purpose of the work is to develop an algorithm for determining the rational parameters of the express mode of buses in urban conditions. The rational parameters should be understood as the number of buses on the route operating in express A^E and conventional A^{CUST} (poster) modes, as well as a list of stops a Z_i t which express buses stop.

3. METHODOLOGY

The following initial data is required to determine the rational parameters of the express movement of buses: the results of the passenger traffic survey (during which the number of passengers that have entered a_i and left b_j the vehicle at stops are determined); capacity q, technical speed V_t and bus movement interval I; duration of its downtime at intermediate t_{in} and final stops t_{end}; the distance between the route stops $l_{i,i+1}$, the sum of which is equal to its length L_{route}.

The authors offer the following sequence of calculations.

1. Verification of the expediency of introducing an express mode of traffic.

The paper [1] has established the conditions for the expediency of the introduction of different modes of movement of buses, which depend on the quantitative parameters of the passenger traffic: η_{turn}, the coefficient of variability of passengers and $\eta_{unev/\sec}$, the coefficient of uneven passenger traffic on the route. It is proposed for these indicators to use the appropriate standardized coefficients k_{turn}^{norm} and $k_{unev/\sec}^{norm}$ to establish the feasibility of organizing the modes of traffic of buses on urban routes (Fig.1).

$$k_{turn}^{norn} = \frac{1}{\eta_{turn}} = \frac{l_{av}}{L_{route}}; \quad k_{turn}^{norn} \in (0...1];$$
$$k_{unev/\sec}^{norm} = \frac{1}{\eta_{unev/\sec}} = \frac{H_{av}}{H_{\max}}; \quad k_{unev/\sec}^{norm} \in (0...1] \tag{1}$$

where l_{av} average passenger trip length, km; H_{av} and $H_{\max}$ are medium and maximum passenger traffic on the route, pass.

2. Determination of the list of stops for the express route.

In express mode of traffic, the buses do not stop at all stops, so it is advisable to submit options for express route in the form of a logical vector, the elements of which acquire a value of 1 or 0 (of course, that both final stops are necessarily part of the express route, so $\lambda_1 = \lambda_n = 1$):

$$Z_i = \{ \lambda_1, \lambda_2, \lambda_3 \ldots \lambda_j \ldots \lambda_n \}, \tag{2}$$

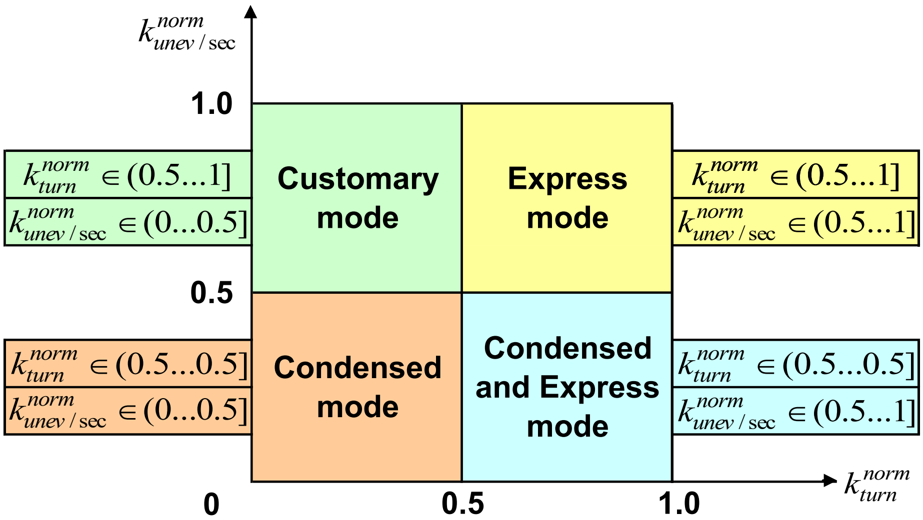

Fig. 1. Conditions for the expediency of organizing modes of traffic on bus routes

where $\lambda_j = 1$, if j-th bus stop is on the express route; $\lambda_j = 0$ – if j-th bus stop is not on the express route.

As for the other stops $\{\lambda_2 \ldots \lambda_{n-1}\}$, the advantage should be given to stops that are characterized by maximum passenger traffic Q_j. To quantify the list of stops that are part of the express route, an empirical condition for exclusion from the express route at j-th stop of the usual route should be used:

$$\frac{F_j}{Q_j} > I\,, \tag{3}$$

where F_j is the number of passengers who do not use j-th stop (4); Q_j is the number of passengers who use j-th stop (5); I is bus movement interval, in normal motion mode.

$$F_j = H_{j-1,j} - b_j\,. \tag{4}$$

where $H_{j-1,j}$ is the level filling the buses between $j-1$ and j-th stops.

$$Q_j = a_j + b_j\,. \tag{5}$$

Considering that during the day the bus interval changes in the range from I the morning "peak" to $2I$ in the interpeak period, an extended method is offered to identify vector variants Z_i:

$$Z_1 \in \left(\frac{F_j}{Q_j} < I\right); \quad Z_2 \in \left(\frac{F_j}{Q_j} < 1{,}5I\right); \quad Z_3 \in \left(\frac{F_j}{Q_j} < 2I\right). \tag{6}$$

This approach to increasing the number of stops for Z_2 and Z_3 slightly offsets the efficiency of the express mode (due to the increase in the number of stops) but increases the potential number of passengers that can use it. It also takes into account the change in buses route intervals during the day and thus allows you to get such combinations Z_i that will allow to organize the most effective options for express mode, both for passengers and for transport enterprises. The final decision on the efficiency of implementation of one or another variant Z_i can only be obtained by modeling results.

3. Restoration of the matrix of interstops correspondence.

One of the main data for calculating the technical and operational indicators of buses on the route with express mode is the matrix of interstops correspondence of passengers K_{ij}. Usually, its elements are determined by the coupon or questionnaire methods of examination of passenger traffic. But these methods are characterized by the high complexity of procedures and primary materials processing. Therefore, the restoration of the matrix of interstops correspondence is proposed to be performed with the help of the calculation and analytical method, which allows for the probabilistic ratios of information about the number of passengers who have entered and left the vehicle at the route stops to calculate K_{ij} components (with a maximum error of 5…7%) according to the following ratios:

$$K_{ij} = \frac{b_j \cdot C_{ij}}{H_{(j-1)j}}, \tag{7}$$

where C_{ij} is the number of passengers who entered the bus at the i-th stop point and left it on j-th and the following stops:

$$C_{ij} = \begin{cases} a_i \text{ if } j = i+1 \\ C_{i(j-1)} - K_{i(j-1)} \text{ if } j \neq i+1 \end{cases}, \tag{8}$$

where a_i is number of passengers who entered the bus at i-th stop.

4. Redistribution of passengers on the route between modes of traffic and calculation of technical and operational indicators of buses.

In [1], the authors offered as the main criteria for evaluating the efficiency of the introduction of an express mode to use the difference between potential and actual transport works performed by buses on the route $W_N \to \min$ and the total time of passenger on travel and waiting at stops: $\sum T \to \min$. The decrease W_N leads to an increase in the dynamic coefficient of use of vehicles and reducing the cost of transportation. The reduction $\sum T$ helps to increase the quality of passenger service and reduce transport fatigue.

For the calculation W_N and $\sum T$ we used elements of the matrix of interstop correspondence K_{ij}. But they require constant redistribution between motion modes depending on the list of stops that are part of the express route Z_i and the number of buses operated in normal A^{CUST} and express A^E modes. The procedure of such redistribution was developed by the authors on the basis of formalization of time spent time in express T_{ij}^{E} and normal modes T_{ij}^{CUST} [1] and represented by calculation dependencies (9-13).

$$q_{ij}^{CUST}(A)=\begin{cases} K_{ij},\ if\ \lambda_i \neq 1\ or\ \lambda_j \neq 1 \\ 0 \end{cases}. \tag{9}$$

$$q_{ij}^{CUST\ or\ E}(B)=\begin{cases} K_{ij},\ if\ \lambda_i = 1\ and\ \lambda_j = 1 \\ 0 \end{cases}. \tag{10}$$

$$q_{ij}^{E}(C)=\begin{cases} q_{ij}^{CUST\ or\ E}(B),\ if\ T_{ij}^{E} < T_{ij}^{CUST} \\ 0 \end{cases}. \tag{11}$$

$$q_{ij}^{E}(D)=\begin{cases} q_{ij}^{CUST\ or\ E}(B)\cdot\dfrac{\psi^{E}}{\psi^{E}+\psi^{CUST}},\ if\ T_{ij}^{E} > T_{ij}^{CUST} \\ 0 \end{cases}; \tag{12}$$

$$q_{ij}^{CUST}(D)=\begin{cases} q_{ij}^{CUST\ або\ E}(B)\cdot\dfrac{\psi^{CUST}}{\psi^{E}+\psi^{CUST}},\ if\ T_{ij}^{E} > T_{ij}^{CUST} \\ 0 \end{cases}. \tag{13}$$

where ψ^E, ψ^{CUST} are the number of bus trips within an hour in express and normal modes, respectively

Thus, the volume of transportation will be distributed between motion modes as follows: $Q^E\left(C+D^E\right)$ and $Q^{CUST}\left(A+D^{CUST}\right)$ (Fig. 2). A closer look should be taken at the structure of the calculation W_N, $\sum T$, components (11-13) and other technical and operational indicators of buses operating in a combined mode with express and conventional modes. Passengers' time spent in express T_{ij}^{E} or normal T_{ij}^{CUST} modes when travelling between i-th and j-th stop points consist of a time of travel ($t_{follow\ ij}^{E}$ or $t_{follow\ ij}^{CUST}$) and the cost of waiting for buses (t_{wait}^{E} or t_{wait}^{CUST}) at stops and calculated by the following dependencies:

$$T_{ij}^{E}=t_{follow\ ij}^{E}+t_{wait}^{E}=t_{follow\ ij}^{E}+\frac{I^{E}}{2};\quad T_{ij}^{CUST}=t_{follow\ ij}^{CUST}+t_{wait}^{CUST}=t_{follow\ ij}^{CUST}+\frac{I^{CUST}}{2}, \tag{14}$$

where I^E, I^{CUST} are buses intervals operating in express and normal modes, respectively, min.

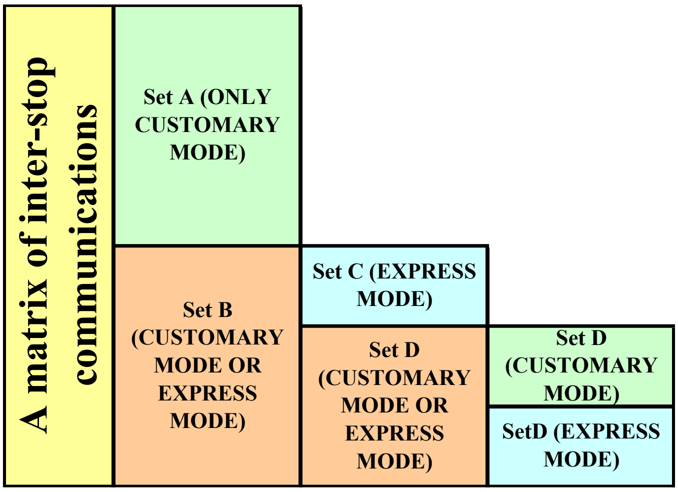

Fig. 2. Distribution A matrix of interstop communications between bus modes

The time for bus travel ($t^{E}_{follow\ \ ij}, t^{CUST}_{follow\ \ ij}$) in the appropriate mode consists of the time of traffic of buses t_{ij} between i-th and j-th stops and cost of downtime at the intermediate route stops:

$$t^{E}_{follow\ ij} = t_{\ ij} + t_{in} \cdot n^{E}_{stop\ ij} = t_{\ ij} + t_{in} \cdot \left[\left(\sum_{j=1}^{j} \lambda_j - \sum_{i=1}^{i} \lambda_i \right) \right]; \tag{15}$$

$$t^{CUST}_{follow\ \ ij} = t_{\ ij} + t_{in} \cdot n^{CUST}_{stop\ \ ij} = t_{\ ij} + t_{in} \cdot [(j\text{-}i)], \tag{16}$$

where $n^{E}_{stop\ ij}$, $n^{CUST}_{stop\ ij}$ are the number of intermediate bus stops on the path between i-th and j-th stop points for buses operating in express and normal modes, respectively.

The time of movement of buses between i-th and j-th stop points is, min.:

$$t_{ij} = \frac{60 \cdot L_{ij}}{V_t}, \tag{17}$$

where L_{ij} – the distance between i-th and j-th stop points, km:

$$L_{ij} = L_{i,j-1} + l_{j-1,j}\,. \tag{18}$$

To calculate the components of the matrices (17) and (18) buses intervals I^{E} and I^{CUST} determine by the following dependencies:

$$I^{E} = \frac{t^{E}_{rev}}{A^{E}}; \quad I^{CUST} = \frac{t^{CUST}_{rev}}{A^{CUST}}, \tag{19}$$

where t_{rev}^{E}, t_{rev}^{CUST} are the duration of buses turnover that operate in express and normal modes respectively, min:

$$t_{rev}^{E} = 2 \cdot \left(t_{follow}^{E} + t_{end} \right) = 2 \cdot \left(\sum_{i=1}^{n^E \in Z_i^E} \left(t_{i,i+1} + t_{in} \right) + t_{end} \right); \quad (20)$$

$$t_{rev}^{CUST} = 2 \cdot \left(t_{follow}^{CUST} + t_{end} \right) = 2 \cdot \left(\sum_{i=1}^{n^{CUST} \in Z_i^{CUST}} \left(t_{i,i+1} + t_{in} \right) + t_{end} \right), \quad (21)$$

where $n^E \in Z_i^E$, $n^{CUST} \in Z_i^{CUST}$ are the lists of stop points belonging to the express and normal route, respectively, min.

Number of trips performed by buses within an hour in express and normal modes, respectively:

$$\psi^E = \frac{60}{I^E}; \qquad \psi^{CUST} = \frac{60}{I^{CUST}}. \quad (22)$$

The total potential transport work performed by buses on the route and by appropriate modes of movement:

$$P_{potential} = P_{potential}^{CUST} + P_{potential}^{E}; \quad P_{potential}^{CUST} = q \cdot L_{route} \cdot \psi^{CUST}; \quad P_{potential}^{E} = q \cdot L_{route} \cdot \psi^{E}. \quad (23)$$

The total actual transport work performed by buses on the route and according to the appropriate modes of transportation:

$$P_{actual} = P_{actual}^{CUST} + P_{actual}^{E}; \quad (24)$$

$$P_{actual}^{CUST} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} q_{ij}^{CUST}(A) \cdot L_{ij} + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} q_{ij}^{CUST}(D) \cdot L_{ij}; \quad (25)$$

$$P_{actual}^{E} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} q_{ij}^{E}(A) \cdot L_{ij} + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} q_{ij}^{E}(D) \cdot L_{ij}. \quad (26)$$

The difference between the potential and actual transport work performed by buses on the route during the billing period:

$$W_N = P_{potential} - P_{actual}. \quad (27)$$

Bus capacity coefficients operating in normal and express motion modes:

$$\gamma^{CUST} = \frac{P_{actual}^{CUST}}{P_{potential}^{CUST}}; \qquad \gamma^{E} = \frac{P_{actual}^{E}}{P_{potential}^{E}}. \tag{28}$$

Total passengers' time spent on traveling using normal mode in the following directions $(i \to j) \in A$:

$$T^{CUST}(A) = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left[q_{ij}^{CUST}(A) \cdot \left(t_{follow\ ij}^{CUST} + \frac{I^{CUST}}{2} \right) \right]. \tag{29}$$

Total passengers' time spent on traveling using the express mode in the following directions $(i \to j) \in C$:

$$T^{E}(C) = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left[q_{ij}^{E}(C) \cdot \left(t_{follow\ ij}^{E} + \frac{I^{E}}{2} \right) \right]. \tag{30}$$

Total passengers' time spent on traveling using the normal mode in the following directions $(i \to j) \in D^{CUST}$:

$$T^{CUST}\left(D^{CUST}\right) = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left[q_{ij}^{CUST}\left(D^{CUST}\right) \cdot \left(t_{follow\ ij}^{CUST} + \frac{I^{Average}}{2} \right) \right]. \tag{31}$$

Total passengers' time spent on traveling using the express mode in the following directions $(i \to j) \in D^{E}$:

$$T^{E}\left(D^{E}\right) = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left[q_{ij}^{E}\left(D^{E}\right) \cdot \left(t_{follow\ ij}^{E} + \frac{I^{Average}}{2} \right) \right]. \tag{32}$$

In expressions (31) and (32) passengers' time spent waiting is calculated on the basis of the value of the average movement interval for both modes $I^{Average}$:

$$I^{Average} = \frac{I^{CUST} \cdot I^{E}}{(I^{CUST} + I^{E})}. \tag{33}$$

Total passengers' time spend traveling on the route:

$$\sum T = T^{CUST}(A) + T^{E}(C) + T^{CUST}\left(D^{CUST}\right) + T^{CUST}\left(D^{CUST}\right). \tag{34}$$

5. A procedure for finding rational parameters.

Considering the fact that not all passenger correspondence can be serviced by the express mode, it is advisable to introduce a combined mode that combines both modes: the express and normal.

The essence of the method of determining the rational parameters of such a mode lies in the mathematical modelling of the process of transportation on the route, which calculates the components of models (27-28) and (34) for (6) combinations of stops of express route and the number of buses operating in normal A^{CUST} and express A^{E} modes. In the future, on the basis of the formed criterion, such parameters of route work, which are characterized by the maximum efficiency and quality of transportation, are selected.

According to the restriction on the maximum permissible interval of conventional buses (35), the modeling must be carried out for several data groups (36).

$$A_{\min}^{CUST} = \frac{t_{rev}^{CUST}}{I_{\max}^{Allowable}}, \tag{35}$$

where $A_{\min}^{CUST}$ is the minimum allowable number of buses operating in the normal mode, provided that the maximum permissible movement interval $I_{\max}^{Allowable}$ is not exceeded (in urban conditions it should not exceed 15… 20 minutes).

$$\begin{cases} A^{CUST} = const \in \left[A_{\min}^{CUST};\ A-1\right]; \\ A^{E} \in \mathrm{var}\left[1;\ A - A^{CUST}\right]. \end{cases} \tag{36}$$

By changing the combination of stops on the express route Z_i and the number of buses operating in normal A^{CUST} and express A^{E} modes, one can obtain the set of values W_N that was chosen as the main criterion for transportation efficiency:

$$\begin{vmatrix} W_N{}^{Z_i}\left(A^{CUST} = A_{\min}^{CUST},\ A^{E} = 1\right), \ldots\ W_N{}^{Z_i}\left(A^{CUST} = A_{\min}^{CUST},\ A^{E} = A - A^{CUST}\right) \\ W_N{}^{Z_i}\left(A^{CUST} = A_{\min}^{CUST} + 1,\ A^{E} = 1\right), \ldots\ W_N{}^{Z_i}\left(A^{CUST} = A_{\min}^{CUST} + 1,\ A^{E} = A - A^{CUST}\right) \\ W_N{}^{Z_i}\left(A^{CUST} = A_{\min}^{CUST} + 2,\ A^{E} = 1\right), \ldots\ W_N{}^{Z_i}\left(A^{CUST} = A_{\min}^{CUST} + 2,\ A^{E} = A - A^{CUST}\right) \\ W_N{}^{Z_i}\left(A^{CUST} = A_{\min}^{CUST} + 3,\ A^{E} = 1\right), \ldots\ W_N{}^{Z_i}\left(A^{CUST} = A_{\min}^{CUST} + 3,\ A^{E} = A - A^{CUST}\right) \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ W_N{}^{Z_i}\left(A^{CUST} = A-1,\ A^{E} = 1\right), \ldots\ W_N{}^{Z_i}\left(A^{CUST} = A-1,\ A^{E} = A - A^{CUST}\right) \end{vmatrix}. \tag{37}$$

The results obtained allow us to determine the area of acceptable values W_N. It should be noted that the function $W_N = f\left(Z_i,\ A^{CUST},\ A^{E}\right)$ is discrete in nature, since the number A^{COST} and A^{E} are the whole values. From above, this area is limited to the level that determines the option of organizing transportation on the route using only the usual mode of traffic. Exceeding this limit, in terms of the selected performance criterion $W_N \to \min$ when organizing express mode on the route is inappropriate. The bottom is limited to the level $W_N \geq 0$, as with negative value W_N s, the potential transport work on the route is less than the actual one. The implementation of such options for express traffic will worsen the quality of the transport service due to the increase in the coefficients of use of bus capacity beyond normalized values. In the future, one option will be selected from the plural $W_N = f\left(Z_i,\ A_i^{CUST},\ A_i^E\right)$ under conditions $A_i^{CUST} = const$ and $Z_i = const$ for further research only one variant is selected, which provides $W_N \to \min$ at $W_N \geq 0$.

It should be noted that the reduction W_N can be achieved in various variants of the organization of the express mode, including those that are unacceptable, both in terms of the quality of transport service of passengers and in view of economic feasibility for transport enterprises. In practice, it is almost impossible fill the busses with on the route with fullness the buses $\gamma > 1{,}5$, and a significant difference in the operating conditions of the modes will lead to uneven provision of transport services and the cost-effectiveness of transportation. For a comprehensive assessment of the obtained i-th variants of the combined mode with express mode the authors in [1] proposed to use a criterion that additionally takes into account the quality of transportation: $\gamma_i^E < 1{,}5$; $\gamma_i^{CUST} < 1{,}5$; $\sum T \to \min$; and an additional economic effect that will be observed in case of minimal difference in the conditions of operation of both modes and the desire of coefficients of use of bus capacity to $\gamma^{CUST} \to 1$ and $\gamma^E \to 1$:

$$K_i^{Complex} = \begin{cases} 0, \ if\ K_i(\gamma) = 0 \\ K_i(W_N) + K_i(\gamma) + K_i\left(\sum T\right), \ if\ K_i(\gamma) > 0 \end{cases} \to \min, \tag{38}$$

where $K_i(W_N)$ is an indicator that takes into account the decrease W_N; $K_i(\gamma)$ is an indicator that takes into account the fullness of buses; $K_i\left(\sum T\right)$ is an indicator that takes into account the reduction of the total time spent by passenger for movement.

The structure of the complex criterion (38) is given on (39-42):

$$K_i(W_N) = \begin{cases} 1.00, \ if\ W_N^i = W_N^{\min} \\ 2.00, \ if\ W_N^i = W_N^{\max} \\ \left(1 + \dfrac{W_N^i - W_N^{\min}}{W_N^{\max} - W_N^{\min}}\right), \ if\ W_N^{\min} < W_N^i < W_N^{\max} \end{cases}; \tag{39}$$

$$K_i(\gamma) = \begin{cases} 0, \ if\ K_i\left(\gamma_i^{CUST}\right) = 0 \ or\ K_i\left(\gamma_i^E\right) = 0 \\ K_i\left(\gamma_i^{CUST}\right) + K_i\left(\gamma_i^E\right), \ if\ K_i\left(\gamma_i^{CUST}\right) > 0 \ and\ K_i\left(\gamma_i^E\right) > 0 \end{cases}; \tag{40}$$

$$K_i\left(\gamma_i^{CUST}\right) = \begin{cases} 0, \ if\ \gamma_i^{CUST} \geq 1{,}5 \\ \gamma_i^{CUST}, \ if\ \gamma_i^{CUST} > 1 \\ \left(1 + \left[1 - \gamma_i^{CUST}\right]\right), \ if\ \gamma_i^{3B} < 1 \end{cases}; \qquad K_i\left(\gamma_i^E\right) = \begin{cases} 0, \ if\ \gamma_i^E \geq 1{,}5 \\ \gamma_i^E, \ if\ \gamma_i^E > 1 \\ \left(1 + \left[1 - \gamma_i^E\right]\right), \ if\ \gamma_i^E < 1 \end{cases} \tag{41}$$

$$K_i\left(\sum T\right)=\begin{cases}1{,}00, & if \quad \sum T_i=\sum T^{\min}\\ 2{,}00, & if \quad \sum T_i=\sum T^{\max}\\ \left(1+\dfrac{\sum T_i-\sum T^{\min}}{\sum T^{\max}-\sum T^{\min}}\right), & if \quad \sum T^{\min}<\sum T_i<\sum T^{\max}\end{cases}. \tag{42}$$

The use of the proposed complex criterion (38) enables the determination of rational parameters for express traffic on city bus routes, which ensure the improvement of the efficiency of vehicles and the quality of passenger service.

Summarizing the results of the study, the authors developed an algorithm for determining the rational parameters of the express buses in urban conditions, which is given in Fig. 3.

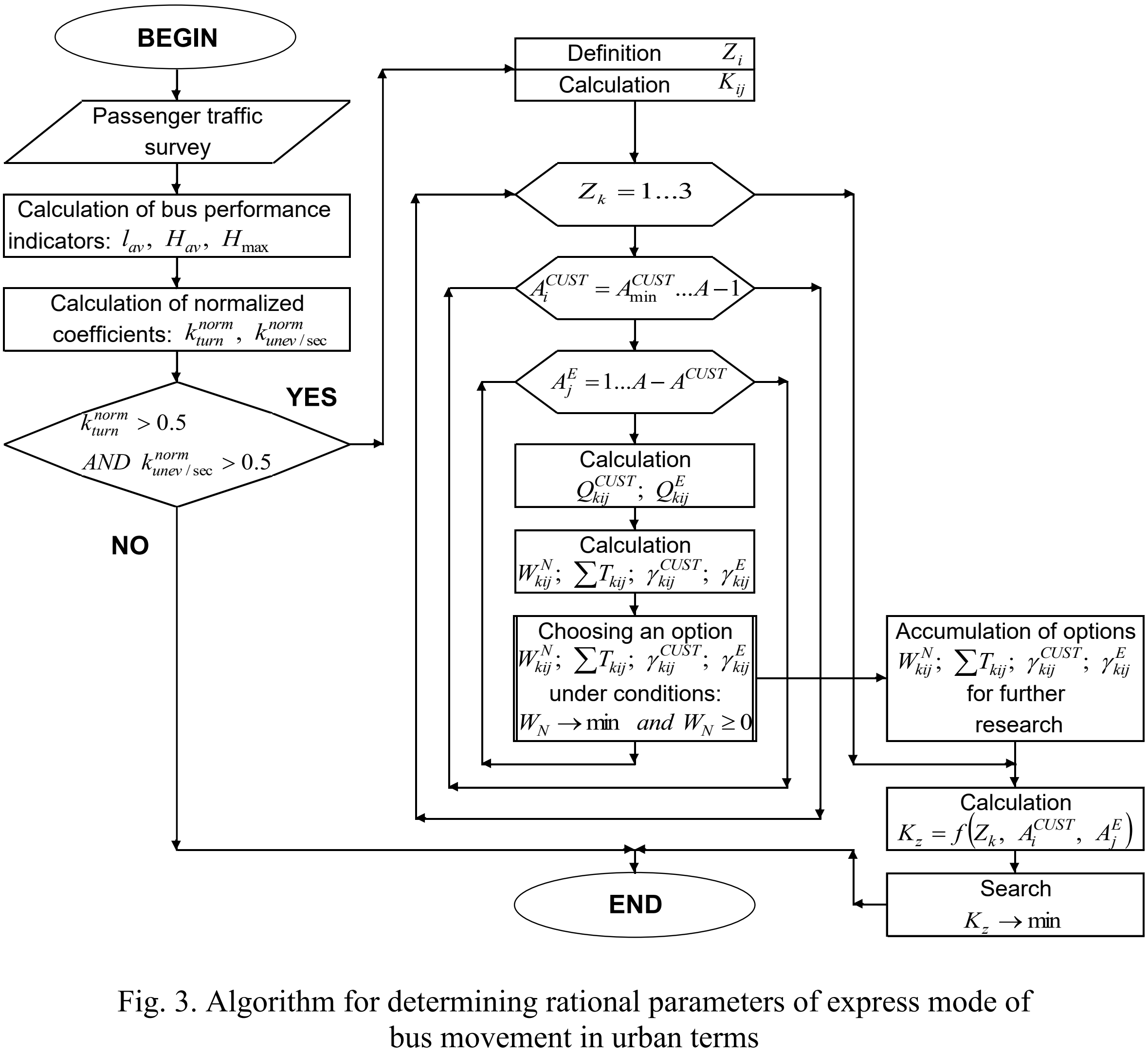

Fig. 3. Algorithm for determining rational parameters of express mode of bus movement in urban terms

4. RESULTS AND DISCUSSION

The testing of the developed algorithm for determining the rational parameters of the express bus movement was carried out in the conditions of Dnipro. City route No. 155 (Topolia-3-Vokzalna Square) was selected as the object of study. The route operates 25 buses BAZ A81 for $q = 46$ passengers in normal mode. The main characteristics of route No. 155 are shown in Table 1.

Tab. 1

The main characteristics of route No. 155

Indicator	value
The length of the route L_{route}, km	20.4
The duration of bus turnover t_{rev}, min.	126
Technical speed V_t, km per hour.	19.4
Number of stops on the route n_{stop}, units.	27
Bus movement interval (morning "peak"), min	5
The capacity provided on the route Q_{Given} (morning "peak"), pass	552

The survey of passenger traffic on route No. 155 was conducted using the tabular method in the morning "peak" in the direct (most loaded) direction of Topolia-3 → Vokzalna Square. Figure 4 shows a compatible analysis of passenger traffic flaws by route $H_{j,j+1}$ and passenger exchange at stop points Q_j, which shows that the capacity provided on the route Q_{Given} is sufficient for the assimilation of passenger traffic on the most loaded section of the route $Q_{Given} > H_{\max}$, and the passenger exchange of stop points is characterized by significant unevenness.

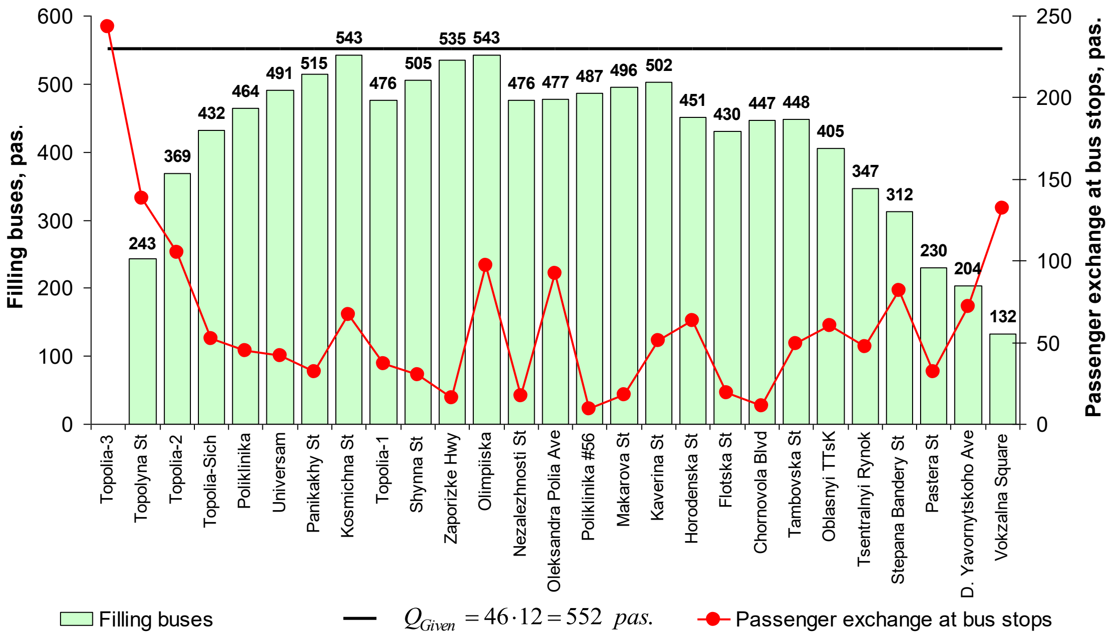

Fig. 4. Compatible analysis of passenger traffic and passenger exchange at stop points

On the other hand, the release of a route of such a number of buses that provides maximum passenger traffic only on the loaded route only, leads to their lack of use in other route parts, which leads to a decrease in the coefficient of use of bus capacity, and therefore increases the cost of transportation.

The structure of distribution of transport work on the route is shown in Figure 5, the analysis of which shows that the vast majority of the route parts have a share of unproductive transport work W_N (27) ranging from 10 to 70%. In general, on the route, potential transport work (23) is $P_{potential} = 11260.8$ pass.·km, and the actual is $P_{actual} = 8789.6$ pass.·km (according to the survey). Thus, $W_N = 2471.2$ which is 23% of $P_{potential}$. This situation significantly reduces the efficiency of transportation.

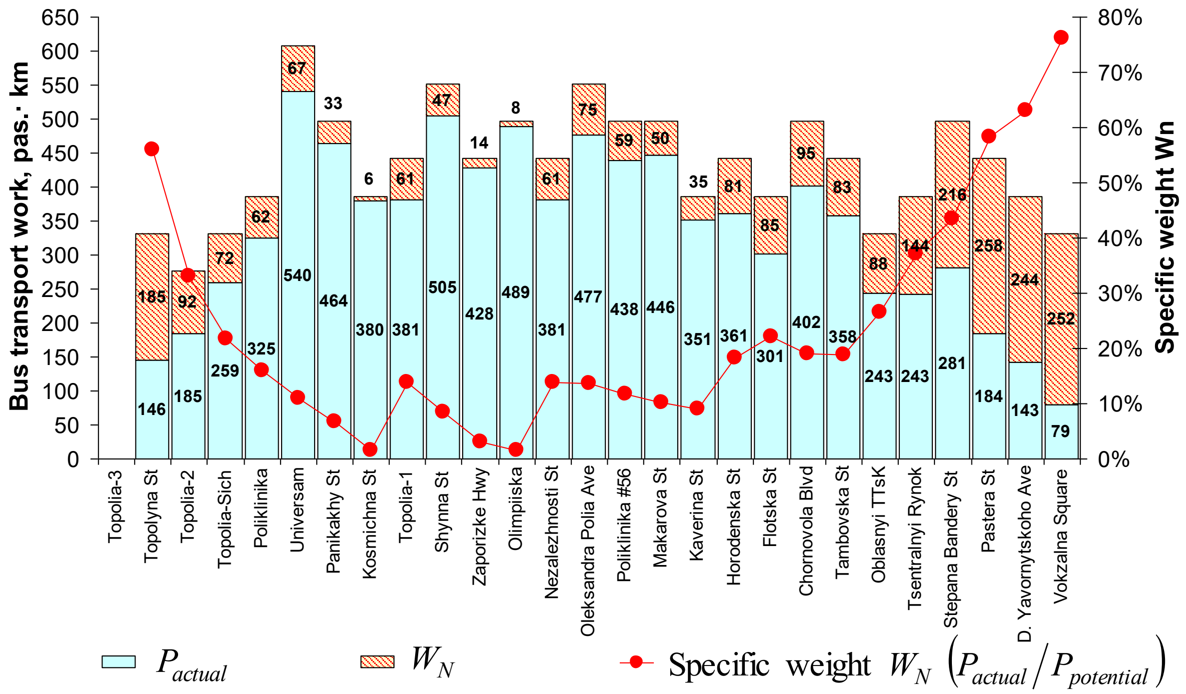

Fig. 5. Structure of distribution of transport work on route №155

However, reducing the number of buses on the route will result in vehicles being more than fully loaded and even refusing passengers, which will reduce the quality of the transportation service. Thus, there is a need to introduce a combined mode of transportation with express service on route No. 155, which will release part of the vehicles (by increasing their capacity) and reduce the total cost of passengers on the trip (by increasing the speed of bus connection).

Also, according to the results of the survey, it was found that: the value of the maximum passenger traffic on the route is $H_{\max} = 543$ pass; medium passenger traffic is $H_{av} = 421.5$ pass; the average length of passenger trip $l_{av} = 10{,}6$ km; passengers' variance ratio $\eta_{turn} = 1.92$. The values calculated for (1-2) normalized varieties k_{turn}^{norn} and uneven passenger traffic on the route $k_{unev/\sec}^{norm}$ (which determine the conditions of organization of the relevant modes of traffic on bus routes) are 0.52 and 0.77, respectively, which confirms the feasibility of introducing of the combined mode with the express mode on the route No. 155 (fig. 1).

On the basis of the conditions (6), three options for the express route consisting of $Z_1 = 8$, $Z_2 = 13$, and $Z_3 = 16$ stops were formed:

- $Z_1\left(\frac{F_j}{Q_j} < I\right)$ – 8 stop points:

$$1 \to 2 \to 3 \to 12 \to 14 \to 24 \to 26 \to 27;$$

- $Z_2\left(\frac{F_j}{Q_j} < 1{,}5I\right)$ – 13 stop points:

$$1 \to 2 \to 3 \to 8 \to 12 \to 14 \to 18 \to 22 \to 24 \to 23 \to 25 \to 26 \to 27;$$

- $Z_3\left(\frac{F_j}{Q_j} < 2I\right)$ – 16 stop points:

$$1 \to 2 \to 3 \to 4 \to 8 \to 12 \to 14 \to 17 \to 18 \to 21 \to 22 \to 24 \to 23 \to 25 \to 26 \to 27.$$

Since the working trip duration on the route is $t_{rev}^{CUST} = 126$ minutes, and the maximum permissible interval of buses in urban conditions is $I_{\max}^{Allowable} = 20$ minutes, for (35) $A_{\min}^{CUST} = 6$ buses. Mathematical modeling of the process of transportation for (9-34) was performed under the conditions (36) for $Z_1 = 8$, $Z_2 = 13$ and $Z_3 = 16$ stops. Selected for further research options, which provide $W_N \to \min$ at $W_N \geq 0$ under conditions $A_i^{CUST} = const$ and $Z_i = const$ are shown in figures (6-8). Figure 9 shows a compatible analysis of the distribution of the number of passengers transported (according to modes) and the total passengers' time spent on the trip.

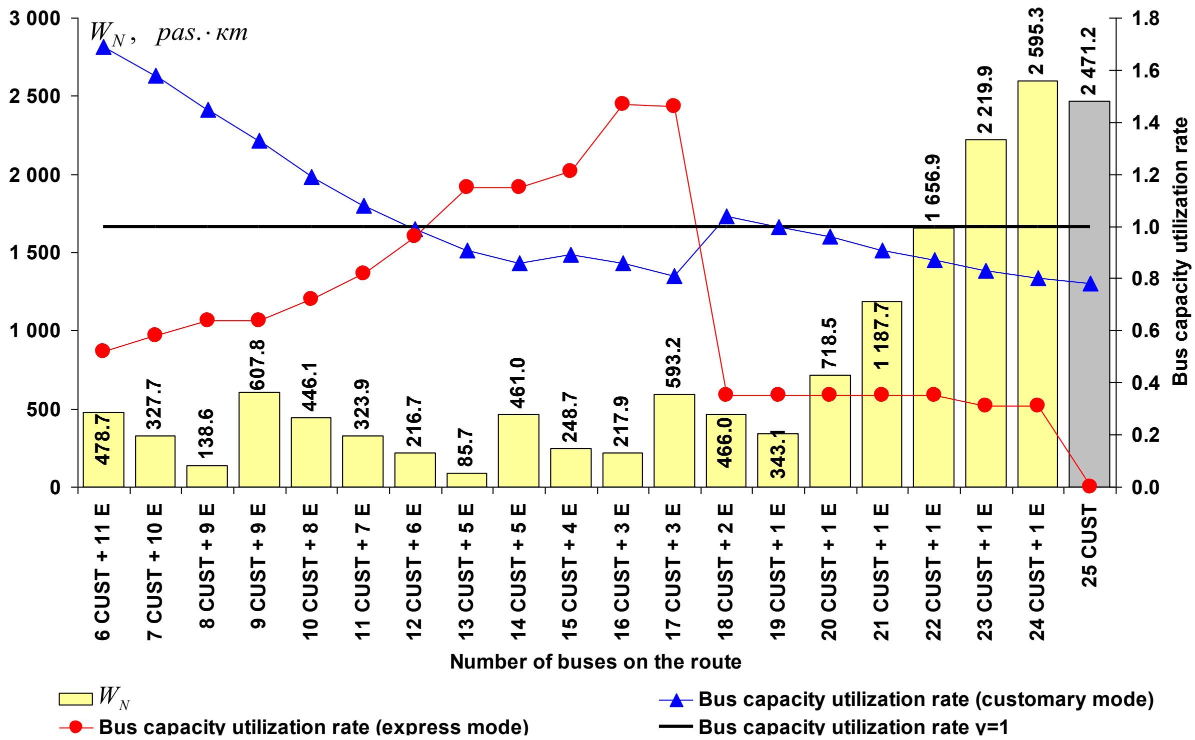

Fig. 6. A compatible distribution analysis W_N, γ^{CUST} and γ^{E} for $Z_1 = 8$

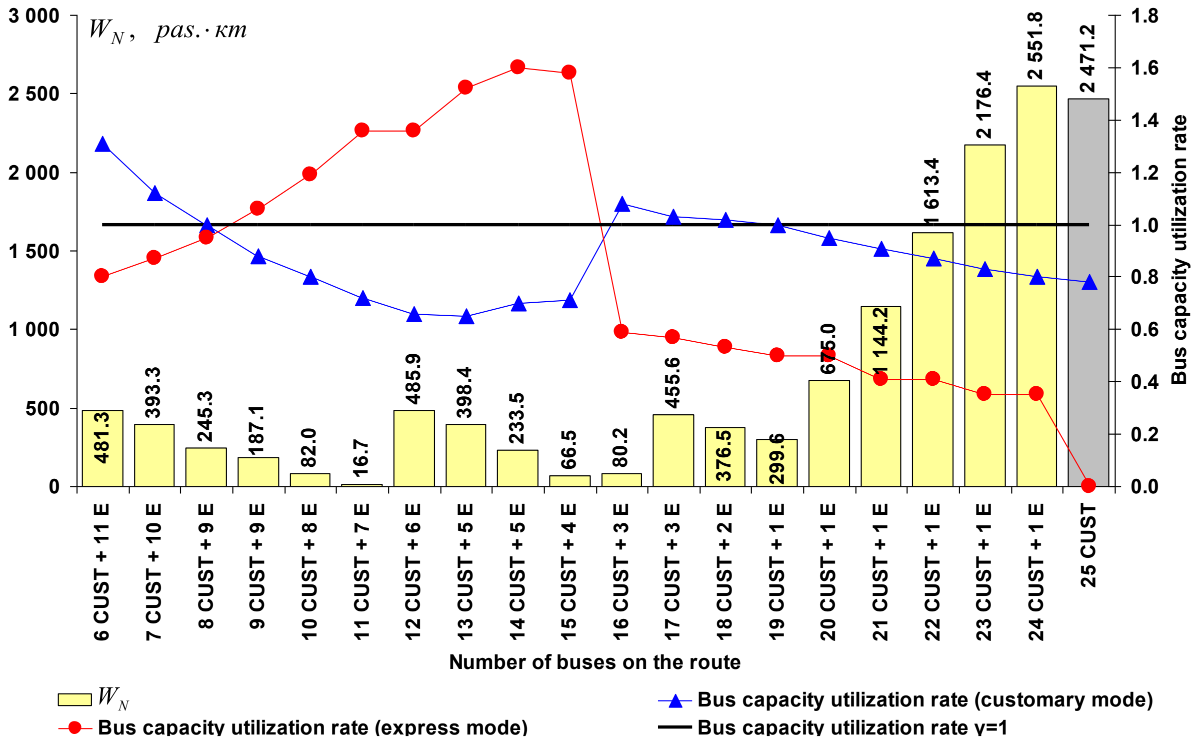

Fig. 7. A compatible distribution analysis W_N, γ^{CUST} and γ^{E} for $Z_2 = 13$

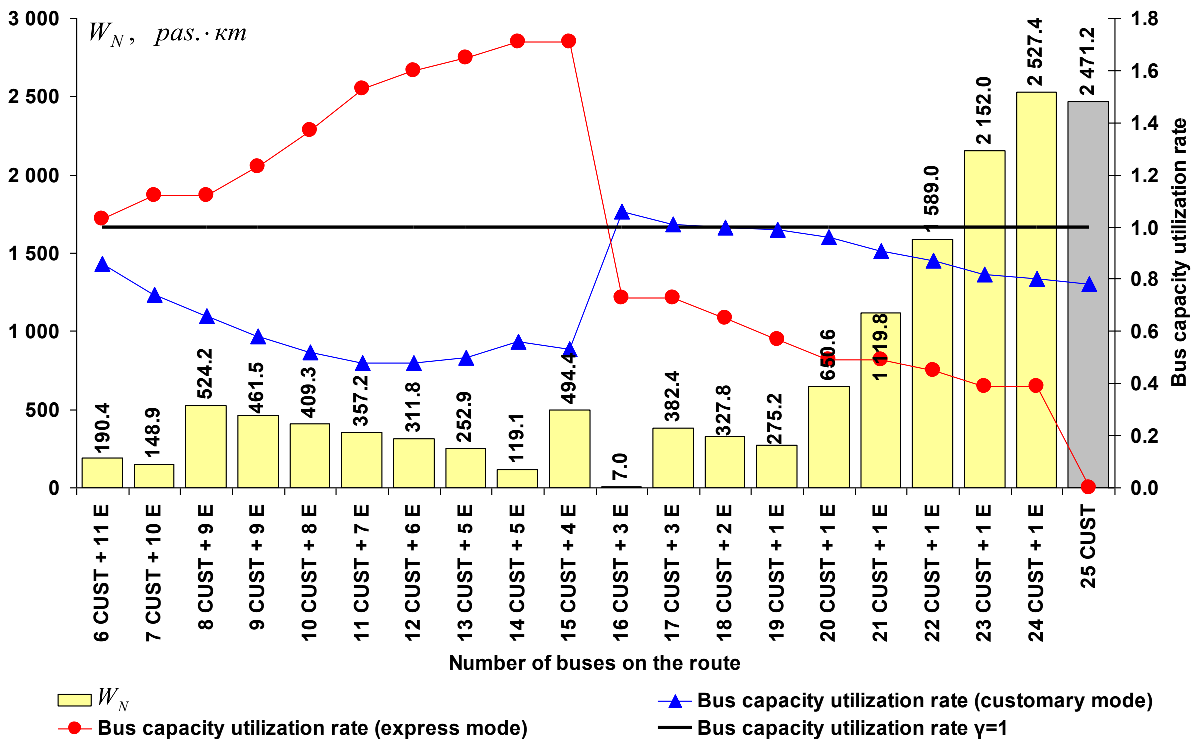

Fig. 8. A compatible distribution analysis W_N, γ^{CUST} and γ^{E} for $Z_3 = 16$

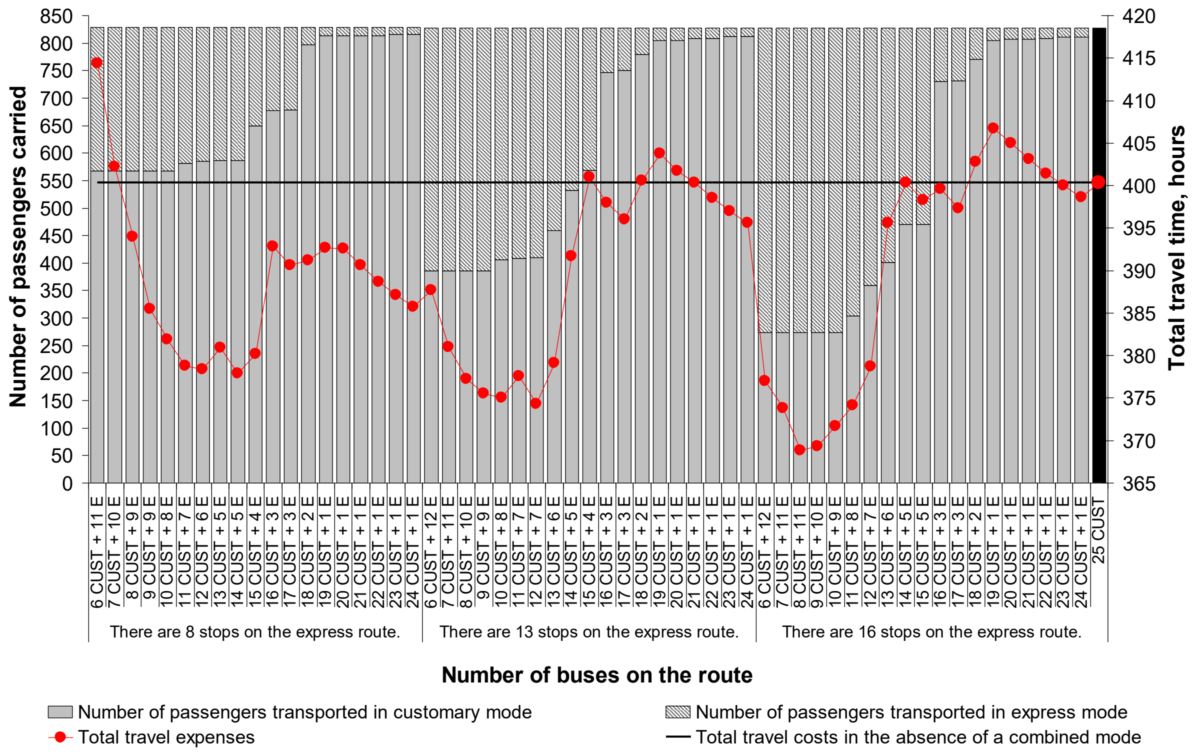

Fig. 9. A compatible analysis of the distribution of the number of passengers transported (according to motion modes) and the total time spent moving.

Analysis of figures (6-9) allows one to draw the following conclusions:

- increasing the number of stops on an express route leads to an increase in the number of passengers using it: $Q^E(Z_1=8)=262$ pass, $Q^E(Z_2=13)=441$ pass, $Q^E(Z_3=16)=553$ pass., which is 32%, 53% and 67% of the total number of passengers, respectively;
- for the vast majority of ratios A^{3B} and A^E there is a reduction in the total travel time by an average of 10%;
- operation of fewer than 3…4 express buses leads to passengers refusing the express service due to a significant increase in waiting time.

The results of the calculations of the complex criterion $K_i^{Complex}$ for (38) are shown in Figure 10, indicating that the maximum efficiency of the passenger transportation process on route No. 155 can be achieved with the following two combined mode variants: $(Z_1=8,\ A^{CUST}=12,\ A^E=6)$ and $(Z_2=13,\ A^{CUST}=8,\ A^E=10)$. These variants will release 28% of vehicles, reduce W_N by 89%, reduce the total expenses of passengers for movement by 6%, increase the speed of connection and the coefficient of bus capacity usage by 15% and 24%, respectively. A comprehensive assessment of the parameters of the express mode of movement of buses on route No. 155 from the standpoint of technological transportation efficiency is given in Table 2. The analysis of the information, which is given in Table 2, shows that both of the proposed options allow for a significant improvement of the efficiency of the transportation process on route No. 155.

Given that the combined modes under study are formed by a combination of normal and express modes, the general technical and operational indicators for buses TOI_i were calculated as average weighted values according to the number of ordinary and express trips:

$$TOI_i = \frac{TOI_i^{CUST} \cdot \psi^{CUST} + TOI_i^{E} \cdot \psi^{E}}{\psi^{CUST} + \psi^{E}}. \tag{43}$$

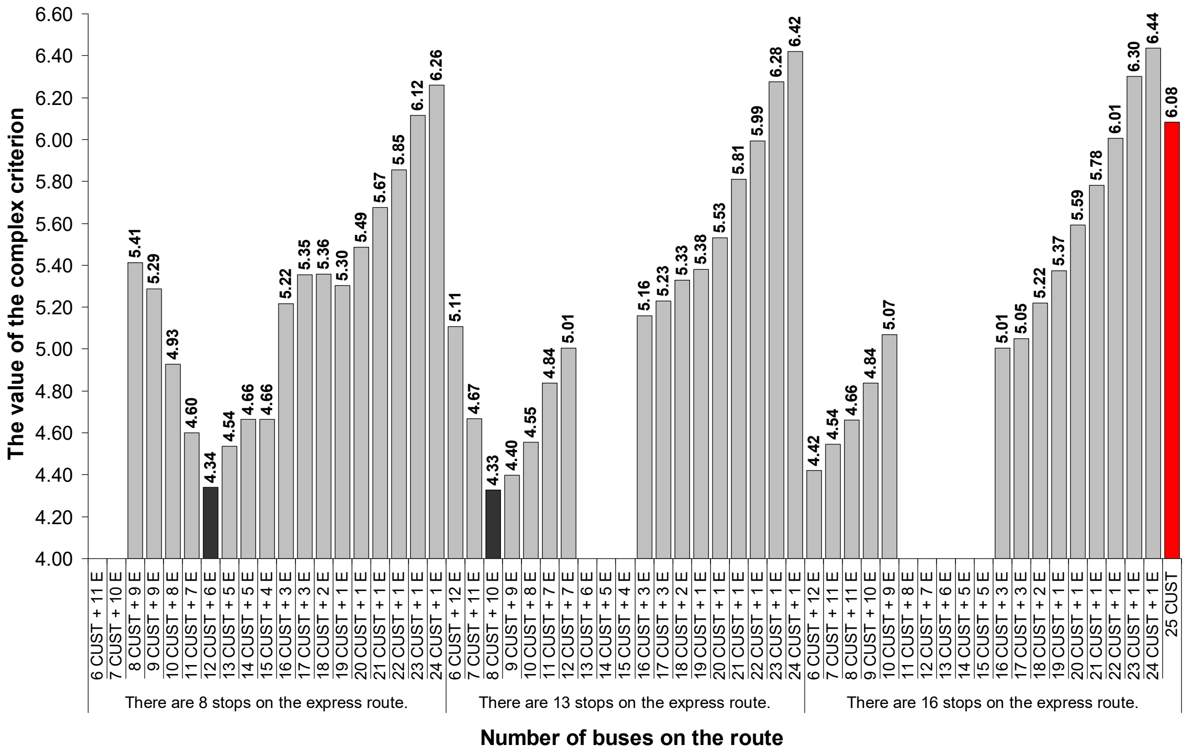

Fig. 10. Results of calculations of a complex criterion $K_i^{Complex}$

However, it should be noted that releasing of part of the buses on route No. 150 will lead to certain but insignificant, negative phenomena. Prior to the implementation of combined modes, the traffic interval on the route was 5 minutes, and after – 6 minutes, which can be considered acceptable and typical for most city bus routes. Also, in some route parts, there will be an exceeding of the rated bus capacity (mainly on the normal mode) by 10-25%. Such overtime fullness of vehicles does not exceed the accepted standard of 8 passengers per 1 m^2 of the free space in the salon and, accordingly, will not lead to passengers being refuse service at stop points along the route. It is considered acceptable in terms of transportation quality during the morning "peak".

Tab. 2

Evaluation of express mode parameters on the route from the point of view of technological transportation efficiency

<table>
<tr><td rowspan="4">Indicator</td><td rowspan="2">Active technology</td><td colspan="3">Combined mode №1</td><td colspan="3">Combined mode №2</td></tr>
<tr><td colspan="3">$Z_1 = 8,\ A^{CUST} = 12,\ A^{E} = 6$</td><td colspan="3">$Z_2 = 13,\ A^{CUST} = 8,\ A^{E} = 10$</td></tr>
<tr><td rowspan="2">CUST</td><td colspan="2">Mode</td><td rowspan="2">Δ</td><td colspan="2">Mode</td><td rowspan="2">Δ</td></tr>
<tr><td>CUST</td><td>E</td><td>CUST</td><td>E</td></tr>
<tr><td rowspan="2">Length route, km</td><td rowspan="2">20.4</td><td>20.4</td><td>20.4</td><td rowspan="2">0.0%</td><td>20.4</td><td>20.4</td><td rowspan="2">0.0%</td></tr>
<tr><td colspan="2">20.4</td><td colspan="2">20.4</td></tr>
<tr><td rowspan="2">Number of buses, units</td><td rowspan="2">25</td><td>12</td><td>6</td><td rowspan="2">-28.0%</td><td>8</td><td>10</td><td rowspan="2">-28.0%</td></tr>
<tr><td colspan="2">18</td><td colspan="2">18</td></tr>
<tr><td rowspan="2">Number of stops, units.</td><td rowspan="2">27</td><td>27</td><td>8</td><td rowspan="2">-28.1%</td><td>27</td><td>13</td><td rowspan="2">-31.1%</td></tr>
<tr><td colspan="2">19.4</td><td colspan="2">18.6</td></tr>
<tr><td rowspan="2">Medium length of route part, km</td><td rowspan="2">0.78</td><td>0.78</td><td>2.91</td><td rowspan="2">109.2%</td><td>0.78</td><td>1.70</td><td rowspan="2">70.8%</td></tr>
<tr><td colspan="2">1.6</td><td colspan="2">1.3</td></tr>
<tr><td rowspan="2">Speed, km/h.</td><td rowspan="2">21.1</td><td>21.1</td><td>29.1</td><td rowspan="2">15.2%</td><td>21.1</td><td>26.6</td><td rowspan="2">15.6%</td></tr>
<tr><td colspan="2">24.3</td><td colspan="2">24.4</td></tr>
<tr><td rowspan="3">Operating speed, km/h.</td><td rowspan="3">19.4</td><td>19.4</td><td>26.0</td><td rowspan="3">13.6%</td><td>19.4</td><td>24.0</td><td rowspan="3">14.2%</td></tr>
<tr><td colspan="2">22.0</td><td colspan="2">22.2</td></tr>
<tr><td colspan="2">57</td><td colspan="2">56</td></tr>
<tr><td rowspan="2">Duration of turnover, min.</td><td rowspan="2">126</td><td>126</td><td>94</td><td rowspan="2">-10.2%</td><td>126</td><td>102</td><td rowspan="2">-11.4%</td></tr>
<tr><td colspan="2">113</td><td colspan="2">112</td></tr>
<tr><td rowspan="2">Movement interval, min.</td><td rowspan="2">5</td><td>10</td><td>15</td><td rowspan="2">20.0%</td><td>15</td><td>10</td><td rowspan="2">20.0%</td></tr>
<tr><td colspan="2">6</td><td colspan="2">6</td></tr>
<tr><td rowspan="2">Number of departures, units</td><td rowspan="2">12</td><td>6</td><td>4</td><td rowspan="2">-16.7%</td><td>4</td><td>6</td><td rowspan="2">-16.7%</td></tr>
<tr><td colspan="2">10</td><td colspan="2">10</td></tr>
<tr><td rowspan="2">Provided capacity, pass.</td><td rowspan="2">552</td><td>276</td><td>184</td><td rowspan="2">-16.7%</td><td>184</td><td>276</td><td rowspan="2">-16.7%</td></tr>
<tr><td colspan="2">460</td><td colspan="2">460</td></tr>
<tr><td rowspan="2">Number of passengers transported pass.</td><td rowspan="2">829</td><td>585</td><td>244</td><td rowspan="2">0.0%</td><td>386</td><td>443</td><td rowspan="2">0.0%</td></tr>
<tr><td colspan="2">829</td><td colspan="2">829</td></tr>
<tr><td rowspan="2">Unproductive transport work, pass. km</td><td rowspan="2">2 471.2</td><td>62.6</td><td>154.1</td><td rowspan="2">-91.2%</td><td>1.3</td><td>244.0</td><td rowspan="2">-90.1%</td></tr>
<tr><td colspan="2">216.7</td><td colspan="2">245.3</td></tr>
<tr><td rowspan="2">The coefficient of using bus capacity</td><td rowspan="2">0.78</td><td>0.99</td><td>0.96</td><td rowspan="2">25.4%</td><td>1.00</td><td>0.95</td><td rowspan="2">24.4%</td></tr>
<tr><td colspan="2">0.98</td><td colspan="2">0.97</td></tr>
<tr><td rowspan="2">Total buses work, km</td><td rowspan="2">244.8</td><td>122.4</td><td>81.6</td><td rowspan="2">-16.7%</td><td>81.6</td><td>122.4</td><td rowspan="2">-16.7%</td></tr>
<tr><td colspan="2">204.0</td><td colspan="2">204.0</td></tr>
<tr><td rowspan="2">Bus productivity, pass/hour.</td><td rowspan="2">66</td><td>93</td><td>78</td><td rowspan="2">31.8%</td><td>92</td><td>87</td><td rowspan="2">34.8%</td></tr>
<tr><td colspan="2">87</td><td colspan="2">89</td></tr>
<tr><td rowspan="2">Fuel consumption, l/100 km</td><td rowspan="2">26.24</td><td>26.24</td><td>19.83</td><td rowspan="2">-9.8%</td><td>26.24</td><td>21.5</td><td rowspan="2">-10.8%</td></tr>
<tr><td colspan="2">23.68</td><td colspan="2">23.40</td></tr>
<tr><td>Hourly fuel consumption, l/h.</td><td>64.24</td><td>32.12</td><td>16.18</td><td>-24.8%</td><td>21.41</td><td>26.32</td><td>-25.7%</td></tr>
</table>

5. CONCLUSIONS

The study is devoted to the development of an algorithm to determine the optimal parameters for the express buses operating in urban areas. Rational parameters include the number of buses on the route operating in express A^E and normal (stop-based) A^{CUST} modes, as well as the list of stops Z_i at which express buses stop. The implementation of such measures can significantly improve the quality of transport services and transportation efficiency. The study identifies the list of required initial data to implement the problem. The developed algorithm consists of the following expanded blocks: verification of the expediency of introducing an express mode of traffic, determining the list of stops on the express route, restoring the matrix of interstop correspondence, redistributing passengers on the route between modes of traffic, and calculating the technical and operational indicators of bus operation.

The testing of the developed algorithm for determining the rational parameters of the express movement was carried out in the conditions of Dnipro. City route No. 155 (Topolia-3-Vokzalna Square) was selected as the object of study. The route operates 25 BAZ A81 buses with capacity of $q = 46$ passengers in normal mode.

According to the results of the survey of passenger traffic, it was found that the vast majority of the route parts the share of unproductive transport work W_N is from 10 to 70% (on average on a route 23%), which significantly reduces the efficiency of buses. The calculated values of normalized variability and the uneven passenger traffic ratio on the route (which determine the conditions for the organization of the relevant modes of traffic on bus routes) are 0.52 and 0.78, respectively, which confirms the expediency of introducing on route No. 155 of the combined mode with express.

Three options for the express route consisting of $Z_1 = 8$, $Z_2 = 13$ and $Z = 16$ stops were formed. According to the results of the mathematical modeling, it was found that the maximum efficiency of the passenger transportation process on route №155 can be achieved in the following two variants of the combined mode with express: ($Z_1 = 8,\ A^{CUST} = 12,\ A^E = 6$) and ($Z_2 = 13,\ A^{CUST} = 8,\ A^E = 10$). This will release 28% of vehicles (28%), increase the speed of connection by 15%, the coefficient of use of bus capacity by 24%, and increase hourly productivity by 35%. They would also reduce the flight duration by 10%; Taking into account the lower fuel costs of buses operating in express mode, the total operating fuel costs would decrease by 25%.

References

1. Taran I., V. Litvin. 2019. „Determination of rational parameters for urban bus route with combined operating mode”. *Transport Problems* 13(4): 158-171. DOI: 10.20858/tp.2018.13.4.14
2. Wang X., T. Zhou, R. Dai, B. Xue, Y. Sun. 2025. „Integrated design and optimization of customized bus travel services for urban commuting”. *Transportation Letters*: 1-14. DOI: 10.1080/19427867.2025.2491532.
3. Jin, Z., H. Mao, D. Chen, H. Li, H. Tu, Y. Yang, M. Attard. 2024. „Multi-objective optimization model of autonomous minibus considering passenger arrival reliability and travel risk”. *Communications in Transportation Research* 4: 100152. DOI: 10.1016/j.commtr.2024.100152.

4. Eriksson E.-L., H. Lidestam, L. Winslott Hiselius. 2023. „Effects on operating costs of adjusting bus departure times during peak-hour traffic in Sweden”. *Research in Transportation Economics* 100: 101327. DOI: 10.1016/j.retrec.2023.101327.
5. Chen Y.-H., Y. Cheng, G.-L. Chang. 2021. „Incorporating bus delay minimization in design of signal progression for arterials accommodating heavy mixed-traffic flows”. *Journal of Intelligent Transportation Systems* 27(2): 187-216. DOI: 10.1080/15472450.2021.2002149.
6. Khakimov B., S. Tanaka. 2024. „Evaluation of the impact of exclusive bus lanes on traffic in Tashkent”. *Asian Transport Studies* 10: 100151. DOI: 10.1016/j.eastsj.2024.100151.
7. Chen X., X. Lin, M. Li, F. He. 2022. „Network-level control of heterogeneous automated traffic guaranteeing bus priority”. *Transportation Research Part C: Emerging Technologies* 140: 103671. DOI: 10.1016/j.trc.2022.103671.
8. Ai G., X. Zuo, G. Chen, B. Wu. 2022. „Deep Reinforcement Learning based dynamic optimization of bus timetable”. *Applied Soft Computing* 131: 109752. DOI: 10.1016/j.asoc.2022.109752.
9. Oliveira R., P.F. Lima, G. Collares Pereira, J. Martensson, B. Wahlberg. 2019. „Path Planning for Autonomous Bus Driving in Highly Constrained Environments”. *IEEE Intelligent Transportation Systems Conference (ITSC)*: 2743-2749. DOI: 10.1109/itsc.2019.8916773.
10. Wei Y., N. Jiang, Z. Li, D. Zheng, M. Chen, M. Zhang. 2022. „An Improved Ant Colony Algorithm for Urban Bus Network Optimization Based on Existing Bus Routes”. *ISPRS International Journal of Geo-Information* 11 (5): 317. DOI: 10.3390/ijgi11050317.
11. Khan Z., S. Fang, A. Koubaa, P. Fan, F. Abbas, H. Farman. 2020. „Street-centric routing scheme using ant colony optimization-based clustering for bus-based vehicular ad-hoc network”. *Electrical Engineering* 86: 106736. DOI: 10.1016/j.compeleceng.2020.106736.
12. Euchi J., R. Mraihi. 2012. „The urban bus routing problem in the Tunisian case by the hybrid artificial ant colony algorithm”. *Swarm and Evolutionary Computation* 2: 15-24. DOI: 10.1016/j.swevo.2011.10.002.
13. Zhen L., W. Gu. 2024. „Feeder bus service design under spatially heterogeneous demand”. *Transportation Research Part A: Policy and Practice* 189: 104214. DOI: 10.1016/j.tra.2024.104214.
14. Wang J., L. Sun. 2021. „Reducing Bus Bunching with Asynchronous Multi-Agent Reinforcement Learning”. *Proceedings of the Thirtieth International Joint Conference on Artificial Intelligence*: 426-433. DOI: 10.24963/ijcai.2021/60.
15. Ren H., Z. Wang, Y. Chen. 2020. „Optimal Express Bus Routes Design with Limited-Stop Services for Long-Distance. *Commuters. Sustainability* 12(4): 1669. DOI: 10.3390/su12041669.
16. Bazarov B.I., A.A. Ernazarov, Zh.Z. Tozhiev. 2024. „Technical and operational evaluation of the introduction of the express bus service on the city routes of Jizzakh”. *Transport: Science, Technology, Management* 10: 44-52. DOI: 10.36535/0236-1914-2024-10-6.
17. Wei H., C. Zhu. 2024. „Optimisation of Bus Routes in Small and Medium-sized Cities: The Case of No. 7 Bus Route in Jiaozuo City”. *Proceedings of the 2024 International Conference on Rail Transit and Transportation (ICRTT 2024)*: 104-114. DOI: 10.2991/978-94-6463-610-9_12.

18. Baghbani A., S. Rahmani, N. Bouguila, Z. Patterson. 2025. „TMS-GNN: Traffic-aware Multistep Graph Neural Network for bus passenger flow prediction”. *Transportation Research Part C: Emerging Technologies* 174: 105107. DOI: 10.1016/j.trc.2025.105107.
19. Bharathi D., L. Vanajakshi, S.C. Subramanian. 2022. „Spatio-temporal modelling and prediction of bus travel time using a higher-order traffic flow model”. *Physica A: Statistical Mechanics and Its Applications* 596: 127086. DOI: 10.1016/j.physa.2022.127086.
20. Shen J., Q. Liu, Y. Zhang, M. Yu. 2025. „A novel model incorporating deep learning and Kalman filter augmentation for route-level bus arrival time prediction with error accumulation mitigation”. *Expert Systems with Applications* 281: 127622. DOI: 10.1016/j.eswa.2025.127622.
21. Khakimov B., S. Tanaka. 2024. „Evaluation of the impact of exclusive bus lanes on traffic in Tashkent”. *Asian Transport Studies* 10: 100151. DOI: 10.1016/j.eastsj.2024.100151.
22. Chen X., H. Guan, Q. Meng. 2025. „Shared use of dedicated lanes by connected and automated buses and private vehicles: A multi-green-wave signal control scheme”. *Transportation Research Part E: Logistics and Transportation Review* 195: 103965. DOI: 10.1016/j.tre.2025.103965.
23. Jiang Q., Y. Wu, J. Sun, Y. Wang, S. Zhang, L. Wang, W. He. 2024. „Is a dedicated bus lane operationally and environmentally beneficial? A case study in Beijing”. *Transportation Letters*: 17(7): 1333-1347. DOI: 10.1080/19427867.2024.2439349.
24. Hollósi J., Á. Ballagi, G. Kovács, S. Fischer, V. Nagy. 2024. „Bus Driver Head Position Detection Using Capsule Networks under Dynamic Driving Conditions”. *Computers* 13(3): 66. DOI: 10.3390/computers13030066.
25. Hollósi J., Á. Ballagi, G. Kovács, S. Fischer, V. Nagy. 2024. „Detection of bus driver mobile phone usage using kolmogorov-arnold networks”. *Computers* 13(9): 218. DOI: 10.3390/computers13090218.
26. Hollósi J., G. Kovács, M. Sysyn, D. Kurhan, S. Fischer, V. Nagy. 2025. „Driver Distraction Detection in Extreme Conditions Using Kolmogorov-Arnold Networks”. *Computers* 13(9): 218. DOI: 10.3390/computers13090218.
27. Rosero F., N. Fonseca, Z. Mera, Mera, J.-M. Mera. 2023. „Assessing on-road emissions from urban buses in different traffic congestion scenarios by integrating real-world driving, traffic, and emissions data”. *Science of The Total Environment* 863: 161002. DOI: 10.1016/j.scitotenv.2022.161002.
28. Naumov V., L. Bekmagambetova, Z. Bitileuova, Z. Zhanbirov, I. Taran. 2022. „Mixed Fuzzy-Logic and Game-Theoretical Approach to Justify Vehicle Models for Servicing the Public Bus Line”. *Communications - Scientific Letters of the University of Zilina* 24(1): A26-A34. DOI: 10.26552/com.c.2022.1.a26-a34.
29. Kim J., R. Ewing. 2024. „Impact of “light” bus rapid transit (BRT-light) on traffic and emissions in a travel corridor”. *Transport Policy* 146: 215-226. DOI: 10.1016/j.tranpol.2023.11.019.

Received 18.06.2025; accepted in revised form 30.09.2025

Scientific Journal of Silesian University of Technology. Series Transport is licensed under a Creative Commons Attribution 4.0 International License