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OPTIMIZATION OF URBAN PASSENGER ROUTE BY GAME SIMULATION METHODS

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Abstract. The growth of the level of motorization of the population has led to a significant increase in road congestion in the cities of Ukraine. All this necessitates the optimization of the spontaneously formed system of urban passenger transport, which does not meet modern challenges.

An effective solution to this problem is the use of decision support systems in the field of urban transport routing.

Theoretical and methodological substantiation of the choice of the method of optimization of the route of urban transport is carried out in the work and the simulation modeling of the process of optimization of passenger transportation on the route №9 in Pryluky by Pareto criterion is carried out. The technique of search of optimum routes by methods of game modeling is developed.

The optimization game model of the process of passenger transportation on the route №9 in Pryluky showed results that take into account the interests of all stakeholders.

Key words: simulation, Pareto efficiency criterion, route, optimization, passenger transport.

Introduction

Passenger transport is one of the most important areas of city’s life, the functioning of which depends on the quality of life, efficiency of the city's economy and the ability to use its urban and socio-economic potential. In recent years, the structure of demand for passenger traffic has changed significantly in many cities of the country. This is due to the process of dynamic socio-economic development of cities, which caused the emergence of new facilities and areas of attraction of passenger flows, such as business, shopping, entertainment and sports centers, changes in the settlement structure of city residents due to new areas of active housing.

Formulation of problem

Simultaneously with the growth of the level of motorization of the population (and minor changes in the transport infrastructure), the congestion of highways in the cities of Ukraine has significantly increased. All this necessitates the optimization of the spontaneously formed system of urban passenger transport, which does not meet modern challenges. An effective solution to this problem is the use of decision support systems in the field of urban transport routing. However, the automation of tasks in this area requires research in order to obtain effective algorithms suitable for use in practice.

Analysis of recent research results

Today there is a large number of scientific papers on the optimization of urban transport routes. In the works [8, 9] the authors propose as a criterion for optimizing the route schemes of urban passenger transport to use the total time spent by passengers on the trip, work [7, 11, 12, 13] aimed at reducing the number of transfers and reducing the non-linearity of the route. Authors of later works [2, 3, 5, 6] aim to take into account the costs of transport organizations for transportation and the cost of estimating the loss of time passengers travel.

However, despite the variety of current research on certain topics, it should be noted that there are not many attempts to comprehensively approach the optimization of urban passenger routes, taking into account the interests of all stakeholders. This determines the relevance of our study.

However, despite the variety of modern research on certain topics, it should be noted that there are almost no attempts to investigate the complex impact of institutional and technological changes on the development of the logistics market. This determines the relevance of our study.

Purpose of research

The purpose of the work is the theoretical and methodological substantiation of the choice of the method of optimization of the route of urban transport, simulation modeling of the process of optimization of passenger transportation on the route №9 in Pryluky by Pareto criterion.

Research results

An important factor in the sustainable socio-economic development of the city, region, country as a whole is the smooth operation of the transport system. Passenger transportation is the main function of urban public passenger transport, which determines the standard of living of the population, barrier-free environment for the development of society and so on.

Changes in the bus route scheme, related to the emergence of new routes, extension or shortening of existing ones, cancellation or relocation of stops, are carried out quite often and are usually not properly justified, as supported only by complaints and suggestions of carriers. In these circumstances, there is a need for more sound decision-making methods. Therefore, the formation of a rational system of urban public transport should include the solution of a number of tasks, among which are:

– selection and construction of routes for urban public transport;

– justification the type and number of vehicles;

– development of schedules and optimization of traffic modes on the route.

Based on such tasks E. A. Kochegurova and Y. A. Martynov believe that to build an optimal route scheme of urban passenger transport must be carried out taking into account the interests of all participants in the transport system (eg, transport organizations and passengers). When describing the task of optimizing the system of urban passenger transport, they identify several main criteria of efficiency, which are presented in the form of target functions [4, p. 80]:

$$\begin{cases} T_n = T_1 + T_2 + T_3 + T_4 \to \min \\ V_n = \sum_{Q_n} Q_{n\partial} \times T \to \max \\ P_{TO} = Q_n \times T - B_E \to \max \end{cases} \quad (1)$$

where: T_n – time spent by passengers on movement;

T_1 – time spent approaching a traffic stop;

T_2 – vehicle waiting time;

T_3 – movement time;

T_4 – time spent traveling to the destination;

Q_n – number of passangers;

V_n – the cost of the trip, taking into account possible transfers;

Q_{nd} – number of trips/transfers per day;

T – tariff for passenger transportation;

P_{TO} – profits of transport organizations;

B_E – operating costs of transport organizations.

Therefore, to determine the optimal number of transport units of the fleet, it is necessary to analyze the route by determining the passenger flow, i.e. the number of passengers actually transported at this time on each race of the bus route, or in general on the bus network of all routes in one direction per unit time. As a rule, passenger flows are different in size at different times of the day, days of the week, months and seasons, as well as sections of routes and directions of buses. Factors affecting passenger traffic: features of the formation of mobility of urban residents; season of the year; month of the year; weekday; year of the day; financial capabilities of passengers; direction of buses on the route; tariff and preferential policy; holding cultural events; meteorological conditions; holy; the number of buses on the route, their type and technical condition; quality of transportation (all components, including quality on the route and quality inside the cabin); regularity of buses on the route; features of the organization of transportation along the route (high-speed and express flights, etc.); availability of information for passengers in the route (information boards, stops, etc.); etc.

Analyzing the state of passenger traffic on the route, first of all it is necessary to determine which state we will consider optimal. The methodology of neo-institutional economics makes it possible to clarify the contradictions between equity and efficiency using various criteria, including the Pareto criterion. As one of the key criteria of game modeling, it is the simplest and most convenient method to use, which is to determine the optimal solution for one criterion with the translation of others into limitations.

This approach does not preclude the analysis of options close to the optimal or simply desired solutions. In general, it can be formulated as follows [1]:

$$\begin{cases} X \to extrem \\ Y_1^{\min} \le Y_1 \le Y_1^{\max} \\ Y_n^{\min} \le Y_n \le Y_n^{\max} \end{cases} \quad (2)$$

where X – the most important criterion determined on the basis of expert assessments;

Y – set of secondary criteria sufficient for a full description of the role of the object under study.

The Pareto efficiency criterion avoids the problem of aggregating benefits. If the law (or court decision) leads to the improvement of the condition of at least one of the members of society and at the same time does not worsen the condition of any of the other members of society, then this rule (norm, law) will be an improvement according to Pareto. If further Pareto improvements are not possible, the situation will be considered optimal for Pareto. This criterion does not require the determination of the absolute value of benefits, as well as the comparison of the benefits of different members of society, it is limited to comparing the benefits of the same person as ordinal quantities. When applying this criterion, you only need to determine, by comparing the two states, whether a person feels better or worse in connection with the new rule.

In practical terms, the criterion means that only those decisions of the legislator should be made that have received the unanimous support of all members of society. The unsuitability of the Pareto criterion for solving practical problems arises from the fact that it attaches excessive importance to the losses suffered by some members of society, no matter how significant the gain of other members of society.

Critics of the Pareto test of effectiveness as a tool for assessing the desirability of legislative change make the following arguments.

Firstly, when using this criterion, people's preferences are considered as predetermined and are not evaluated in any way. Meanwhile, some people's preferences are immoral, or lead to the destruction of the human personality (for example, the preferences of drug addicts or people who benefit from bullying other people).

Secondly, the Pareto efficiency criterion is based on the existing allocation of resources and does not assess its fairness (Pareto may be optimal in a situation where some people are in dire need and others bathe in luxury, provided that the poor cannot be improved encroaching on the wealth of the wealthy).

Thirdly, the criterion does not put any limits on market relations (if there is a buyer and seller willing to enter into an agreement, then everything can become a commodity, because in this case the parties will feel that their situation has improved).

Thus, having conducted a theoretical and methodological justification for choosing the method of optimizing the route of urban transport, we set ourselves the task using the method of game modeling, in particular the Pareto criterion, to improve the route, based on the needs of carriers and passengers.

In order to determine whether the condition of the route №9 in Pryluky is satisfactory, we will analyze the requirements for the carrier, driver and passenger in accordance with the rules of the Law of Ukraine "On Road Transport". In this paper, the route is investigated using two main indicators: the intensity at each stop and passenger turnover at different times of the day. The intensity of passenger traffic on individual sections of the route or on the entire route is determined by the routes of maximum load towards the maximum passenger flow, as well as the maximum race load during the periods of the most intensive passenger flow for a certain period. All route data were obtained using the method of mass observation of the actual number of passengers at each stop at different times of the day. Below are the results that are as close as possible to the real situation on the route with minimal error.

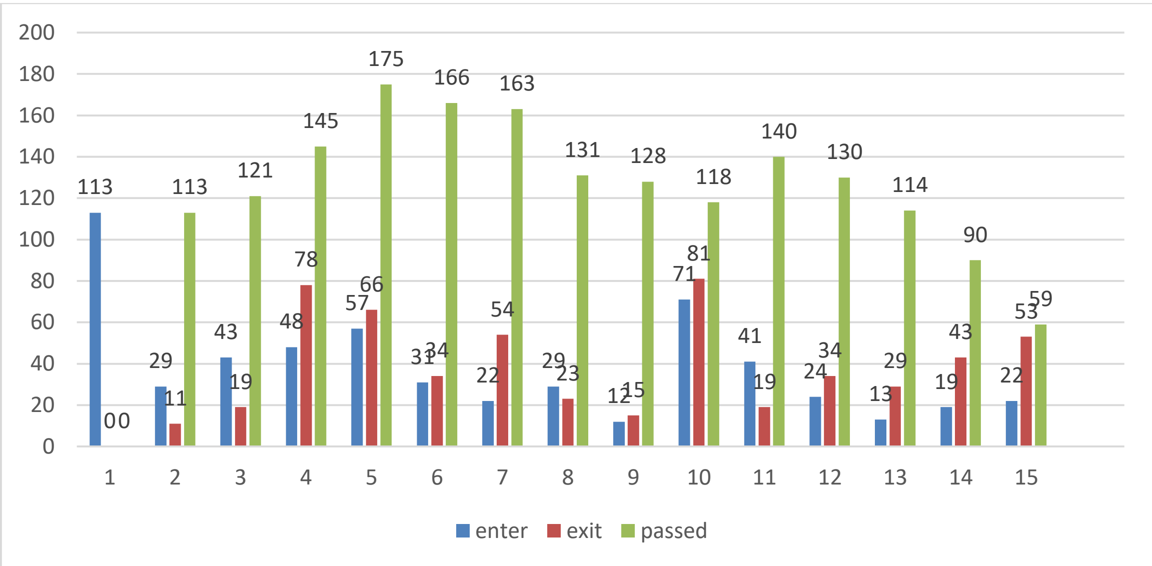

Fig. 1. Average daily passenger turnover per routei
Source: made by the author.

Table 1. Distribution of the volume of traffic on the route by hours of the day.

Hour of the day	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Percent, %	12.2	9.6	6.4	5.3	3.9	3.0	5.7
Amount of traffic, passengers	81	60	39	29	22	17	33
Hour if the day	14-15	15-16	16-17	17-18	18-19	19-20	20-21
Percent, %	6.5	9.8	12.0	6.3	5.1	3.0	2.2
Amount of traffic, passengers	47	64	79	37	27	17	12

Source: made by the author

Passenger turnover is calculated by the formula:

$$P= LnQп. \quad (3)$$

To analyze the inequalities of passengers at different times of the day, we determine the standard deviation. The standard deviation indicates how much the mean values of the feature deviate from their mean value. If you calculate the variance for all variants, the values obtained will be negative and positive, adding to 0, i.e. compensating each other. This means that it is impossible to calculate the mean deviation as the arithmetic mean of the deviations. There are several ways to avoid compensating for negative and negative values. The most common is the distribution of each difference (xi - M). Adding the squares of all the differences and dividing by the number of these differences, we obtain a value called the variance. In fact, it shows the arithmetic mean of the deviations squared. To get rid of the square of the value, calculate the square dispersion root. The value obtained is called the square root of the deviation. We apply the formula:

$$\sigma = \frac{\Sigma(x_i - \bar{x})}{n} \quad (4)$$

where: x_j – individual values of a separate feature, options;

$\bar{x}$ – arithmetic mean (average value of the sign);

n – the volume of the population, the number of features in the population;
and get $\bar{x} = 40.2$; σ = 25.6. Each value differs from the average value of 40.2 by an average of 25.6 units.

Differentiated standards of flight time by hours of movement are calculated on the basis of timing observations, records of devices or approved methods, are the starting materials for scheduling. The movement of buses on the routes is carried out in strict accordance with the approved schedule. The bus timetable is the main document of the operation department, on the basis of which the work of all parts of the operational and technical services is built.

Properly compiled route schedule should provide: the shortest waiting time for bus passengers and travel to the destination; normal filling on all races of a route; high regularity during the whole period of movement; high speed of communication at observance of safety of trips; efficient use of buses, normal mode of operation of drivers, consistency of intervals of movement on departure at nodal stops; fulfillment of planned performance indicators of transport enterprises. Calculating the volume of traffic by hours of the day:

Q days = Q directly entered + Q the reverse entered (5)
Get the meaning Q days in 564 passangers.

The distribution by hours of the day should be performed by arithmetic proportion. Consider the time interval from 7 to 8 hours.

Q days – 100%; X 7-8 – 12.2%.

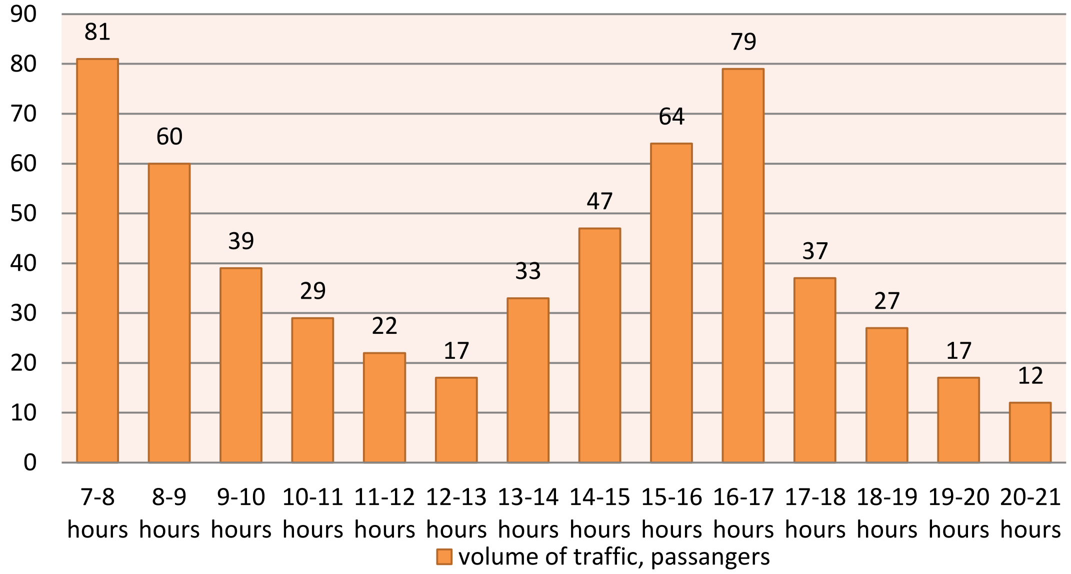

Fig. 2. The average daily volume of traffic on the route.
Source: made by the author.

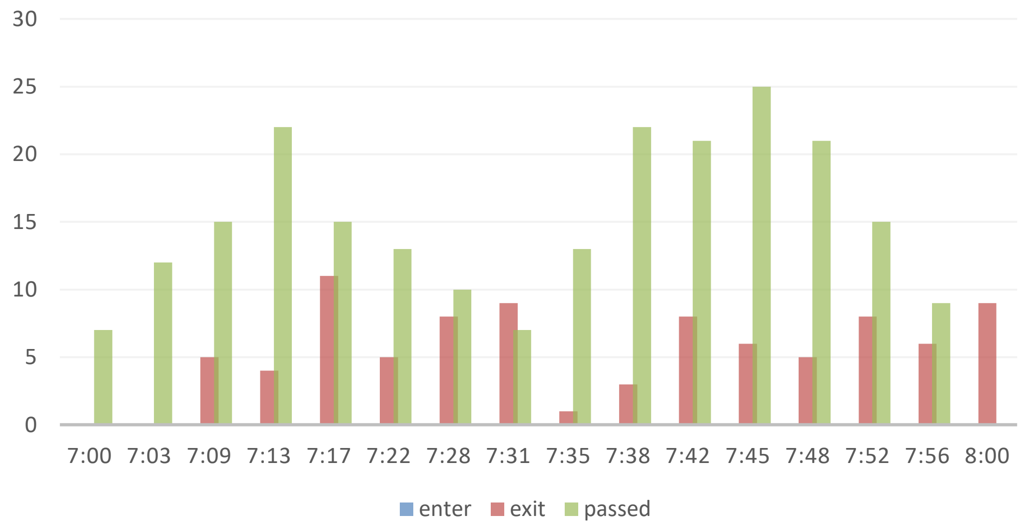

Fig. 3. Schedule of passenger turnover for the period from 7 to 8 o'clock in the morning.
Source: made by the author.

Based on the histogram, we can conclude that the busiest hours of the day are the period from 7 to 8 o'clock in the morning, at noon from 15 to 16, and from 16 to 17 o'clock in the evening. The least busy are the periods from 12 to 13, from 19 to 20, from 20 to 21.

For a more detailed study of the comfort criterion, consider passenger traffic during peak hours between 7 and 8 am. During this period, the number of passengers on the bus is critical and sometimes exceeds the maximum capacity of the vehicle on a particular route. This situation is frustrating for passengers who are in uncomfortable conditions while traveling. In some cases, overloading the vehicle can injure passengers. It is clear that non-compliance with the operating conditions also leads to faster destruction of the vehicle and increases the probability of its failure.

To achieve the maximum Pareto result, we must consider the benefits for both the passenger and the carrier.

Thus, game models were built that show the position of the vehicle at different times of the day. And the number of trips during the day does not change so as not to impose additional costs on the carrier. By increasing the number of buses in a certain period of time, we reduce them in proportion to another, optimal time in this regard. Having built the first game model, we reduce the number of buses per day from periods of low passenger traffic, namely from 11 to 12, from 12 to 13, from 19 to 21 and vice versa, we produce an additional bus from 7 to 8, from 8 to 9, 16 to 17.

Table 2. Distribution of the volume of traffic on the route by hours of the day according to the first game model.

Hour of the day	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Volume of traffic, passengers	86	64	39	29	18	30	39
Amount of buses	4	4	3	3	2	2	3
Hour of the day	14-15	15-16	16-17	17-18	18-19	19-20	20-21
Volume of traffic, passengers	33	50	80	37	27	13	10
Amount of buses	3	3	4	3	3	2	2

Source: made by the author.

Determine the standard deviation of the first game model on the form 4, and get $\sigma = 25, 23$

Let's analyze how passenger traffic changes with the change in the number of transport units.

For example, let's determine the passenger traffic for the period from 7 to 8. If the cost of passenger traffic is 86 passengers, and currently there are 3 transport units on the route, we can calculate that approximately 28 passengers correspond to one bus. So, if you increase the number of buses (in this case by 1 unit), the voltage in this time interval will decrease by 28 passengers.

In the case when, on the contrary, it was decided to reduce the number of buses per hour, passenger turnover increased similarly, as the tension of passengers in the vehicle increased.

If $x > y$, then $z` = z - (x - y)(z / x)$; (6)

If $x < y$, then $z` = z + (x - y)(z / x)$. (7)

where: X – the actual amount of buses;

Y – optimized amount;

Z – passengers traffic;

Z` – optimized passengers traffic.

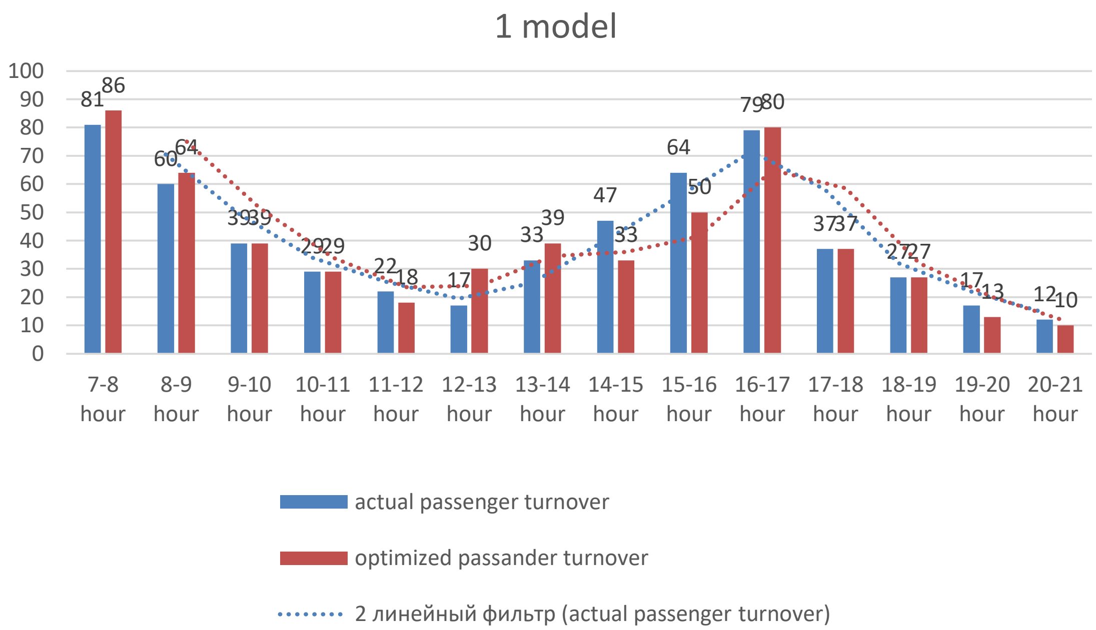

Fig. 4. 1 intropretation of the game model according to the Pareto criterion.
Source: made by the author.

Table 3. Distribution of volume of traffic on the route by hours of the day according to the second game model.

Hour of the day	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Volume of traffic, passengers	84	59	39	29	18	30	39
Amount of buses	5	5	3	3	1	1	3
Hour of the day	14-15	15-16	16-17	17-18	18-19	19-20	20-21
Volume of traffic, passengers	33	50	73	37	27	17	15
Amount of buses	3	3	5	3	3	1	1

Source: made by the author.

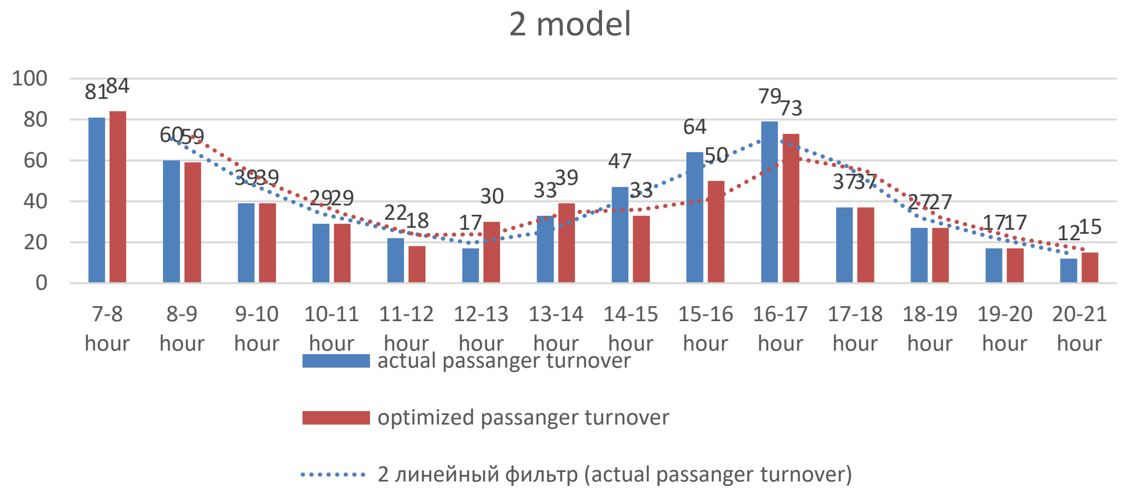

Fig. 5. 2 intropretation of the game model according to the Pareto criterion.
Source: made by the author.

Trend lines allow you to clearly see the difference between the starting position and the optimized. There have been slight improvements, which allows for a change for the better, but they are small.

Determine the standard deviation of the first game Determine the standard deviation of the second game model on form 4, and get: σ =23.1. Thus, the trend line showed relative stability throughout the day.

To make the best or at least not the worst decision, we analyze the situation in five stages: diagnosing the problem, formulating constraints and criteria for making decisions, identifying alternatives, evaluating alternatives, and making the final choice. To do this, we compare two alternative models, which are presented in Fig. 6.

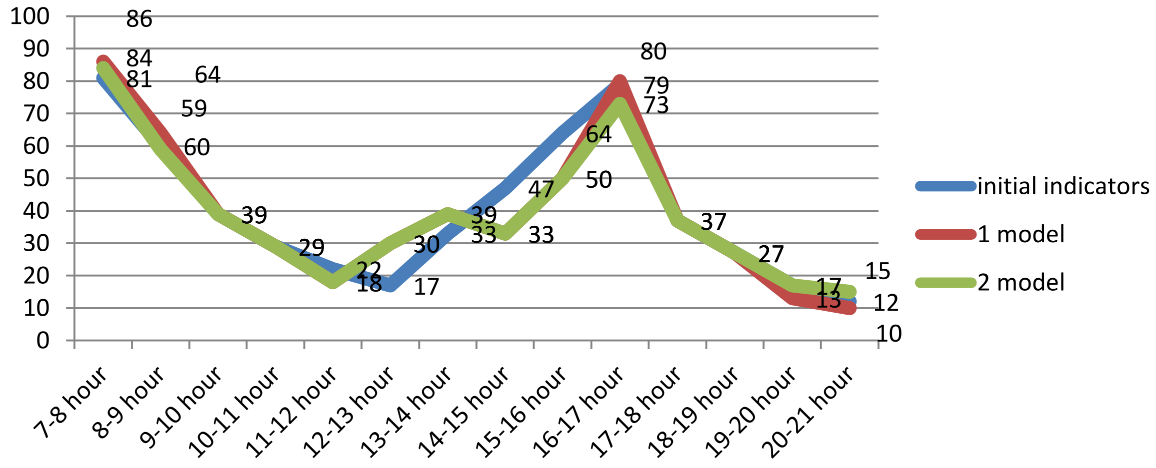

Fig 6. Passenger turnover according to the initial statistics and built game models.
Source: made by the author.

The graph shows that the second model is the best compared to the others, because the situation on the route is stable during the day. To do this, it is proposed to use the following number of buses on the route by hours of the day 7:00 to 8:00 – 5, from 8:00 to 9:00 – 5, from 9:00 to 10:00 – 3, from 10:00 to 11:00 – 3, from 11:00 to 12:00 – 1, from 12:00 to 13:00 – 1, from 13:00 to 14:00 – 3, from 14:00 to 15:00 – 3, from 15:00 to 16:00 – 3, from 16:00 to 17:00 – 5, from 17:00 to 18:00 – 4, from 18:00 to 19:00 – 4, from 19:00 – 20:00 – 1, from 20:00 to 21:00 – 1. In this case, the model of traffic and passenger traffic on the route №9 in Pryluky will be optimal for Pareto.

Conclusions

1. In the analysis of the optimization of route schemes of urban public transport, the interests of all participants in the urban transport system were considered and the efficiency indicators of the system as a whole were formulated. The classical problem of transport routing, its varieties and methods of solution are considered. As an optimization criterion for the urban public transport system, it is proposed to use the density of passenger traffic on a certain section of the road. Analysis of methods for solving problems of transport routing showed that the most promising today are the methods of game modeling.

2. As a result of the performed work by methods of game modeling the technique of search of optimum routes on Pareto criterion is developed. Optimization game model of the process of passenger transportation on the route №9 in Pryluky showed results that take into account the interests of all stakeholders.

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ОПТИМІЗАЦІЯ МІСЬКОГО ПАСАЖИРСЬКОГО МАРШРУТУ МЕТОДАМИ ІГРОВОГО МОДЕЛЮВАННЯ

О. М. Загурський, А. Г. Кумейко, Ю. В. Шатківська

Анотація. Зростання рівня автомобілізації населення призвело до суттєво збільшило завантаженість автомобільних шляхів в містах України. Все це зумовлює необхідність оптимізації стихійно сформованої системи міського пасажирського транспорту, що не відповідає сучасним викликам. Ефективним вирішенням даної проблеми є застосування систем підтримки прийняття рішень у сфері маршрутизації міського транспорту.

Вроботі проведено теоретико-методологічне обґрунтування вибору методу оптимізації маршруту міського транспорту та здійснено імітаційне моделювання процесу оптимізації перевезення пасажирів на маршруті № 9 м. Прилуки за критерієм Парето. Розроблено методику пошуку оптимальних маршрутів методами ігрового моделювання. Оптимізаційна ігрова модель процесу перевезення пасажирів на маршруті № 9 м. Прилуки показала результати, що враховують інтереси усіх стейкхолдерів.

Ключові слова: ігрове моделювання, критерій ефективності Парето, маршрут, оптимізація, пасажирський транспорт.

ОПТИМИЗАЦИЯ ГОРОДСКОГО ПАССАЖИРСКОГО МАРШРУТА МЕТОДАМИ ИГРОВОГО МОДЕЛИРОВАНИЯ

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Аннотация. Рост уровня автомобилизации населения существенно увеличил загруженность автомобильных дорог в городах Украины. Все это обуславливает необходимость оптимизации стихийно сложившейся системы городского пассажирского транспорта, которая не отвечает современным вызовам. Эффективным решением данной проблемы является применение систем поддержки принятия решений в сфере маршрутизации транспорта.

В работе проведено теоретико-методологическое обоснование выбора метода оптимизации маршрута городского транспорта и осуществлено имитационное моделирование процесса оптимизации перевозки пассажиров на маршруте № 9 г. Прилуки за критерием Парето.

Разработана методика поиска оптимальных маршрутов методами игрового моделирования. Оптимизационная игровая модель процесса перевозки пассажиров на маршруте № 9 г. Прилуки показала результаты, учитывающие интересы всех стейкхолдеров.

Ключевые слова: игровое моделирование, критерий эффективности Парето, маршрут, оптимизация, пассажирский транспорт.

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