AUTOMATED SYSTEM FOR OPTIMIZING THE MOVEMENT OF URBAN PASSENGER TRANSPORT USING GIS

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ABSTRACT:

This article discusses the issue related to the prospects for the introduction of an automated control system for urban passenger transport in the city of Ust-Kamenogorsk, which includes: "Management of passenger transportation by road" on the 1C: Enterprise platform; assessment of the difficulty of communication by constructing an isochron; forecasting the need for the number of buses using fuzzy logic and sets; conclusion of the result in GIS, namely in the application "OckemenBus".

The initial stage of the system includes the task of systematization and storage of information about the urban passenger transport system using the 1C: Enterprise platform. It is also possible to store calculated information on transport performance indicators. To determine the quantitative indicators of assessing the accessibility of the center, isochronograms were calculated and constructed taking into account the movements of the city's population in all ways. The calculation of the isochronogram indicates the transport problems of growing neighborhoods located on the left bank of the Irtysh River, the city of Ust-Kamenogorsk. Further, using the theory of fuzzy logic and fuzzy sets, it is possible to make changes to the UPT movement scheme using the standard interface of the geoinformation system shell.

It should be noted that the proposed model for optimizing the movement of urban passenger transport using the 1C platform, the construction of an isochronogram, the theory of fuzzy logic and fuzzy sets and GIS allows you to organize the work of urban passenger transport.

1. THE IMPACT OF URBAN PLANNING ON URBAN PASSENGER TRANSPORT

1.1 Introduction

Urbanization is a process that is going on all over the world. Now more than half of the population lives in cities, in Kazakhstan, population growth is also approaching 63% of the population in cities (Online population statistics, 2023). Urbanization and motorization are two processes that go hand in hand. The specifics of urbanization in the Republic of Kazakhstan are well known: since 2010, there has been a significant increase in the population of large cities, largely due to internal migration from small, medium-sized cities and rural areas. The concentration of population in cities is characterized by the overgrowth of cities with suburbs and the merging of suburbs into one agglomeration. All this contributes to the expansion of urban areas and an increase in the length of transport correspondence and the number of trips. In many cases, the insufficient quality and development of public passenger transport services leads to an increase in the use of personal transport.

Urban planning policy also contributes to the growth of motorization — mass construction in the largest cities, without sufficient consideration of the necessary social, commercial and other infrastructure, further stimulates people to purchase a personal car. So in the city of Ust-Kamenogorsk, East Kazakhstan region, the population growth according to the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan, was about 11% (National Bureau of Statistics, 2023). Due to the above circumstances, new microdistricts of the city with their own infrastructure are emerging, so in 2022 it was commissioned under housing mortgage lending programs: "7-20-25. New opportunities to purchase housing for every family", "Nurly Zher", "One-story East" and commercial construction of more than 2000 apartments. Most of the construction is carried out in the left–bank part of the city - this is the KShT district. Due to the growth of construction projects and the expansion of the residential districts of Ust-Kamenogorsk, the load on the transport arteries and passenger transport of the city is logically increasing.

According to the Administrative Police Department of the East Kazakhstan Region Police Department, the number of vehicles in the city of Ust-Kamenogorsk shows that the number of buses for 2012-2022 was changed slightly. For example, in 2012 the number of buses of legal entities was 1,285 units, in 2022 - 1,455 units (Table 1, Figure 1).

Years	Type of vehicles (individuals/legal)					
	Cars	Trucks	Buses	Motor bikes	Trailers	Total
1	2	3	4	5	6	7
2012	73879	3297	854	1681	3420	83131
	6906	4842	1285	32	1375	14440
2013	77411	3409	942	1681	3558	89657
	7170	4894	1295	32	1421	15011
2014	79866	3409	956	1743	3683	3683
	7354	4894	1281	35	1447	1447
2015	85802	3521	1015	1897	3963	96198
	7614	5056	1318	40	1512	15540
2016	84910	3479	1007	41	3966	95251
	7490	4948	1289	3966	1488	15256
2017	82217	3512	963	1934	3808	92434

	7655	5030	1314	38	1519	15556
2018	82177	3540	953	1941	3784	92395
	7680	4995	1308	36	1498	15517
2019	81956	3647	914	1863	3772	92152
	7876	4779	1277	37	1451	15512
2020	81956	3647	914	1863	3772	92152
	7980	4779	1272	38	1442	15511
2021	82667	3745	796	1835	4341	93384
	7926	4756	1272	38	1509	15501
2022	97710	4268	785	1935	7165	111863
	9185	5666	1455	37	1522	17865

Table 1. Number of vehicles in the city of Ust-Kamenogorsk.
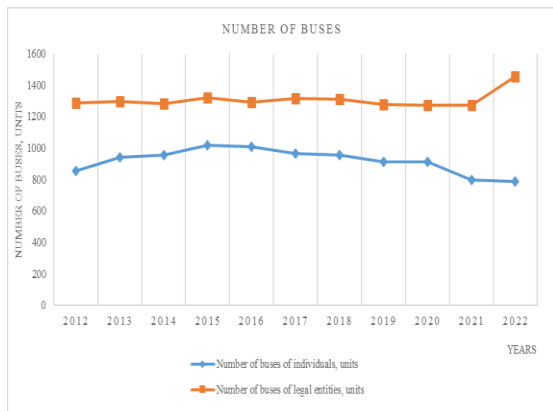

Figure 1. Dynamics of changes in the number of buses.

Figure 1 shows that over the past 10 years, with the emergence of new neighborhoods and, accordingly, population growth in the city of Ust-Kamenogorsk, the number of buses has not changed. Therefore, it is necessary to optimize the movement of urban passenger transport, taking into account the transport layout of cities.

2. THE PROPOSED AUTOMATED CONTROL SYSTEM AT THE UPT USING GIS

2.1 Database design in an automated transport management system

When analyzing the operation of urban passenger transport (UPT), it is necessary to take into account the high density of the route network, different fares on routes, dividing the population into categories, which, when solving optimization problems, allows an automated system designed to optimize the operation of UPT, taking into account the overlap of routes.

One of the most urgent tasks related to the development of high-tech software is the modeling of complex systems, the key features of which in this case can be considered a large number of composite elements, long-distance connections between elements and multiscale variability. The task of systematization and storage of information about the UPT system is carried out by a database (DB). The program "Management of automobile transportation of passengers" on the 1C platform, which is part of the automated system, allows you to take into account, when optimizing, the overlap of routes, the length of the stage, different fares, the division of the population into categories, taking into account the transport planning of the city of Ust-Kamenogorsk.

The first step in the database design process is to identify all the objects (entities) and their properties (attributes) that should be placed in the database, since the lack of information of interest negates the value of the entire database. In addition, it is necessary to identify relationships not only between database objects, but also between the properties of objects.

All information intended for storage in the database can be divided into primary, reference and calculation. The primary one includes all the information collected by means of a tabular survey on the flights made by vehicles and the number of passengers entering/exiting at each stopping point and the length of the stage. The reference information includes information about the route network of the city; vehicles carrying passengers; the date of the survey; time intervals; possible directions of movement.

Based on this, the following main database entities can be distinguished: "City map", "Flight", "Route", "Passengers", "Stops", "Rolling stock", "Date", "Hours of the day", "Direction".

Figure 2 shows an ER diagram reflecting the above entities and the relationships between them. The "Hours of the Day" object is needed only for calculations, therefore it is not associated with other entities characterizing primary information, and it is not displayed on the ER diagram. The next step after creating an ER diagram that includes all the important entities and relationships is to build a set of preliminary tables and specify the intended primary key for each table in the 1C platform. Preliminary tables are obtained from the ER diagram based on the class of entities belonging and the degree of relationships.
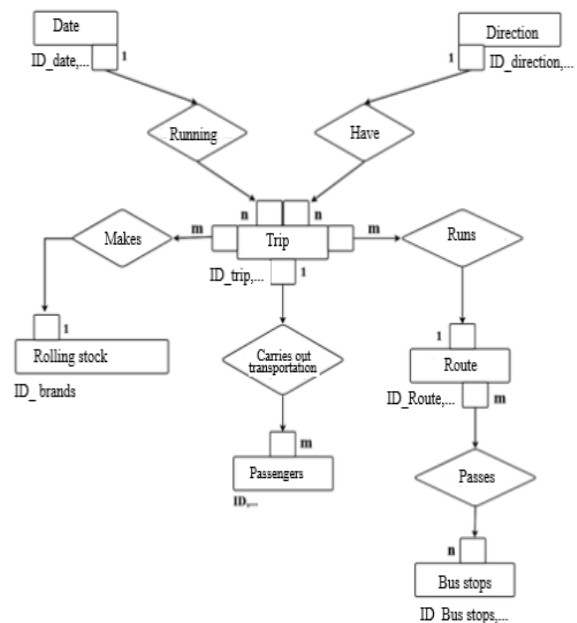

Figure 2. Database ER Diagram.

For most entities in the projected database, the degree of binary relationship is ("one-to-many") and the membership class of both entities is mandatory, therefore, one table for each entity is necessary for data storage. The degree of binary connection between the entities «Route» and "Stops" is equal ("many-to-many"), therefore, three tables are required for data storage – one for each entity and one table of the 1C program for communication (Maslennikova and Petelyak, 2019).

At the final design stage, a list of all attributes of interest was compiled and distributed among the entities. At this stage, inter-attribute functional dependencies were also determined, with the help of which the correspondence of the tables obtained from the ER diagram to the third normal form was checked, according to which all non-key columns of tables should depend on the primary key, but not depend on each other.

In addition to primary and reference information, the database should provide for the possibility of storing settlement (secondary) information. For efficient and rational work with the database, it is necessary to store the following data:
1. Technical and operational indicators of transport operation;
2. Passenger traffic by hours of the day, real, suboptimal and optimal traffic intensities, filling factors;
3. Matrices of inter-stop correspondence;
4. Coefficients indicating the possibility of moving along the route between stopping points;
5. The estimated number of buses required for transportation at a certain hour of the day;
6. Filling the bus on each stage of the route while driving with optimal intensity.

To eliminate data redundancy and minimize the number of tables for storing secondary information, the following objects were provided: "Technical and operational indicators of transport operation", "Optimization table", "Inter-stop correspondence matrix", "Stops", "Number of buses", "Filling (at)".

2.2 The proposed algorithm of urban passenger transport

The main task of the automated transport system with the use of GIS is to optimize the work of the UPT, taking into account the overlap of routes and the transport layout of the city. The secondary tasks include the determination of the technical and operational characteristics of the operation of the UPT, the route coefficient, etc. The Optimization algorithm consists of the following steps:

Stage 1 - collection of reference and primary information about the UPT and its placement in the database, automatic correction of erroneous information. At this stage, the following information is loaded from the tables of the 1C platform: date, route number, brand of the vehicle, the trip, the number of passengers entering and exiting at each stop on the route. Then the total number of incoming/outgoing passengers for the flight is calculated, flights with erroneous data are entered in the «Table of erroneous data». After that, the erroneous information is corrected. Also at this stage, the time of arrival of the vehicle at each stopping point is determined by calculation methods and reference tables are filled in;

Stage 2 - the formation of a block of initial data based on information from the tables of software 1C: Enterprises «Flight», «Route», «Passengers», «Stops», «Rolling stock», «Date», 2Hours of the day», «Direction», «Hours of the day»;

Stage 3 - calculation of the matrix of inter-stop passenger correspondence for each flight, the formation of the calculation table «Matrix of correspondence»; determination of the elements of the global matrix of inter-stop correspondence for each hour of the day;

Stage 4 - determination of coefficients indicating the possibility of moving along the route between and stopping points, the formation of the calculation table «Stopping points»;

Stage 5 - determination of the coefficient of overlap of passenger flows on the route network. At this stage, the choice of the direction of solving optimization problems is carried out - with or without taking into account the overlap of routes;

Stage 6 - solving mathematical problems of optimizing the movement of the UPT: determining the intensity of the movement of vehicles along the routes (suboptimal, optimal), using different problem statements depending on the availability of initial data and the required level of detail. At this stage, the actual traffic intensity of the UPT is also determined for all time intervals and routes;

Stage 7 - determination of the filling factor of the rolling stock for the calculated traffic rates. The analysis of information on the filling of vehicles on hauls allows us to conclude that it is possible to use mathematical problems to optimize the movement of urban passenger transport without limiting the passenger capacity of the vehicle;

Stage 8 - evaluation of optimization results: determination of total transport costs and total loss of passenger time, calculation of the cost of a passenger hour for the actual traffic intensity, determination of the number of buses required for transportation. For the implementation of the above stages in the software package, forms are responsible (determine the order of calculations), modules and queries.

As part of an automated system, one can single out a core that provides the basic functionality of the complex, and a set of modules that expand it. Various extension modules can be aimed at solving additional tasks, which include determining the technical and operational indicators of the UPT, calculating the matrix of inter-stop passenger correspondence, determining the required number of vehicles for transportation and passenger traffic by hours of the day, etc. By combining and, if necessary, developing new extension modules, such as a module for designing new routes, you can accurately and quickly solve most problems that arise in practice.

2.3 The proposed program «Management of automobile transportation of passengers» on the 1C Platform

The developed program for optimizing the movement of urban passenger transport using the 1C platform and geospatial system makes it possible to optimize the operation of the UPT based on minimizing the total transport costs and loss of passenger time in conditions of different density of the route network, fares, and division of the population into categories.

When optimizing, data from a full-scale survey of passenger traffic on all routes of the city are used; route network of the city; number of routes; list of stopping points on the routes; the list number of rolling stock carrying out transportation. All of the above information is taken from the relevant tables and queries from the database of the Ust-Kamenogorsk City Passenger Transport Administration.

The calculation of the optimal traffic intensity of vehicles along the routes is based on the solution of a system of nonlinear equations of large dimensions, which in itself is a great complexity. The solution of such systems of equations is carried out by numerical iterative methods, while problems of convergence and uniqueness of the solution arise. Almost all convergence problems are somehow related to the correctness of the input data. When collecting and digitizing a large amount of data required for calculations, there is a high probability of making an error, which can lead to a divergent iterative process. The problem of errors can be solved by automatically correcting incorrect information using the "Correction_In_Exit" module. The adjustment is made by multiplying the number of incoming passengers by a coefficient representing the ratio of the total number of exiting passengers to those in.

For the efficient operation of the automated system, 3 class modules have been developed that are directly related to forms,

and 14 standard modules (Figure 3). Since each optimization step should be performed only after the previous one has been completed and the correctness of its implementation has been verified, it is best to perform optimization calculations using forms that indicate the sequence of calculations to maintain the correct order.

The executable modules of the class directly related to these forms include: the «Optimization» module, designed to perform all stages of optimizing the operation of the transport; as well as the module of the «Technical and operational indicators» form, which allows you to calculate the technical and operational indicators of the transport operation, and the "Reference" form module, which allows you to access reference tables.
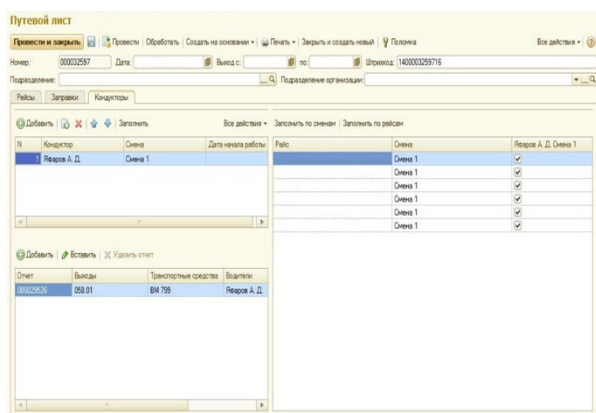

Figure 3. Module in the program «Management of road transport of passengers» on the 1C platform. Registration of travel documentation.

In the developed software package, queries perform an auxiliary function, allowing with minimal effort to access a certain set of data from several tables or group several records into one. Most of the requests are called from modules, thereby significantly reducing the program code, as well as reducing its execution time.

The remaining queries are intended either for displaying reference information in a convenient form (for example, the names of stops on a specific route), or for building graphs, charts and Excel tables based on grouped data.

Developed and optimized for urban passenger bus depots of the city of Ust-Kamenogorsk, the program "Management of road transportation of passengers" on the 1C Platform can work both independently and in combination with other software products. The program has technological advantages over software competitors:
1. The program can cover all the main areas of a motor transport company - these are transportation, waybills, income and expenses, repairs, fuel and lubricants, wages;
2. Detailing the performance of the enterprise, including production, income by type of transportation, routes, flights, car brands, up to a specific vehicle;
3. The use of the "1C" Platform - involves the widespread use of software and specialists who own this programming tool, also creates the possibility of a quick change in functionality and easy integration with other programs.
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Tasks that can be solved by the adopted program "Management of road transportation of passengers" on the 1C platform:
1. Formation of the work schedule of vehicles, drivers and conductors;
2. Calculation of the production of vehicles, drivers and conductors with details by type of transportation, routes, flights;
3. Registration of travel documentation;
4. Planning and accounting of actual income with details by types of transportation, routes, flights;
5. Accounting for income on boarding lists, cash, electronic cards;
6. Formation of a time sheet for drivers and conductors based on waybills;
7. Viewing the results of the company's activities with details on the types of transportation, routes, flights;
8. Calculation of wages of drivers and conductors with details on types of transportation, routes, flights, vehicles;
9. Calculation of planned and actual fuel consumption with details by types of transportation, routes, flights;
10. Calculation of data on the remaining mileage until the next scheduled repair;
11. Control of the transfer of fuel residues between drivers;
12. Maintenance of repair maps with a description of the scope of work and repair standards;
13. Control of materials spent on repairs and installed spare parts;
14. Calculation of wages of repairmen based on the work performed.

In addition to the above modules, the program has a connection with the application 1C: Accounting. Accounting and tax accounting, as well as with the application 1C: Salary and personnel management. Personnel accounting and payroll.

2.4   Assessment of the city plan in the transport needs using GIS

Based on the above automation of the database using the 1C: Enterprise program, calculations were carried out to assess the city plan in terms of transport needs according to the methodology developed by A.M. Yakshin (TSNIIPGRAD). The planning state of the city, which affects the need for transport, is calculated in the work according to absolute and relative indicators.

Indicators of the efficiency of the transport system are the difficulty of communication with the city center ($T_{communication}$), the efficiency coefficient of the transport system (ε) and the speed of movement ($V_{movement}$). To determine the quantitative indicators of assessing the accessibility of the center, isochronograms were calculated and constructed taking into account movements in all ways. The construction of isochronograms and the determination of these indicators were carried out using the developments of A.M. Yakshin.

An isochron is a geometric place of points equidistant in time of movement from the center of the construction. Isochrons are built at intervals of 10 minutes in all possible directions of movement within the city. The time spent on movement was determined for three speeds: the speed of pedestrian traffic, ground public transport and off-street high-speed transport.

To build an isochron from the center of the construction along the streets of Ust-Kamenogorsk in all directions, the distance (L_{walker}) overcome by a pedestrian in the time corresponding to the isochron (T_i) was postponed.

$$\mathrm{L}_{\mathrm{walker}} = T_i \cdot V_{\mathrm{walker}}, \qquad (1)$$

where $T_i =$ the time corresponding to the isochron of 10, 20, etc., min

V_{walker} = the speed of pedestrian traffic is 70 m/min

According to the principle of constructing kilometer lines, a contour of a 10 - 20 minute pedestrian distance from the center of construction, etc. was built. To build a contour of the transport distance of the center from all stopping points along the streets in all directions, the distance of departure from stops was postponed, possible within the time corresponding to the isochron. Lines were drawn through the obtained points at an angle of 45 ° to the axis of the streets to their mutual intersection (Figure 4). The distance of departure from the stops for the remaining time within each isochron was determined by the equations (Sadenova et al., 2022).
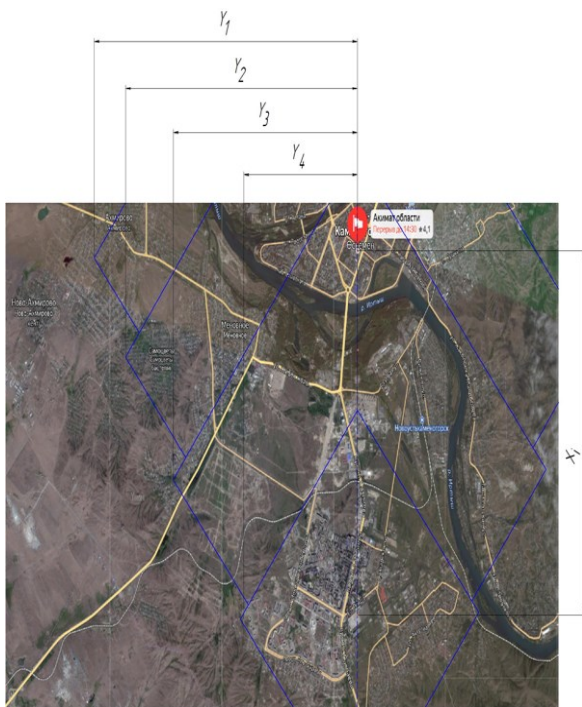

Figure 4. Construction of an isochron for the streets of Ust-Kamenogorsk.

When using public transport, the travel time corresponding to the isochron was summed up from the elements:

$$T_i = t_1 + t_2 + t_3 + t_4 + t_5, \qquad (2)$$

where t_1 = is the time of approach to the stopping point, min.

$$t_1 = \frac{l_1}{V_{\mathrm{walker}}}, \qquad (3)$$

where l_1 = is the approach distance from the construction center to the boarding stop, m

t_2 = waiting time for the desired transport route at the stop, min.

t_3 = travel time by transport, min.

t_4 = possible remaining departure time from the stopping point within the isochron, min

t_5 = transfer time, including the transition time and waiting time for the desired route, min

At the stage of the integrated transport scheme for transfers on street modes of transport, the transition time was not taken into account.

The distance of departure (*Y*) from the landing stop to the point where the time corresponding to the isochron will be completely spent was determined in calculations by the formula:

$$Y = t_4 \cdot V_{\mathrm{walker}}. \qquad (4)$$

The residual time t_4 was determined by the equation:

$$t_4 = T_i - \left(t_1 + t_2 + t_3 + t_5\right). \qquad (5)$$

Substituting the values of the components into formula (5), we obtained the isochron equation according to which calculations were made (Figure 4):

1) For non-stop movements (not taken into account in the calculations):

$$Y = V_{\mathrm{walket}} \cdot T_i - \left(\begin{array}{c} l_1 + V_{\mathrm{walker}} \cdot \dfrac{t_{\mathrm{route}}}{2} + \\ + V_{\mathrm{walker}} \cdot \dfrac{X}{V_{\mathrm{message}}} \end{array} \right); \qquad (6)$$

2) For transfer movements using ground public transport:

$$Y = V_{\mathrm{walker}} \cdot T_i - \left(\begin{array}{c} l_1 + V_{\mathrm{walker}} \cdot \dfrac{t_{\mathrm{route}} \cdot (n+1)}{2} + \\ + V_{\mathrm{walker}} \cdot t_{\mathrm{movement}} + \\ + V_{\mathrm{wal\,ker}} \cdot \dfrac{X}{V_{\mathrm{message}}} \end{array} \right), \qquad (7)$$

where t_{route} = route or network interval, min
n = number of transfers
X = distance between stopping points of embarkation and disembarkation (travel distance), m
$V_{message}$ = speed of transport communication, m/min
$t_{movement}$ = transit time during transfer, min

When traveling using two routes with different route intervals, the formula was used in the calculations:

$$Y = V_{\text{walker}} \cdot T_i - \begin{pmatrix} l_1 + V_{wal\,ker} \cdot \dfrac{t_{\text{route1}}}{2} + \\ + V_{\text{walker}} \cdot \dfrac{t_{\text{route2}}}{2} + \\ + V_{\text{walker}} \cdot \dfrac{X}{V_{message}} \end{pmatrix}. \quad (8)$$

The values Y were calculated for all public transport stops, except for the stop in the center of the construction. When placing the stopping point of landing in the center of the construction of the value $l_1=0$. Isochrons were constructed using the recommended values of route intervals and normalized communication speeds for various modes of transport in actual real time based on data from surveys of traffic speeds and delays on the way by the method of «arrivals in the stream» (Toguzova,et al., 2022).

To determine $T_{communication}$ the difficulty of communication in the calculations, an isochronogram relative to the city center was combined with a point planogram of population placement, taking into account the population in each time zone. The difficulty $T_{communication}$ indicator of the message was determined by the formula (9), the calculation was made in tabular form (Table 2).

№ zones bet-ween iso-chrones	Zone boun-daries between isochro-nes, min.	Num-ber of inhabi-tants $N_{i-(i+1)}$, thousand people	Average travel time to city center, $\dfrac{T_i + T_{i+1}}{2}$, min.	Moment $\dfrac{N_{i-(i+1)} \cdot (T_i + T_{i+1})}{2}$
1	1 - 10	88,4	5	1170
2	10 - 20	29,4	10	110
3	20 – 30	20,0	15	80
4	over 30	42,2	25	720
Total		180,0		2080

Table 2. Calculation of the difficulty of communication with the center of the city of Ust-Kamenogorsk.

The difficulty of communication with the city center was:

$$T_{\text{communication}} = \frac{\sum_1^n N_{i-(i+1)} \cdot (T_i + T_{i+1})}{2N} = 11{,}6 \ \text{min}, \ (9)$$

where $N_{i-(i+1)} =$ is the population in the zone between adjacent isochrones i and $i+1$

$i, i+1=$ indices of isochrones
$N=$ population of the city
$n=$ the number of isochrones

The efficiency coefficient of the system was determined by the formula:

$$\varepsilon = \frac{t_{communication}}{T_{ccmmucation}} = \frac{V_{movement}}{V_{walker}} = \frac{15}{11{,}6} = 1{,}30, \quad (10)$$

where $t_{communication} =$ pedestrian difficulty of communication with the city center, min
$V_{movement} =$ average final conditional speed of movement of the population to the main transport hub, km/h
$V_{walker} =$ walking speed, km/h. $V_{walker} = 4.2$ km/h

The value $t_{communication}$ was calculated by the formula:

$$\text{t}_{\text{communication}} = \frac{60 \cdot L_{\text{remoteness}}}{V_{\text{walker}}} \approx 15 \ min, \quad (11)$$

where $L_{remoteness} =$ is the actual distance of the population from the main transport hub or city center, $L_{remoteness} = 1.03$ km

The above calculation indicates the transport problems of growing micro-districts located on the left bank of the Irtysh River, the city of Ust-Kamenogorsk, these problems are especially evident during peak hours of the city's traffic load.

2.5 Forecasting and organization of UPT using fuzzy set theory and fuzzy logic

When searching for optimal design solutions in the process of urban passenger transport management, there is a need for multifactorial system accounting of both internal route parameters and external factors on its dynamics.

Therefore, an urgent task is to use mathematical modeling that allows you to calculate the time (flight time, turnaround time and interval), provided that the route parameters are changed, indicating the route scheme on the GIS.

To formalize the route management process for transport performance indicators, for example, "FLIGHT TIME" and "INTERVAL", two methods can be used.

The first method involves the use of fuzzy set theory and fuzzy logic. L. Zadeh introduced the concept of fuzziness and developed this concept into the theory of fuzzy sets and fuzzy logic. Fuzziness is a concept related to such sets in which gradations of the degree of belonging to them are possible, from complete belonging to complete non-belonging, i.e. such a class of objects in which there is no sharp boundary between objects with full belonging to it and its environment.

To describe fuzzy sets, the concepts of fuzzy and linguistic variables are introduced, the values of which are not numbers, but natural language words called terms. To set a fuzzy variable, you need (Abedzhanova, 2007):
the name of the variable;
universal set (measurement range);
fuzzy set is universal.

In the case of passenger transport management, the following linguistic variables are used: "NUMBER OF BUSES (QUANTITY)" - an estimate of the number of buses; "FLIGHT TIME" - the flight time of the route; "INTERVAL" - the interval of the route.

The linguistic variable "QUANTITY" can be defined by five terms: VERY SMALL, SMALL, MEDIUM, HIGH and VERY HIGH.

The linguistic variable "FLIGHT TIME" can be represented by three terms: SMALL, MEDIUM and LARGE (meaning flight time).

The linguistic variable "INTERVAL" is also represented by three terms: SMALL, MEDIUM and LARGE.

The trapezoidal function of the form is most often used as membership functions

$$MF(x) = \begin{cases} 1 - \dfrac{b-x}{b-a}, a \le x \le b \\ 1, b \le x \le c \\ 1 - \dfrac{x-c}{d-c}, c \le x \le d \\ 0. \end{cases}$$

The effectiveness of the application of fuzzy set theory and fuzzy logic leads to a decrease in the flight time and the interval of movement between buses; an increase in the average bus service on the stages between stops.

The main disadvantage of fuzzy logic is the lack of a single method of modeling systems, i.e. for each case it is necessary to re-design a fuzzy subroutine, determining step by step all the parameters and building its own table of solutions.

The second method proposed in this paper is to use the generalized Harrington desirability function (scale).

The use of traditional fuzzy logic in modern systems is extremely limited by the following factors:
as a rule, a complex control system has more inputs than the most ordinary fuzzy application;
adding input variables increases the complexity of calculations exponentially;
as a consequence of the previous paragraph, the rule base increases, which leads to its difficult perception (let me remind you, the rule base is typed manually);
operations on a real scale.

For this purpose, Steven Goodridge suggests using a system that processes big data using several fuzzy microcontrollers combined together. This approach allows you to efficiently manage fuzzy processes that are difficult to describe.

 Each element of the resulting fuzzy network is designated as a fuzzy node. Now, if you link the output of one node with the input of another, all calculations are noticeably simplified. This approach is called fuzzy precomputation (Figure 5).
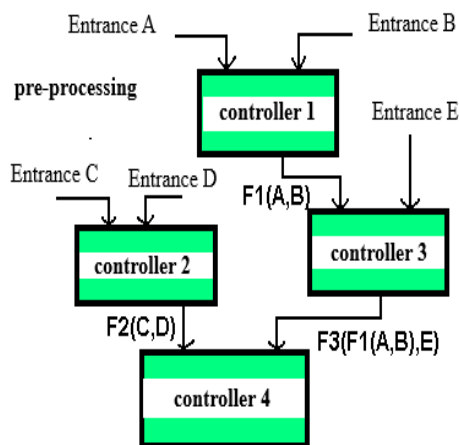

Figure 5. Fuzzy precomputations.

In addition, the outputs of fuzzy nodes can be combined using a multiplexer. In this way, a smoother transition is achieved between the set of recommendations obtained after processing the rule base (Figure 6).
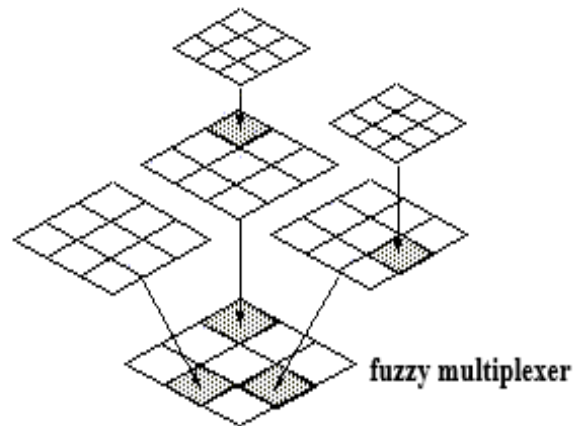

Figure 6. Fuzzy multiplexer.

The main program works as follows: with the help of a random number generator built into Matlab, the number of buses is generated during one flight time for the North-South and West-East directions.

Some of the buses from this number manage to complete the route during the flight, the rest stop the movement if the interval between routes is the minimum calculated value. All those buses that remained at the initial or final destination are considered unserved applications.

The average number of unserved applications for a given number of buses is taken as an indicator of the effectiveness of this system. Accordingly, the less important the efficiency indicator is, the more buses serve the route.
The number of buses should not be too small, because in this case objective information is not obtained, or too large, because the program will take a very long time to calculate the required value. The recommended number of cycles in the whole city is 100.

Thus, the algorithm of the program is as follows: the 1C: Enterprise platform database receives information about the number of passengers and other indicators from sensors.

These data are translated into a fuzzy format according to the specified membership functions, then, their processing takes place inside the subroutine, the resulting value of the change in the time interval of movement is defuzzified (i.e. translated back into a clear format) and enters the database as a control signal to generate a motion graph. According to this signal, the flight time in the next flight or turn will be different. The result of calculations is presented in the form of a graph (Figure7).
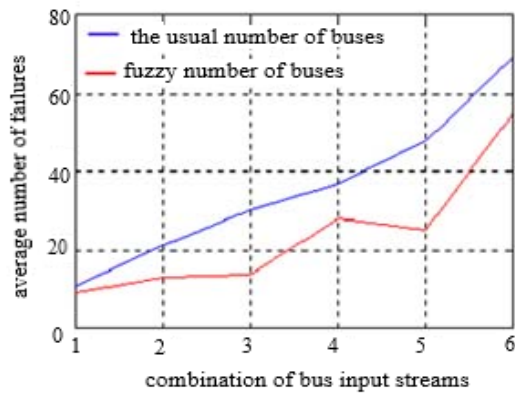
Figure 7. Calculation results.

The practical use of such an approach to the management and organization of passenger transportation is supposed to be implemented in an adaptive control system with visual control, designed in the form of a geoinformation model of the city on the map of the road network. Currently, the application "OckemenBus" is used in the city of Ust-Kamenogorsk.

Therefore, using the standard interface of the geoinformation system shell makes it easy to adapt the control system for an arbitrary configuration of the road network. For example, it is possible to show changes in the existing application "OckemenBus" (Figure8).
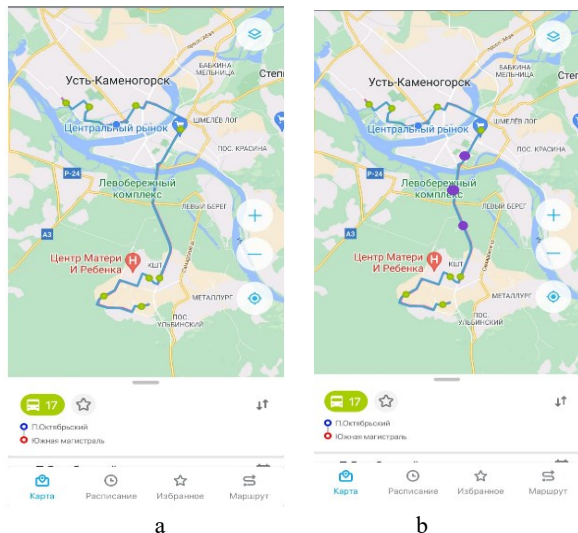

Figure 8. Example of a bus route number 17 in Ust-Kamenogorsk: a- the existing scheme, b – the proposed scheme.

When changing the configuration of roads and streets (the appearance of new roads and streets, bus stops, updating old ones, redesigning intersections, replacing the intersection with a multi-level interchange, etc.), standard means of geoinformation systems make it easy to make the necessary changes to the UPT organization system.

As shown in Figure 8, it is necessary to additionally include three buses in the route. In the geoinformation model, the route, the number of buses and the traffic pattern are presented in color design for visual control by the dispatcher of the control center.

Further improvement of the software package is possible thanks to the development of algorithms and the construction of modules for scheduling routes of passenger vehicles.

3. CONCLUSIONS

To optimize the UPT, an automated system is proposed using the 1C Platform for a database, an assessment of the city plan in terms of transport needs, the theory of fuzzy logic and fuzzy sets, and the use of GIS. The proposed system is used both for modeling various situations such as changes in passenger traffic, calculating the cost of passenger-hour, transport costs and for optimizing traffic flows. The optimization algorithm takes into account the transfer rate of passenger traffic and other indicators, so the software package can be used to optimize the operation of UPT in small, medium and large cities (taking into account the transfer rate).

It should be noted that any standard interface of a geoinformation system allows you to embed an automated UPT management system into the passenger transportation control center. In this case, it becomes possible to manage the UPT, namely, to open and coordinate various routes, change traffic patterns, the length of the stretch, etc. The central management provides an operational exchange of information between various services and the UPT management system.

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