Using Simulation to Evaluate Shuttle Service Efficiency

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Abstract: The work is devoted to the study of the influence of the Smart City concept on the city transport system. It is shown that in cities where industrial zones are separated from residential ones, there are problems with increasing transport load in the morning and evening peak hours. Various methods (special routes, special tariffs, etc.) are used to solve the problem of delivering workers to places of work, but, in our opinion, these solutions should be combined with the concept of E-mobility, which implies both a transition to environmentally friendly types of transport, and an increase in the stability of the transport system by reducing the intensity of the traffic flow. This can be done through the organization of shuttle service of enterprises' employees, which will allow to refuse using of personal cars for trips to work. An example of the solution of the transport routing problem for the Naberezhnye Chelny city is given.

1 INTRODUCTION

Having entered the third millennium the modern human civilization has faced global problems. Poor air quality, climate change, unhealthy lifestyles and a lack of balance between society and the natural environment have an increasing impact on human health and create new risks. All this requires radical changes in energy, mobility and urban systems, which are reflected in the concept of Smart City.

In recent years in the field of architecture and urban science more attention is paid to the implementation of the Smart Cities concept (Williamson B., 2015). The main goal of creating Smart City is to ensure the sustainable development of cities and preserve the quality of life of their citizens (Pribyl O., Svitek M., Lom M., 2016). This concept combines various technologies that contribute to reducing the negative impact on the environment, which will ensure a more comfortable living conditions. At the same time, it is necessary to take into account the peculiarities of cities' planning decisions, which have a significant impact on both the population mobility and the stability of the transport systems in general.

2 METHODS

The solution can be the implementation of E-mobility concept, which implies two ways: the transition to sustainable (public) and environmentally friendly (non-motorized and electric transport) types of transport, as well as minimizing the need for movement of residents through the management optimization (Pribyl O., Svitek M., Lom M., 2016). If it is impossible to refuse trips or minimize them, you can reduce the number of vehicles on the city roads by optimizing their occupancy and more rational use of carrying capacity. This initiative aimed at improving the environmental efficiency and sustainability of urban systems will help reduce the negative impact on the environment caused by human activities.

One of these methods of reducing the intensity of the traffic flow is the organization of shuttle service of enterprises' employees, which can bring the following benefits:

- improvement of the workers' health due to the lack of stress associated with the regular driving of a personal vehicle;

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- enhancement of the company's image as an organization that provides additional bonuses to its employees in the form of free transport;
- increase of corporate culture and social interaction of employees through regular joint trips;
- savings for the enterprise, since the organization of a suburban transfer can be a cheaper way than the construction and maintenance of parking for the personal transport of employees;
- implementation of an environmental mission to reduce the level of exhaust gas both by a single employee and by the enterprise as a whole ("5 Reasons Why Employee Shuttles Are Good For Business", 2019).

Highlighting shuttle service as one of the key practices of E-mobility, foreign researchers note the need for efficient routing algorithms for this type of public transport (Zhao, Y., Zhou, H., Liu, Y., 2017.; Wicaksono A., Pasa Pratama P., Sulistio H., Kusumaningrum R., 2017).

The transport system is one of the main intelligent systems in Smart City. Ensuring its safety and sustainability is conducted in three directions: smart infrastructure, smart vehicles, smart users.

For solving the problem of population's mobility it is necessary that the carrying capacity of the city's transport system conforms to the transport needs of its inhabitants. Searching for more rational ways of using existing road capacity requires the creation of intelligent traffic control systems (Tretyakova, M.L., 2015).

The first generation of Intelligent Transport Systems (ITS) focused on improving vehicle efficiency and driver awareness to ensure the safety and comfort of transport service consumers. For solving such problems microscopic simulation models are used (Bakibayev, T., Bekmagambetova, G., Turarbek, A., 2015). Macroscopic models of vehicle traffic imitate determining the dynamics of the flow, the maximum road and infrastructure capacity (Viti, F., Tampere, C., 2014.).

From a technological point of view a huge breakthrough in the field of ITS occurred in the last decade, when wireless communication between sensors and decision support systems (DSS) was developed (Tsybunov, E., Shubenkova, K., Buyvol, P., Mukhametdinov, E., 2018). This made it possible to implement integrated multi-object systems (Wismans, L., Berkum, E., Bliemer, M., 2014), for example, to solve the problems of intellectualization of traffic lights (Gorodokin, V., Almetova, Z., Shepelev, V., 2017; Makarova, I., Shubenkova, K., Mavrin, V., Buyvol, P., 2018).

Any DSS can't be implemented without an intelligent core, a module, that taking into account a wide range of characteristics of the traffic flow, the patterns of influence on it of a large number of external and internal factors, will make well-founded management decisions in the field of traffic management. The intelligent core can be a program module for improving the urban passenger transport network, since the vehicle routing problem is one of the most important in the management of urban passenger transport (Makarova, I., Khabibullin, R., Shubenkova, K., 2015).

The construction of city's bus transport routes can be attributed to the stochastic problem of transport routing, where the demand for transportation varies randomly depending on a large number of factors.

Since the city's public transport route network is a complex system, and its optimization is a complex multi-parameter task, a scientifically grounded solution when developing and adjusting it requires heuristic, meta-heuristic, fuzzy logic methods (Belyakov, S., Savelyeva, M., Kiyashko, D., Lashchenkova, A., 2018), and modeling of processes using a mathematical apparatus.

Today criterion function in developed mathematical models is one of the following characteristics:

- the minimum total time spent by passengers for the whole process of moving;
- the minimum waiting time at the stopping point;
- the minimum total costs for the movement of vehicles along the routes per unit time;
- the maximum profit of the transport company taking into account the costs of operating vehicles (Makarova, I., Khabibullin, R., Shubenkova, K., 2015).

However, it should be borne in mind that obtaining an analytical solution using mathematical models used to describe multiparametric processes in multifunctional systems may require considerable resources. When solving this class of problems, it is more rational to use information technologies in the form of simulation models of transport systems, since they can be applied to determine the optimal state of the systems under study for different values of the parameters repeatedly (Makarova, I., Khabibullin, R., Shubenkova, K., 2011). Today for simulating transport flows, software packages such as the programs of PTV Vision (VISUM and VISSIM), AnyLogic, GPSS World, Dracula, Paramics, Sistm, etc. are used (Devyatkov, V., Vlasov, S., Devyatkov, T., 2009).

Each program of simulation has its advantages and disadvantages. So, GPSS World is characterized by a simple user interface, not enough functional models editor, poorly automated research technology, an outdated way of presenting and analyzing results, etc. The main advantage of AnyLogic is that it is the only simulation tool that combines system dynamics, agent and discrete-event modeling. The disadvantages of AnyLogic can be attributed to the fact that when modeling such a complex multi-parameter process as road traffic, for a good performance requires a powerful processor. Therefore, for modeling traffic flows it is more productive to use specialized packages, such as programs of PTV Vision, which simulate various motion scenarios at both the micro level (VISSIM) and the macro level (VISUM).

3 RESULTS AND DISCUSSION

For verifying the adequacy of the above theoretical provisions the Naberezhnye Chelny city was chosen. The planning structure of the city was based on a linear structure of the open type with a "classical" functional zoning, with a parallel location of industrial and residential areas, a suburban recreation area. Transport-planning framework of the city is a longitudinal highway connecting the city's residential areas, which gives grounds for attributing the planning scheme of its street-road network to a rectangular one. The main "diameter" of the city is the longitudinal highway, which includes M. Jalil Ave., Naberezhnochelninsky Ave., Mira Ave.

Today, Naberezhnye Chelny has 28 routes of municipal passenger transport, 14 tram routes and 14 passenger transport routes involved in the transportation of KAMAZ employees. However, the industrial zone also includes areas that can't be reached by any of the existing routes. The BSI zone is deserved particular attention from the point of view of transport accessibility: if other city's industrial zones are connected with residential by tram or bus routes, 20.3 thousand employees of 195 enterprises located on the BSI are forced to get to their jobs on private vehicles. This leads to the fact that the carrying capacity of the road linking residents to their place of work can't cope with the load estimated at 20,000 vehicles per day.

For solving this problem it is necessary to determine what will be more effective - using regular public transport or shuttle service. Since the main demand for transportation to this city's industrial zone falls on the morning and evening hours, the functioning of regular public transport routes can be disadvantageous. At the same time, the organization of shuttle service on the enterprises located in the considered zone also involves several problems:

1. the need to organize the delivery of employees of different enterprises located in close proximity to each other on one bus;
2. the need to agree on schedules for the beginning and end of the working day of all enterprises located in this zone;
3. the need to develop such routes to ensure the delivery of workers from different points of the city, as well as neighboring settlements, to the designated hour for a certain (limited) period of time, with a minimum number of vehicles and with minimal costs;
4. shuttle routes should be laid in such a way as to minimize the mileage, and at the same time avoid overloaded sections of the road network.

In such conditions, it is possible to adopt the optimal management decision in the sphere of passenger transportation organization in Naberezhnye Chelny only by analyzing the existing situation and choosing the best possible option, taking into account the redistribution of the transport load to the problem areas of the street-road network (SRN).

The mathematical formulation of the problem consists in the need to determine the performance indicator, describe the variables of the model influencing it, and also to determine the fundamental and technical limitations so that the problem is correct and solvable.

The performance indicator (objective function or optimization parameter) should be measurable, and, most importantly, really evaluate the effectiveness of the system in a pre-selected sense. Since when organizing urban transportation it is necessary to satisfy the needs of the population in moving for the minimum time, as well as reduce the transport load on the problematic sections of the SRN, the target functional of the model is:

$$\begin{cases} Z_1 \rightarrow \min, Z_1 = f(X_i^1) \quad \text{- total number of route vehicles;} \\ Z_2 \rightarrow \min, Z_2 = f_1 + f_2 + f_3 + f_4 + f_5 \quad \text{- average passenger delive} \end{cases} \quad (1)$$

where X_i^1 – number of vehicles on the i-th route;

f_1 – average passenger stopping time;

f_2 – average passenger waiting time for a bus;

f_3 – average time of embarkation and debarkation of passengers;

f_4 – average delay time of vehicles at a stop due to waiting in line for supplying vehicles to the place of embarkation and debarkation;

f_5 – average bus ride time.

After formulating the optimization criterion, it can begin to build a transport model, which is a software package consisting of a network model, a demand model for transport, and an impact model. The network model is an image of a road network in the form of nodes and segments superimposed on a map of the city taking into account the scale for subsequent automatic calculation of the length of each section. The demand model consists of many demand objects and describes the transport needs of the population using the standard four-stage model integrated in the PTV VISUM software package. The network model and the demand model are the basis for constructing a model of impact (on the user, on the carrier, on the environment).

The user model allows to select the optimal route for moving the passenger, which forms the basis for constructing cartograms of transport loads on sections of the city's SRN. The core of the motion simulation procedures are search algorithms that calculate the paths between transport areas. In PTV VISUM, the routing problem can be solved either by the branch and bound method (VISUM User Manual, 2018), or reduced to the task of finding the shortest paths.

When applying the branch and bound method in the PTV VISUM transport model for each passenger flow formation area, a search tree for suitable partial routes is generated in which all fairly good route options are saved. The result is not just one best route, but many good options, which further ensures a differentiated distribution of transport demand between routes. To assess the quality of the considered route options, the so-called "search resistance" is used in PTV VISUM. It is the sum of functions such as travel time and frequency of transfers. A feature of the branch and bound method, adapted for PTV VISUM, is that, in principle, if single route option was optimal at some level of research it is not deleted.

When routing, the optimal route can also be determined by solving the "shortest path problem." In this case, the road network is presented in the form of a graph, where road junctions are the peaks, and roads are the edges connecting them. One-way streets can be represented by oriented ribs. This method also allows to enter the characteristics of the ribs to indicate priority directions of movement. The weights of the ribs can be calculated on the basis of the length of the SRN section or the time and money costs of moving along this section (Abraham, I., Delling, D., 2010). In PTV VISUM, if the shortest path search method is used, which is performed according to only one criterion, the best route option is established between two transport areas. The search procedure determines the path with the smallest "search resistance", that is the best route will be considered for which a linear combination of travel time and transfer frequency is minimal.

For this purpose, a city's transport model was built in the environment of macroscopic modeling VISUM, and then the calculation of the distribution of traffic loads along sections of the street-road network was carried out. Figure 1a shows the peak load on the road segment linking the city's residential area to the BSI zone (red figures indicate the number of private vehicles passing through these sections, and blue figures indicate the number of public transport passengers). Passenger traffic is 9450 vehicles per peak-hour, which exceeds the capacity of this site by more than 2000 vehicles. Verification and validation of the model was carried out by comparing the calculated values with the data obtained as a result of field observations.

For carrying out the analysis of "what will happen if ..." a shuttle route was added to the city's transport model, where buses powered by Nefaz 5299 gas-engine fuel with a nominal capacity of 119 people operate. The choice of this fleet is due to the need to improve the environmental friendliness of transportation. When selecting the optimal number of substations, the PTV VISUM "Create Revolutions" procedure was used. The calculated time of the bus's turnover along the route was 40 minutes. The possibility of organizing the delivery of employees to the enterprises at the beginning of the working shift at 6:00, 7:00 and 8:00 is considered. In this case, the transport load can be reduced from 9,450 to 7,200 individual transport units, if three buses are used on the route (Figure 1b).

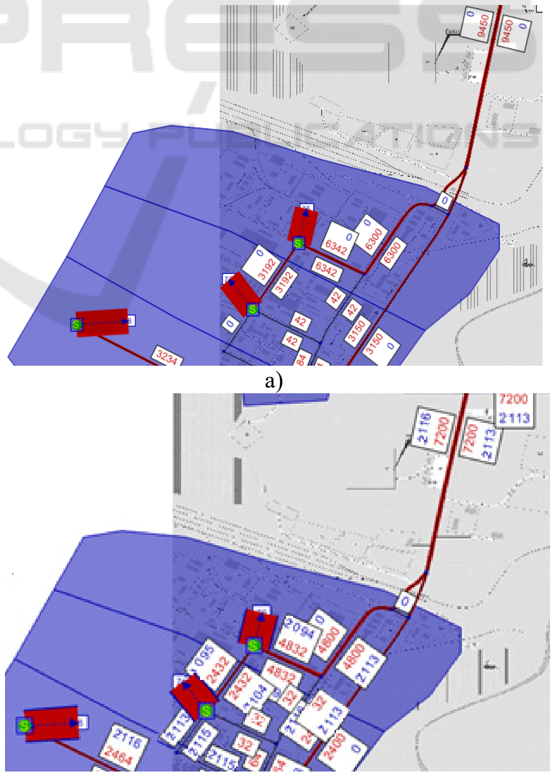

Figure 1: a) Existing transport load in the zone of the BSI, b) Expected transport load when adding a shuttle route.

4 SUMMARY

Managing urban passenger transport is a complex task, the solution of which is impossible without the intellectualization of management. Existing domestic and foreign experience shows that the implementation of management decisions in the field of transport should be carried out only after they are tested on models (both analytical and simulation). Modern means of simulation allow to solve problems of different levels in complex systems. The choice of a particular system is performed depending on the task class and system capabilities. For modeling the city's transport systems and solving routing problems, the optimal option is the environment of macromodelling VISUM. The shuttle operations allow solving a number of tasks that are related to the optimization of processes in both the transport and production systems. The adequacy of the proposed solution was tested on a model developed for the Naberezhnye Chelny city. When developing the transport model, methods of transport routing, determination of passenger traffic and transport correspondence, simulation, computer experiment were applied. After verification and validation of the developed model, a computer experiment with current parameters and with the shuttle route was conducted. Experiments on the model showed that the opening to the BSI zone of the shuttle route would reduce the transport load on the problem area of the city's road network by 21%.

5 CONCLUSIONS

Growing motorization of the population along with problems in the organization of public transport created a number of problems that adversely affect the functioning of the city's transport system and its security. This causes both economic and environmental damage and negatively affects the environment and health of city residents. The concept of Smart City implies the creation of an urban area that provides sustainable economic development and a high quality of life through superiority in many key areas. Realization of the main goal of sustainable mobility is to gain access to destination points for city's residents while reducing the negative impact on the environment. This can be achieved either by switching to environmentally friendly transport, or by reducing the number of trips by private transport due to the predominant use of public transport. In the case of separation of residential and industrial zones one of the effective methods of solving the problem is the creation of new opportunities for collective mobility – using of shuttle service of enterprises' employees. Simulation is the best way to find the best option of a new shuttle transportation route.

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REFERENCES

"5 Reasons Why Employee Shuttles Are Good For Business", access mode: https://shuttleexpress.com/5-reasons-employee-shuttles-good-business// (accessed 14.04.2019).

Abraham, I., Delling, D., 2010. A Hub-Based Labeling Algorithm for Shortest Paths on Road Networks. In *SODA 2010,* access mode: https://www.microsoft.com/en-us/research/wpcontent/uploads/2010/12/HL-TR.pdf.

Bakibayev, T., Bekmagambetova, G., Turarbek, A., 2015. Reversible Express Bus Lanes Simulation Software. In *Embracing Global Computing in Emerging Economies, Communications in Computer and Information Science*, № 514, pp. 54-63.

Belyakov, S., Savelyeva, M., Kiyashko, D., Lashchenkova, A., 2018. Decision-Making on Flow Control Under Fuzzy Conditions in the Mechanical Transport System. In *Advances in Intelligent Systems and Computing*, № 641, pp. 168-176.

Devyatkov, V., Vlasov, S., Devyatkov, T., 2009. GPSS World modeling language and simulation automation system: application experience and use perspectives. In *IV Russian scientific-practical conference "Simulation modeling, theory and practice"*, vol. 1, pp.11-18.

Gorodokin, V., Almetova, Z., Shepelev, V., 2017. Procedure for calculating on-time duration of the main cycle of a set of coordinated traffic lights. In *Transportation Research Procedia*, № 20, pp. 231-235.

Makarova, I., Khabibullin, R., Shubenkova, K., 2011. Decision support system as a means of managing the city's transport system. In *Transport: science, technology, management*, vol. 9, pp. 57-60.

Makarova, I., Khabibullin, R., Shubenkova, K., 2015. Optimization of the route network of passenger transport using the city's transport model. In *The world of transport and technological machines, Orel: State University-UNPK*, №3 (50), pp.103-114.

Makarova, I., Shubenkova, K., Mavrin, V., Buyvol, P., 2018. Improving safety on the crosswalks with the use of fuzzy logic. In *Transport Problems*, vol. 13, iss. 1, pp. 97-109.

Pribyl O., Svitek M., Lom M., 2016. Industry 4.0 as a Part of Smart Cities. In *Smart Cities Symposium, Prague*, pp. 1-6.

Tretyakova, M.L., 2015. Intelligent transport systems and technologies as a factor in ensuring road safety. In *Alternative energy sources in the transport-technological complex: problems and perspectives of rational use*, vol. 1, pp. 302-305.
Tsybunov, E., Shubenkova, K., Buyvol, P., Mukhametdinov, E., 2018. Interactive (Intelligent) Integrated System for the Road Vehicles' Diagnostics. In *Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering*, vol. 222, pp. 195-204.
VISUM User Manual, access mode: http://www.chinautc.com/information/manage/UNCC_Editor/uploadfile/20081105144806983.pdf (accessed 17.07.2018).
Viti, F., Tampere, C., 2014. Models and Technologies for Intelligent Transportation Systems: New Challenges and Metaheuristic Solutions for Large-Scale Network Applications. In *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations*, № 18, pp. 1-4.
Wicaksono A., Pasa Pratama P., Sulistio H., Kusumaningrum R., 2017. Review on Operational Performance of Employee Shuttle Service in Industrial Areas of Jababeka-1, Cikarang, West Java. In *MATEC Web of Conferences*, vol. 103.
Williamson B., 2015. Educating the smart city: Schooling smart citizens through computational urbanism. In *Big Data & Society*, July-December, p. 1-13.
Wismans, L., Berkum, E., Bliemer, M., 2014. Acceleration of solving the dynamic multi-objective network design problem using response surface methods. In *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations*, № 18, pp. 17-29, access mode: http://www.tandfonline.com/doi/full/10.1080/15472450.2013.773250#abstract.
Zhao, Y., Zhou, H., Liu, Y., 2017. A Cost-Effective Offline Routing Optimization Approach to Employee Shuttle Services. In *SAE Technical Papers*.