Keywords: simulation mathematical model; urban transport network; information system; SIMUL8

Vladimir NEMTINOV*, Yulia NEMTINOVA, Andrey BORISENKO, Vladimir MOKROZUB
Tambov State Technical University
Sovetskaya, 106, 392000 Tambov, Russia
**Corresponding author*. E-mail: nemtinov@mail.gaps.tstu.ru

INFORMATION SUPPORT OF DECISION MAKING IN URBAN PASSENGER TRANSPORT MANAGEMENT

Summary. In this paper, we examine the problems of simulating modeling of urban transport route network operation and development of an information system for automating the process of modeling and processing of simulation results with SIMUL8 software. In order to solve this problem, it is required to solve the following set of related tasks: formal description of the urban transport systems structure and parameters of its functioning, development of mathematical models of urban transport network performance, database structure and an algorithm for simulation model creation.

1. INTRODUCTION

Nowadays, urban traffic has become a complex dynamic system in many cities all over the world, which is characterized by a high level of uncertainty of initial information and complexity of its behavior. The number of vehicles has increased exponentially, but the bedrock capacities of roads and transportation systems have not developed in an equivalent way to efficiently cope with the number of vehicles traveling on them. Due to this, road jamming and traffic correlated pollution have increased with the associated adverse societal and financial effect on different markets worldwide [1]. In order to solve many of the problems associated with urban traffic management, it is appropriate to use computer modeling based on system analysis aimed on building a generalized model that reflects all the parameters of the real system. Computer modeling greatly enhances the efficiency of decision makers' work by providing them a convenient tool for achieving their goals. It implements iterative development of the model, step by step detailing of the simulated subsystems, which allows gradually increasing assessment accuracy as new issues and new information are identified. Current trends in the field of simulation are associated with development of problem-oriented systems, creation of built-in tools for integration of models into a single complex; technological level of modern simulation systems is characterized by a large selection of basic concepts of formalization and structuring of simulated systems, developed graphical interface and animated displaying of the results [2, 3].

A transport system is one of the main components of the city's infrastructure, which provides satisfaction of vital needs of the population. Functioning of all branches of the city's economy is not possible without efficient and structured operation of an urban transport system (UTS). Therefore, its rational planning and development become one of the urgent problems of the UTS planning theory and practice. Planning includes tasks connected with centralized decision making aimed at using UTS resources. This group includes planning of transport system development, routing, scheduling, etc. [4].

The growth of concentration and increasing share of urban population is an objective trend of modern social development. Rapid growth of urban population and increase of its mobility give rise to a number of problems related to development of transport systems in the cities. The scope of the urban traffic control (UTC) work and its importance within continuous urbanization and saturation with vehicles require a wide range of scientific research and practical work aimed at improving urban transport networks (UTN).

The problem of urban traffic control and management has been extensively discussed in the literature. The history of urban traffic control and management throughout the past century has been a continued race to keep pace with ever more complex policy objectives and consistently increasing vehicle demand. Many benefits can be observed from an efficient UTC system, such as reduced congestion, increased economic efficiency and improved road safety and air quality. In this connection, the paper by Hamilton et al. [5] considers current and future transport policy and technological landscape in which UTC needs to operate over the coming decades, where technological advancements are expected to move UTC from an era of limited data availability to an era of data abundance.

Nellore and Hancke [1] present a survey of current urban traffic management schemes for priority-based signaling, and reducing congestion and the Average Waiting Time (AWT) of vehicles. The main objective of this survey is to provide taxonomy of different traffic management schemes used for avoiding congestion. Existing urban traffic management schemes for the avoidance of congestion and providing priority to emergency vehicles are considered and set the foundation for further research.

A system for heterogeneous stream processing and crowdsourcing supporting intelligent urban traffic management is presented in [6]. To deal with data veracity, a crowd sourcing component handles and resolves sensor disagreement, and a traffic modeling component offers information in areas with low sensor coverage. The system with a real-world use-case from Dublin city, Ireland, is demonstrated.

Osorio and Nanduri [7] propose a methodology that combines a stochastic microscopic traffic simulation model with an instantaneous vehicular fuel consumption model. The proposed technique couples detailed, stochastic, and computationally inefficient models, yet is an efficient optimization technique. Efficiency is achieved by combining simulated observations with analytical approximations of both travel time and fuel consumption. This methodology is applied to a network in the Swiss city of Lausanne.

In the paper by Dang et al. [8], there is a discussion about the perspective of the energy-circle cards platform in modern cities, applied aspects, feasibility, impacts on urban traffic management and specific ways to put intelligent urban traffic management system based on the energy-circle cards platform (the IUTMS) into practice according to the development situations at home and abroad.

A paper by Li et al [9] takes Shenzhen Futian comprehensive transportation junction as the case and makes use of continuous multiple real-time dynamic traffic information to carry out monitoring and analysis on spatial and temporal distribution of passenger flow under different means of transportation and service capacity of junction from multi-dimensional space-time perspectives such as different period and special period. Virtual reality geographic information system is employed to present the forecasting result.

To reduce traffic delays and traffic emissions for urban traffic networks, Lin et al. [10] propose an integrated macroscopic traffic model that integrates a macroscopic urban traffic flow model with a microscopic traffic emission model for individual vehicles. This integrated model is able to predict the traffic flow states and the emissions released by every vehicle at different operational conditions, i.e., the speed and the acceleration. Then, model predictive control (MPC) is applied to control urban traffic networks based on this integrated traffic model, aiming at reducing both travel delays and traffic emissions of different gases. Finally, simulations are performed to assess this multiobjective control approach.

Baldi et al. [11] conducted a study to analyze the performance of an adaptive traffic-responsive strategy that manages the traffic light parameters (the cycle time and the split time) in an urban network to reduce traffic congestion. The proposed traffic-responsive strategy adopts a nearly optimal control formulation: first, an (approximate) solution of the HJB is parametrized via an appropriate Lyapunov positive definite matrix; then, the solution is updated via a procedure that generates candidate control strategies and selects at each iteration the best one based on the estimation of close to optimality and the information coming from the simulation model of the network (simulation-based design). Simulation results obtained using an AIMSUN model of the traffic network of Chania, Greece, an urban traffic network containing many varieties of junction staging, demonstrate the efficiency of the proposed approach.

In the paper by Sun et al. [12], the architecture of the intelligent collaborative urban traffic management system based on Service Oriented Architecture (SOA) and cloud computing is proposed. A collaborative service model based on SOA is given to realize intelligent collaborative management of urban traffic. The technology of service request and response dispatching based on SOA is proposed in the paper to match the collaborative event processing. Mass calculation was realized by the application of the cloud computing platform. The system fundamentally realizes the intelligent monitoring and management of urban traffic and realizes the purpose of intelligent dredge of urban traffic.

The study by Kim et al. [13] aims on investigating direct and indirect influence areas from incidents on urban interrupted roadways and in order to develop traffic management strategies for each influence area. Based on a literature review, various traffic management strategies for certain incidents were collected. In addition, the relationship between the measure of effectiveness and the characteristics of incidents was explored using an extensive simulation study. The direct and indirect influence areas resulting from incidents were defined, and traffic management strategies were established for each direct and indirect influence area and for each level of incident.

The article by Pamula [14] reviews neural networks applications in urban traffic management systems and presents a method of traffic flow prediction based on neural networks. It describes neural networks features, which allows them to be used to solve optimization tasks involved in designing optimal road traffic control strategies in urban traffic systems. In presented examples, neural networks estimate road infrastructure throughput and length of waiting vehicles queue.

The aim of this work is to develop a mathematical model of the UTN functioning, which has maximal resemblance to the real situation in urban passenger transportation networks, and the mechanism, which allows automating the process of simulation model development for further computer experiments. In order to solve this problem, it is required to solve the following set of related tasks: formal description of the UTN's structure and parameters of its functioning, development of mathematical models of UTN performance, database structure and an algorithm for simulation model creation. A number of visual modeling tools are widely used for simulation. SIMUL8 is a universal simulation tool for the described class of problems [15].

2. DEVELOPMENT OF A MATHEMATICAL MODEL OF TRANSPORT NETWORK FUNCTIONING

The most common and obvious approach to the description of a transport network is its representation as a graph. Nodes of the graph represent stopping points (stops) - specially equipped places for boarding and exiting of passengers. Edges of the graph are identified with stretches between the stopping points. Their main characteristics are length and maximum permissible speed. Vehicles in the network move along predetermined routes. A route is a list of stopping points, which are toured by a vehicle in a predetermined order. Each route is characterized by control points. These are stopping points, where actual arrival time is compared with the scheduled arrival time.

Presentation of a transport network as a graph gives a possibility of using a large number of existing algorithms for computerized optimization of transport routes based on the results provided by the model.

The mode of transport network functioning is regulated primarily by the schedule. It provides information on the number of vehicles on each route, the number of hauls for each vehicle and the time of going through the control points on the route. Thus, by optimizing the work of UTN we primarily mean determination of an optimal schedule, as well as the characteristics of vehicles, which include speed, capacity, service costs, fares, etc.

Scheduling is a usual linear programming problem, but in practice it is not so. The schedule is influenced by such external factors as traffic jams, accidents, and traffic lights. Thus, the schedule drawn up with usual methods has to be checked on a simulation model (which takes into account the aforementioned nuances) and based on the results of its execution adjustments can be made into the transport network operation.

In this regard, the purpose of this work is to solve the problem of minimizing waiting time for the passengers on the busiest routes of the city transport network, as well as to determine the optimal number of vehicles en route, depending on the operating time during weekdays, weekends and holidays.

Since UTN is a complex dynamic system and is characterized by a large number of stochastic data, its mathematical model is based on different kinds of probabilities.

Background information for the mathematical model of transport network functioning can be described by the following parameters: $n_{ik}^{l}(t)$ – the number of passengers, who get on the *i*-th route at the *k*-th stop at time *t*; $n_{ik}^{m}(t)$ – the number of passengers, who get off the *i*-th route at the *k*-th stop; L_{j}^{i} – the distance between the *i*-th and *j*-th stopping points; N_i – the number of vehicles on the *i*-th route.

$R_{ic} = \{t_{ik1}, t_{ik2}, ..., t_{ikn}\}$ – UTN timetables, where *i* – route number, *c* – number of the vehicle on the route, *n* – the number of control points of the route, *kn* – number of control points of the route, t – vehicle arrival time.

The whole period of transport network operation is divided into a finite number of intervals, where *T* – period of transport network functioning, *s* – the number of intervals.

The probability of a passenger getting on the *k*-th route at the *i*-th stop at time t is as follows:

$$p_{ij}^{l} = \frac{\sum_{t} n_{ik}^{l}(t)}{\sum_{t}\sum_{r=1}^{n} n_{rk}^{l}(t)}. \tag{1}$$

The probability of a passenger getting off the *k*-th route at the *i*-th stop is as follows:

$$p_{ij}^{m} = \frac{\sum_{t} n_{ik}^{m}(t)}{\sum_{t}\sum_{r=1}^{n} n_{rk}^{m}(t)}. \tag{2}$$

The interval of passenger’s appearance at the *i*-th stop, who will take the *k*-th route, is determined by:

$$\Delta t^{l}(t_s) = \frac{t_s}{\sum_{t}\sum_{r=1}^{n} n_{rk}^{l}(t_s)}. \tag{3}$$

The interval of passenger’s getting off the *k*-th route at the *i*-th stop is as follows:

$$\Delta t^{m}(t_s) = \frac{t_s}{\sum_{t}\sum_{r=1}^{n} n_{rk}^{m}(t_s)}. \tag{4}$$

Traffic speed between the stopping points:

$$V = \frac{t_{k_{i-1}} - t_{k_i}}{L_{t_{k_{i-1}}}^{t_{k_i}}}. \tag{5}$$

Vehicle arrival time at the *b*-th control point is equal to the following:

$$T_{b}^{prib} = t_{k_i} + V \cdot L_{b}^{k_i} + \alpha_1(t), \tag{6}$$

where t_{k_i} – time to arrival at the nearest control point, $L_{b}^{k_i}$ – the distance from the nearest control point to the current stop, $\alpha_1(t)$ – random variable, reflecting inaccuracy in following the schedule arising under the influence of traffic jams and accidents on the roads, as well as operation of traffic lights.

The number of passengers on the *c*-th bus of the *k*-th route at the *i*-th stop is equal to the following:

$$Q_{ic}^{k} = Q_{ic}^{k-1}(t) + N_{ic}^{\text{get on}} - N_{ic}^{\text{get off}}, \tag{7}$$

where:

$$N_{ic}^{\text{get on}} = \frac{t_s}{\Delta t^l(t_s)} \cdot p_{ic}^{l}, \quad N_{ic}^{\text{get off}} = \frac{t_s}{\Delta t^m(t_s)} \cdot p_{ic}^{m}. \tag{8}$$

Most of the inputs used in the model (1) – (8) were collected for an extended period of time as a result of field research of public transport network of the city of Tambov (Russia), which contains more than 60 bus routes and more than 150 bus stops.

3. IMPLEMENTATION OF THE SIMULATION MODEL AND THE SYSTEM OF ITS AUTOMATED CONSTRUCTION IN SIMUL8

The system for simulation of dynamic processes SIMUL8 [16] has been selected for our simulation. This system has a powerful set of tools for modelling and further processing of results. SIMUL8 is based on object-oriented approach. Every real object or process is associated with an object (or their combination) in a SIMUL8 simulation.

The following elements of UTN can be defined in the simulation model as follows:

– a stopping point – Work Center;
– a vehicle – Work Item;
– the process of passengers' coming at the bus stop – Work Entry Point;
– passengers queue at the bus stop, as well as vehicles queue at its front are modeled using such objects as a Storage Bin;
– routes and timetables are defined by a Job Matrix.

In order to store information about the current number of passengers, total number of transported people, etc., we use Label objects that are attached to such objects as Work Item. We have developed a database in MS Access for storage of all necessary information about the transport network (see. Fig. 1). We have also developed a program in Visual Basic for the convenience of filling the database and automated construction of the model in SIMUL8 based on the information from the database. Its work window is shown in Fig. 2.

As a result, we have obtained the simulation model of UTN in SIMUL8 environment (see. Fig. 3).

The following sets of data were obtained for each element of the network (route of urban passenger transport): coordinates of stops, average travel time between them depending on the operating time during weekdays, weekends and holidays, etc.

Fig. 4 shows the results of simulation at a single stopping point, including a block diagram, which shows the dependence of the number of people at the bus stop and time. These results confirm the efficiency of using public transport in the area of the Tambov Regional Hospital (the bus stop «Obl.bolnitsa»).

4. CONCLUSION

The inevitable growth of urban population has posed a number of problems related to development of transport systems in the cities that can adequately serve the needs of population. Computer modeling was chosen as a tool for solving the problems of routing and urban traffic control as it implements iterative development of the model, step by step detailing of the simulated subsystems, which allows gradually increasing assessment accuracy as new issues and new information are identified. Using simulation modeling, the authors have developed a mathematical model of transport network functioning and an information system, implemented in the SIMUL8 environment on the example of the urban public transport network in the city of Tambov (Russia), comprising more than

60 bus routes, which allow automating the process of simulation modeling and processing of simulation results. As a result of implementing the model and carrying out computational experiments, the following was possible:

- to minimize waiting time for the passengers on the busiest routes, in particular, on the route №50 with the length of 11.5 km, connecting the southern and the northern parts of Tambov and including more than forty stopping points;
- to determine the optimal number of vehicles en route, depending operating time during weekdays, weekends and holidays.

Thus, the obtained model is a powerful tool for analysis, optimization and development of the transport network. It can be used for simulation of various situations and think through the possible solutions to the problems, which arise in the UTN systems.

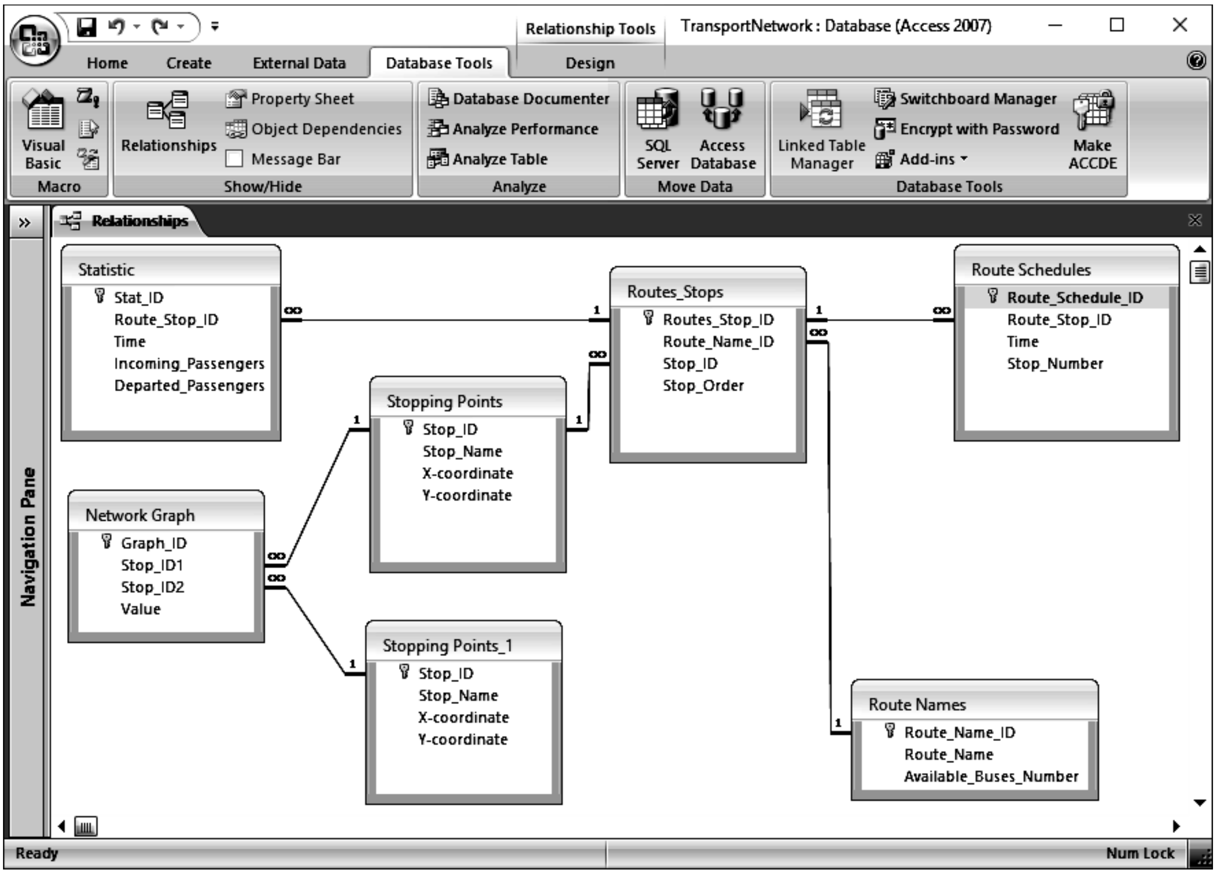

Fig. 1. Scheme of a database for storing information about the UTN

References

1. Nellore, K. & Hancke, G. A Survey on Urban Traffic Management System Using Wireless Sensor Networks. *Sensors*. 2016. Vol. 16. No. 2. P. 157.
2. Taha, H.A. *Operations Research: An Introduction*. *10th*. Pearson. 2017. 830 p.
3. Fishman, G. *Discrete-event simulation: modeling, programming, and analysis*. Springer Science & Business Media. 2013. 537 p.
4. Grant-Muller, S. & Usher, M. Intelligent Transport Systems: The propensity for environmental and economic benefits. *Technol Forecast Soc Change.* 2014. No 82. P. 149–166.
5. Hamilton, A. & Waterson, B. & Cherrett, T. & et al. The evolution of urban traffic control: changing policy and technology. *Transp Plan Technol* 2013. No 36. P. 24–43.
6. Artikis, A. & Weidlich, M. & Schnitzler, F. & et al. Heterogeneous Stream Processing and Crowdsourcing for Urban Traffic Management. In: *EDBT*. 2014. P. 712–723.

7. Osorio, C. & Nanduri, K. Energy-Efficient Urban Traffic Management: A Microscopic Simulation-Based Approach. *Transp Sci.* 2015. No 49. P. 637–651.
8. Dang, S. & Hong, Z. & Yang, S. & et al. Intelligent urban traffic management system based on the energy-circle cards platform. In: *2014 International Conference on Information Science, Electronics and Electrical Engineering*. IEEE. P. 457–459.
9. Li, X. & Lv, Z. & Hu, J. & et al. Traffic Management and Forecasting System Based on 3D GIS. In: *2015 15th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing*. IEEE. P. 991–998.
10. Lin, S. & De Schutter, B. & Xi, Y. & et al. Integrated Urban Traffic Control for the Reduction of Travel Delays and Emissions. *IEEE Trans Intell Transp Syst.* 2013. No 14. P. 1609–1619.
11. Baldi, S. & Michailidis, I. & Ntampasi, V. & et al. Simulation-based synthesis for approximately optimal urban traffic light management. In: *2015 American Control Conference (ACC)*. IEEE. P. 868–873.
12. Sun, F. & Yu, X.& Liu, S. & et al. Intelligent collaborative urban traffic management system based on SOA and cloud computing. In: *The 26th Chinese Control and Decision Conference (2014 CCDC)*. IEEE. P. 1692–1695.
13. Kim, Y. & Lee, S. & Yun, I. Development of Traffic Management Strategies for Incident Conditions on Urban Highways Considering Traffic Safety. *Int J Highw Eng.* 2015. No 17. P. 117–126.
14. Pamula, T. Road Traffic Parameters Prediction in Urban Traffic Management Systems Using Neural Networks. *Transport Problems.* 2011. Vol. 6. Issue 3. P. 123–128.
15. Nemtinov, V.A. & Nemtinova, Y.V. & Donskih, Y.A. Operative Management of Transport Streams in Settlements with the Use of Dynamic Processes Modeling System. *Her Comput Inf Technol*. 2009. P. 21–23.
16. Hauge, J.W. & Paige, K.N. *Learning SIMUL8: the complete guide*. PlainVu Publishers. 2004. 1013 p.

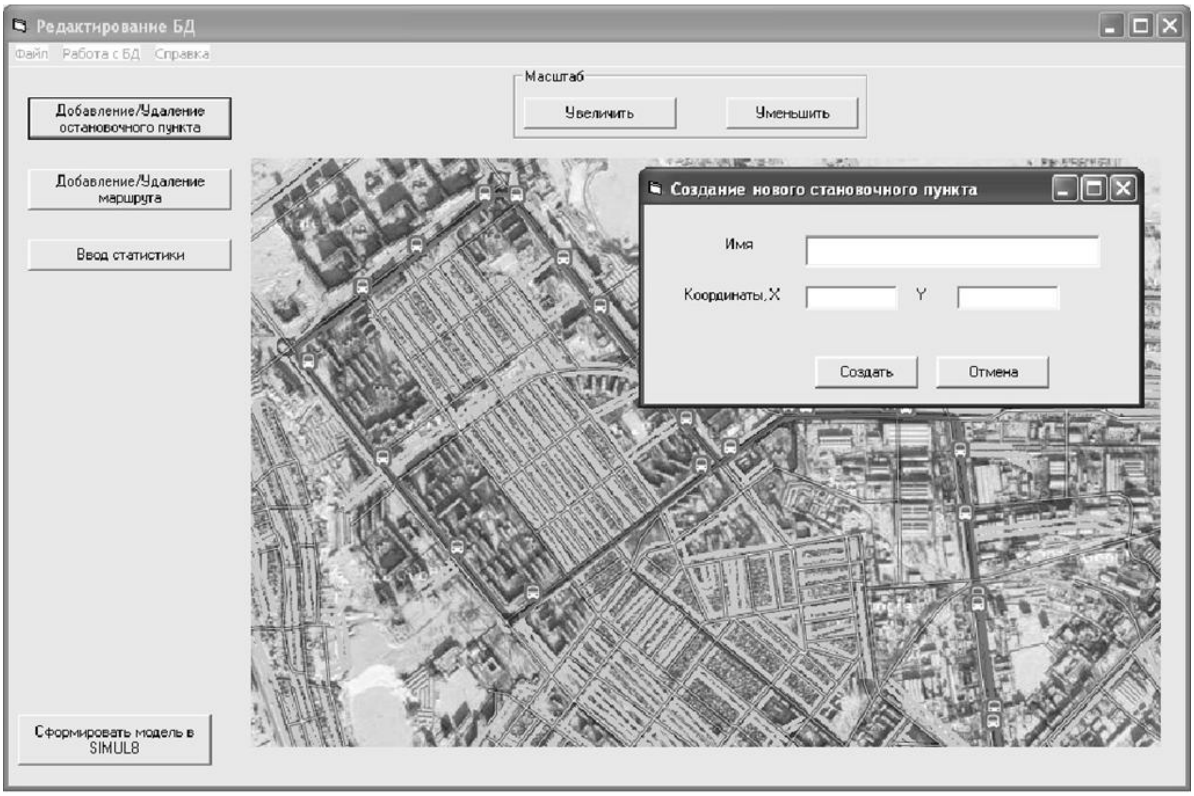

Fig. 2. Work window of the program

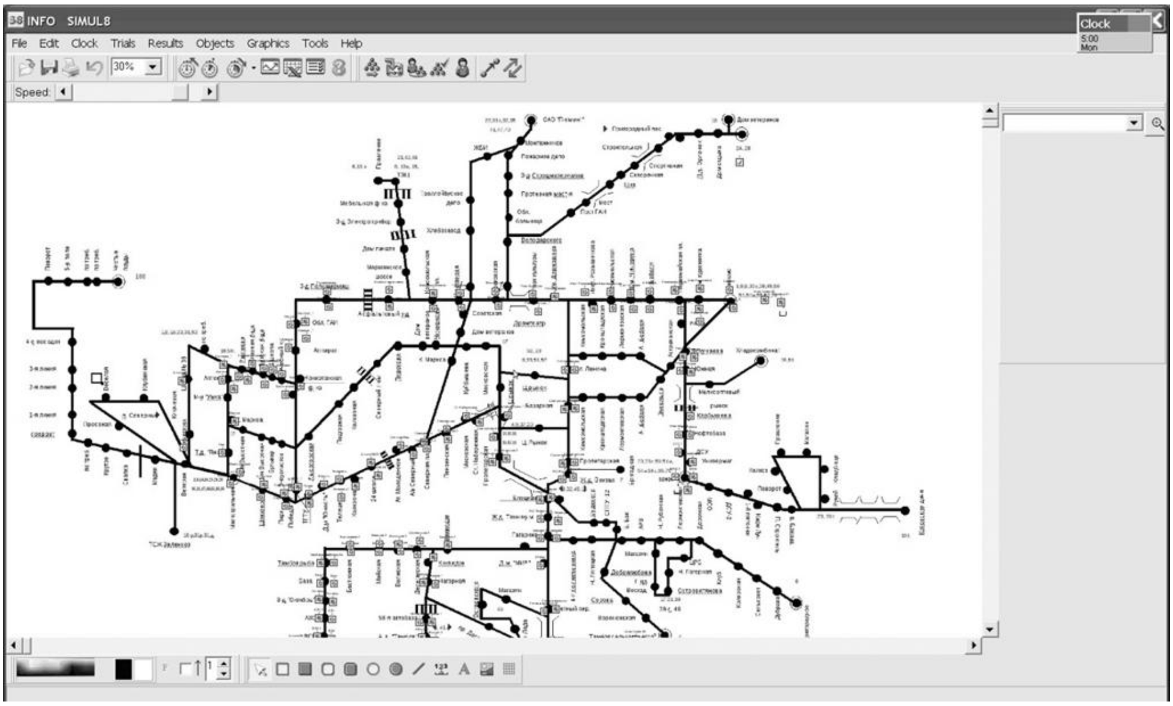

Fig. 3. Visualization of the general view of UTN model of the city of Tambov

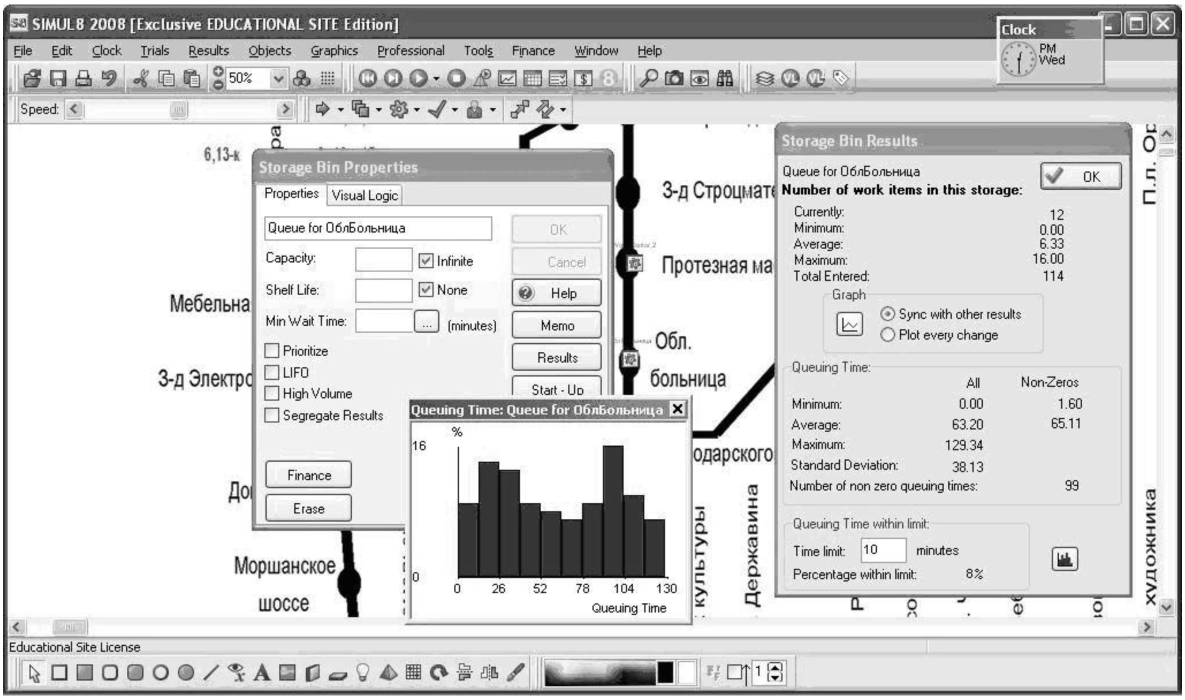

Fig. 4. An example of a single stopping point simulation

Received 21.05.2016 accepted in revised form 13.12.2017