Computer simulation of traffic flows

E V Kasatkina¹ and D D Vavilova¹

¹Department of Mathematical Support of Information Systems, Kalashnikov Izhevsk State Technical University, Izhevsk, 426069, Russia

E-mail: vavilova_dd@mail.ru

Abstract. The paper is presented to the simulation of traffic flows in conditions of traffic light regulation. A simulation multi-agent model of traffic flows was developed, which includes three agents: a car, a traffic light, a generator. A computational algorithm for the movement of vehicles for imitating the movement of vehicles along the driving lanes and its behavior at the intersection was developed. The simulation multi-agent model and the computational algorithm are implemented in the form of an intelligent analytical system that includes a database designed in the MS SQL DBMS environment, as well as a visualization module. During the simulation of traffic flows in the system, the required output parameters of the model are fixed. By simulation tools one of the problematic road sections of the city of Izhevsk was built, including a network of intersections of 10 years of October Street, Udmurtskaya Street, Pushkinskaya Street. The developed simulation model allows calculating the indicators of the average queue length at different times of the day, taking into account the intensity of input traffic flows. Thus, graphs of the dynamics of changes in the average queue length can be obtained and, on their basis, the time periods of congestion occurrence are determined. For example, during the simulation of the operation of a section of the transport network of the city of Izhevsk, it was established that there are two time periods for the occurrence of traffic congestion: from 7:00-9:00 AM and 5:00-7:00 PM, in which the indicator of the maximum queue length reaches 40 cars.

1. Introduction

The organization of urban traffic flows is one of the most important problem of modern cities. The solution of this issue affects the quality of people life and the interests of the overwhelming majority of the population. In addition, there is a problem of road congestions for many large cities, which requires an immediate solution [1]. For example, over the past fifteen years in Russia, the number of cars per thousand people has more than doubled [2]. This rate of growth in the number of personal cars of citizens in modern cities is ahead of the rate of development of the road system. The lag in the methods of organizing traffic and the development of control systems lead to complex transport problems. In this regard, congestion occurs and the accident rate on the roads increases. Accordingly, the need to address the issue of unloading urban transport and road systems is an actual task.

There are various methods, which allows to eliminate queues on the roads, for example, the introduction of special engineering and technical escorts at intersections, multi-level junctions with lanes for braking and acceleration, reducing the number of turns on the road, additional lanes on the road to enter adjacent roads, widening roads [3, 4]. Also, the efficiency of the functioning of the urban transport system is largely determined by the modes of traffic light regulation at intersections [5].
Mathematical modelling in conjunction with modern information technology allows to create a software environment [6], with which you can simulate road network schemes, change the parameters of traffic lights and monitor in real time, how it affects the network bandwidth. The virtual environment allows to quickly check the effectiveness of certain measures aimed at improving the functioning of a section of the city's road network.

2. Materials and research methods

2.1. Multi-agent modeling of traffic flows

One of the simulation modelling methods is agent-based modelling, which explores the behaviour of decentralized agents and how such behaviour determines the behaviour of the entire system as a whole. An agent is a kind of entity, which has activity, autonomous behaviour, can make decisions in accordance with a certain set of rules, interact with the environment, and also change independently [7].

In this work, a simulation model of the city's transport network section was created. Methods of multi-agent modelling are used to describe the parameters, properties and physical traffic laws. In a multi-agent system, agents have a few important characteristics: autonomy, limited presentation, decentralization [8].

The purpose of using multi-agent models for road transport purposes is to get general behavior of the road network system, based on the characteristics and behavior of individual vehicles, as well as their particular behavior and interaction with each other in the system. During the simulation of traffic in the system, all the required output parameters of the model are recorded.

The developed model is microscopic in terms of the level of detail, the time is discrete, and the space is continuous. System changes are calculated at a specified frequency in time, which provides a simulation of a continuous process.

Traffic flow simulation model components:
1) Coordinate system (map);
2) Dynamic objects (car, traffic light, vehicle input stream generator);
3) Counter of time intervals;
4) Algorithm of car movement.

The construction of the road network and simulation of the movement of vehicles are performed in a two-dimensional plane – on the map. The road network is interconnected roads with installed traffic lights and places where cars are generated (Figure 1).

The general principle of modeling: roads are built on the map with a certain number of lanes, the length and width of the roadway are taken into account. Traffic lights are installed at intersections. At certain places on the map, generators are installed – sources of car traffic that simulate the birthplace of traffic flow, for example, at shops, enterprises, places of study, etc.

At the software level, the map is a two-dimensional plane. Point on the map is plane coordinates, two numbers \((x, y)\) indicate a specific point.
Map resolution describes how detailed the image of objects on the map. Map resolution data is stored in $dpm$ (dot per meter) format. Higher resolution means higher level of detail. This property makes it possible to simulate the movement of vehicles of various sizes: cars and trucks, buses, motorcycles.

2.2. Properties and functions of agents of the computer model of the transport network

The agents are cars, traffic lights and generators. Reactive agents with simple behavior are used (agents that represent only on the basis of current knowledge of the environment); its agent function is based on the “condition-action” scheme [8]. Each of the listed agents at the programming language level is a separate class with characteristic properties and methods.

Cars are mobile agents that can move around the map and change driving lanes between lanes. These agents have the properties, inherent in a real car, and the properties necessary for the full functioning of the model:

- Identifier (unique car number);
- Geometric coordinate of the position of the upper left point along the abscissa axis, $X$;
- Geometric coordinate of the position of the upper left point along the ordinate axis, $Y$;
- Point of disappearance of the car (yes / no);
- Vehicle condition (stop or movement);
- Average vehicle speed;
- Driving lane number;
- Identifiers of points by which it is determined from where and where the car will be moved (from point "A" to point "B")
- Direction of movement from point "A" to point "B" (straight ahead, left, right, back);
- Intensity of movement along the axes (X-axis and Y-axis).

Car agent functions:

- Creation of a new car;
- Vehicle movement (main function that calls functions for checking, moving forward, changing lanes);
- Checks the ability to move forward, determines the distance to the obstacle;
- Performs movement: from point "A" to point "B", taking into account the average speed;
- Carries out a lane change: first, the possibility of changing lanes to the left is checked, if not, then to the right;
- Performs a shutdown of the car if it goes beyond the map.

Traffic lights are static agents designed to regulate the movement of other agents (cars); the traffic light either allows traffic or prohibits it.

Traffic light properties:

- Traffic light identifier (unique object number);
- Identifier of the road covered by the traffic light;
- Red signal operating time, millisecond in directions;
- Green signal operating time, millisecond in directions;
- Operating time of the yellow signal, millisecond in directions;
- Time of the next phase of the traffic light (when it is necessary to change one signal to another), time;
- Current phase: 1 – green, 2 – yellow, 3 – red;
- Identifier of the point at which the traffic light is generated.

Functions of the Traffic Light agent:

- Creation of a new traffic light;
- Switching the phases of the traffic light at the appropriate times;
- Change of stop lines.

Generators are static agents that perform the function of creating new cars. There can be an unlimited number of generators, each of which with a given intensity and in a certain place creates
cars. Memory optimization is applied, when the car reaches its destination, it is not deleted from the memory, only the maps are hidden.

Generator properties:
- Identifier of generator;
- Intensity of car production, vehicles per hour;
- Set speed of created cars, meters per second;
- Identifier of the road on which the generator is located;
- Time of the next generation;
- Time of the next phase of the traffic light, time.

Generator agent functions:
- Determination of the time of the next generation of the car according to the exponential distribution law;
- Creation of a car with the required parameters in the specified location;
- Checking the possibility of creating a car at the specified place at the specified time, that is, whether the place is occupied by another car.

In addition to standard agents, the database contains tables: points, roads, road characteristics, traffic light characteristics.

2.3. Time interval counter
The time slot counter is a section of the program that performs the function of reporting internal time slots. A counter performs exactly the same function as a pendulum in a mechanical watch or a quartz oscillator in an electronic watch. The program performs a set of key actions (Table 1) required for the operation of the simulation model.

| Action                  | Description                                                                 |
|-------------------------|-----------------------------------------------------------------------------|
| Car movement            | All vehicles are given the command "Drive". Each car, independently of the others, performs movement at its own speed and acceleration or stops. |
| Creation of new cars    | Each generator is assigned an internal time value (number of ticks). If necessary, the generator creates a new car (agent) and calculates the time of the next generation of the car (agent) according to the exponential law. |
| Traffic light work      | The internal time value is transmitted to each traffic light. If necessary, switches the traffic light signal (green, yellow, red) and calculates the time of the next phase change. |
| Capturing statistical data | Collection, processing and saving of parameters of all cars.               |

The counter in a closed loop performs either key actions, or pauses equal to the length of the bar. A time is length of a measure between successive key actions of the program.

All procedures and functions in the program are based on the fact that one time within the program is equal to 0.1 seconds of real time. In other words, if it is necessary to simulate the movement of real cars in 1 seconds, then the counter must perform 10 times. The bar length is a very important counter parameter. By changing the values of the bar length, you can change the simulation speed, for example, if the bar length is reduced 10 times, setting it to 0.01 seconds, the simulation speed will increase by 10 times.

Using a counter of time intervals allows you to achieve the accuracy of calculations; acceleration of computations by reducing the cycle length.
2.4. Algorithm of movement of cars

Cars are moving at a constant speed. At regular intervals, each vehicle moves in the specified direction, unless another vehicle or stop line obstructs its movement. The movement of each car is performed according to the following order for one cycle of simulation (Figure 2):

1 – Free movement forward,
2 – Avoiding the obstacle to the left,
3 – Avoiding the obstacle to the right,
4 – Stop.

![Figure 2. Change driving lanes rules for 1 times](image)

The model takes into account traffic light signals in individual directions of movement (Figure 3). When approaching an intersection, traffic is controlled by traffic lights in each direction, this allows you to create a more realistic imitation at those intersections where traffic light regulation is divided into sections.

![Figure 3. Traffic light operating modes.](image)

When crossing an intersection, the car selects the direction of travel. The choice is dictated by the lane, as well as probabilistic characteristics \( (p_{i,j}) \), which are set for each driving lane \( (i) \) in the current direction of travel, as well as road indices are set \( (j) \), into which the evolution will be performed. Possible options for car movement, when is crossing an intersection, are shown in Figure 4.

![Figure 4. Possible options for car movement.](image)

There are ready-made programs for visualization of simulation models of traffic flows, but not always they can be adjusted to the developed model [9]. You can use raster or vector graphics to render such a model. Support for interaction with both chart types is implemented in JavaScript. This language is used as an embedded language for programmatic access to application objects, as well as websites for interactivity. After comparing the target application, as well as the capabilities and features, raster graphics were selected as part of solving the problem of creating a software package for simulation.
2.5. Database

To build a simulation model based on multi-agent modelling in MS SQL, the Server database has been designed. The database contains statistical data for all agents, its structure is shown in Figure 5.

![Figure 5. Simulation model database structure](image)

The developed database is integrated into the software package, in which the ability to add and change information, as well as obtain the necessary statistical information for calculations, is realized in the SQL query language.

3. Research results

The paper is considered the transport network of two intersections of the city of Izhevsk: 10 years of October Street – Pushkinskaya Street and 10 years of October Street – Udmurtskaya Street. Demonstration of the resulting model of the transport network of one of the intersections during "rush hours" is shown in Figure 6.
As a result of simulation, the values of the length of movement ($L$) were determined in each driving lane of cars. The graph of the length of the change in the length of the queue in the system is shown in Figure 7.

![Figure 7](image_url)

**Figure 7.** Dynamics of changes in the maximum queue length

Figure 7 is showed the maximum queue length during peak hours reaches 37 cars. To solve the problems with congestion in Izhevsk city, it is necessary to build optimal control of the phases of the traffic lights at the most loaded intersections [10].

4. **Conclusion**
A simulation multi-agent model of traffic flows has been developed. The multi-agent model includes three main agents: car, traffic light and generator.

An algorithm was developed for designing a software product that simulates a transport system, taking into account the movement of cars along the lanes and its behavior at the intersection.
The simulation multi-agent model and the algorithm are software implemented in the form of an intelligent analytical system, which includes a database designed in the MS SQL DBMS environment, as well as a visualization module.

During the simulation of traffic flows, all the required output parameters of the model are fixed in the system. Based on the analysis of these parameters, it is further possible to solve the problem of optimizing traffic light regulation, but on the basis of various optimization approaches, tested in various works on optimizing logistics processes [11, 12].

By simulation tools, one of the problematic sections of the city of Izhevsk was built, which includes a network of intersections of 10 years of October Street, Udmurtskaya Street and Pushkinskaya Street.

The developed simulation model allows calculating the indicators of the average queue length at different times of the day, taking into account the intensity of input traffic flows. Thus, graphs of the dynamics of changes in the average queue length can be obtained and, on their basis, the time periods of congestion occurrence are determined. For example, during the simulation of the operation of a section of the transport network of the city of Izhevsk, it was established that there are two time periods for the occurrence of traffic congestion: from 7:00-9:00 AM and 5:00-7:00 PM, in which the indicator of the maximum queue length reaches 40 cars.

References
[1] Kasatkina E V 2017 Statistical Analysis of Traffic Environment in the Udmurt Republic Bulletin of Kalashnikov ISTU 20(1) 53-59 DOI:10.22213/2413-1172-2017-1-53-59 (in Russian)
[2] Federal State Statistics Service of the Russian Federation https://rosstat.gov.ru/folder/23455
[3] Rongxia Wang 2020 Research on Short-term Traffic Flow Forecast and Auxiliary Guidance Based on Artificial Intelligence Theory J. Phys.: Conf. Ser. 1544 012164 DOI:10.1088/1742-6596/1544/1/012164
[4] Marcelo Z, Regina Célia P L, Esteban C, Anselmo M and Edgar B L 2010 A Probabilistic Cellular Automata Model for Highway Traffic Simulation J. Procedia Computer Science 1(1) 337-345
[5] Vlasov A A 2014 Traffic flow theory (Penza: PGUAS publishing house) p 124 (in Russian)
[6] Ketova K V, Rusyak I G, Saburova E A and Vavilova D D 2020 Regional Socio-Economic Parameters Modeling and System Analysis by Means of Programming and Computing Suite IOP Conference Series: Materials Science and Engineering 862 052044 DOI:10.1088/1757-899X/862/5/052044
[7] Omsushin A A, Mikheeva T I and Mikheev S V 2018 System Analysis for Managing Transport Network in Case of Emergency Situations Izvestia of the Samara Scientific Center of the Russian Academy of Sciences 6-2 (86) 364-372 (in Russian)
[8] Duran-Fernandez R, Santos G 2014 Res Transp Econ 46 55-69
[9] Bouarfa S, Blom H H, Curran R and Everdij M H 2013 Agent-Based Modeling and Simulation of Emergent Behavior in Air Transportation Aviat. Technol. Integr. Oper. Conf. 1 1-16
[10] Kasatkina E V 2018 Development and Testing of a Genetic Algorithm to Solve the Routing Problem Journal of Applied Informatics 5(77) 32-43 (in Russian)
[11] Sairanov A S, Kasatkina E V, Nefedov D G and Rusyak I G 2019 The Application of Genetic Algorithms for Organizational Systems' Management in Case of Emergency Computer Research and Modeling 11(3) 533-556 DOI:10.20537/2076-7633-2019-11-3-533-556
[12] Rusyak I G, Ketova K V and Nefedov D G 2017 Mathematical Model and Method for Solving Problem of Optimal Location of Wood Fuels Facility Proceedings of the Russian Academy of Sciences. Power Engineering 2 177-187