Imitation Simulation of Transport Flow with the Help of Cellular Automatas

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Abstract

The article discusses a method for modeling traffic flow on a highway and a network of intersections using cellular automatas. A set of parameters characterizing vehicle drivers is considered, as well as taking into account the influence of the states of turn signals and braking signals of neighboring vehicles when deciding on a maneuver. An algorithm is proposed that describes the procedure for taking into account the factors affecting a possible rearrangement, braking or acceleration when vehicles move along a highway that has separate entrances and exits from it. Possible situations in which a vehicle can go into an accident state are given. A numerical experiment is presented that simulates the theory of three phases of traffic flow, proposed by Boris Kerner [6].

Keywords

Cellular Automata, Simulation Transport Modeling, Individual Characteristics of Drivers.

Introduction

The relevance of the problem under consideration is associated with the need to solve the problems of traffic congestion and the possibility of competent urban planning. It is important to be able to simulate the movement of a heterogeneous stream of cars and predict the main transport and operational indicators.

Information about the initial state of the stream is obtained using traffic cameras with speed fixing, car DVRs, satellite images. Models based on cellular automata are microscopic models and are attractive due to their low resource costs (both computational and time).

The work used the concept of a cellular transport automata proposed by K. Nagel and M. Shreckenberg [1], as well as modifications of the model, taking into account various characteristics of the flow. A model has been developed that takes into account the structure of the traffic flow, the individual characteristics of drivers (speed preferences, "politeness", "radicality", goals), possible accidents, occupied road sections and branches from the main highway. A distinctive feature of the model is a neighborhood of variable radius. Methods of traffic light regulation based on state control of a cellular automaton simulating a traffic light are considered.

Basic Concepts of a Cellular Transport Automata

In the model under consideration, space and time are discrete. Each cell of the transport automata represents a part of the lane of the road; a rectangular grid of size $m \times n$, where m – is the number of roadway strips, n – is the length of the modeled section in cells. The length of the cell is given and is equal to Δx, with each vehicle occupying several cells of the roadway (for example, a non-uniform flow consisting of long vehicles such as buses, trucks, cars with trailers, etc.), and the lane width can be neglected. A value of Δx = 1.5 m provides a realistic representation of the lowest possible acceleration; then it will take 5 cells to model one car. The state of the cellular automata system is updated at each time iteration $\Delta t \approx 1$ second, (the driver's reaction time). Each cell can be in one of the states - the cell is free or occupied by a vehicle, and in addition the third state - the cell is occupied by an obstacle and cannot be occupied by a moving vehicle, thus, the cell needs a detour, which will lead to a rearrangement to the adjacent traffic lane. An obstacle may be: a faulty vehicle; a vehicle parked near the curb; road repair area, etc.

The position x_i (the number of cells in the lane) for each vehicle at each iteration can be determined by the formula $x_i^j = x_{i-1}^j + v^j$, where x_{i-1}^j – is the position at the previous iteration and v^j is the speed of the vehicle, measured in the number of cells that the vehicle passes means in one iteration.

To illustrate the simulation of the movement of vehicles, consider the algorithm of the one-cell case:

1. Acceleration of free vehicles. If the speed v_i of transport is lower than v_{max} and the distance to the next vehicle is greater than $v_i + 1$ the speed is increased by

one:: $v_i(t) = \min(v_i(t-1)+1, v_{max})$. The rule reflects the desire of all road users to move at maximum speed.

2. Slowdowns caused by other road users. If a vehicle in cell i notices a vehicle in front of it in cell $i+j$ (for $j \leq v$), it reduces the speed to $j-1$: $v_i(t) = \min(v_i(t), g_i(t-1))$, where g_i the gap between $i^{\text{м}}$ and $i+1^{\text{м}}$ vehicles can be calculated as $g_i = x_{i+1} - x_i - 1$. The rule guarantees that there are no collisions between vehicles in front.
3. Randomness. With probability $p_v = const$ the vehicle speed decreases by 1 if it is greater than 0: if $\zeta(t) < p_v$, then $v_i(t) = \max(v_i(t)-1, 0)$, where $\zeta(t) \in [0, 1)$ – is a random uniformly distributed value. The rule gives the model an element of stochasticity, introducing randomness into the behavior of drivers, close to the behavior in real life.
4. Movement. The vehicle position is recalculated using the formula $x_i^j = x_{i-1}^j + v^j$. The rule determines the distance in cells that the car travels in one time iteration.

The proposed model uses an extended dynamic neighborhood consisting of the number of cells required to observe a given number of vehicles located in front and behind the vehicle under consideration. For optimal consumption of computing resources, two vehicles are taken into account in front, front right and front left, as well as one each behind, rear left and rear right.

Accounting the Individual Characteristics of Drivers

The model is expanded by adding two steps [2]:

1. Finding out the need to change the lane. The vehicle changes lanes if there is an obstacle in front of the current lane or the average speed of vehicles in the adjacent lane is significantly higher than the possible speed of the vehicle in the current lane. A vehicle is described with the characteristic “target” if there are additional entrances and exits from the highway and the “target” of the vehicle is one of them, that is, it is necessary to occupy the lane closest to the exit.
2. Understanding lane change safety. If the distance between the vehicle in question and the two vehicles in front and behind of it after the lane change allows the lane change without forcing the two vehicles to change speeds, then the lane change is considered safe. Otherwise, it is necessary to turn on the turn signal and continue driving at the current speed or at a reduced speed, limited by the presence of an obstacle. The likelihood of changing lanes on subsequent iterations increases when the turn signal is turned on, since this vehicle may be missed in the next lane.

The advantage of taking into account the state of braking and turning signals of vehicles [2, 3] is that with a high flow density and the presence of an obstacle, all vehicles are forced to stop until there is space for changing lanes in the adjacent lane, which will lead to an endless traffic jam. In fig. 1 is shown an example of modelling obstacle avoidance without taking turn signals into account.

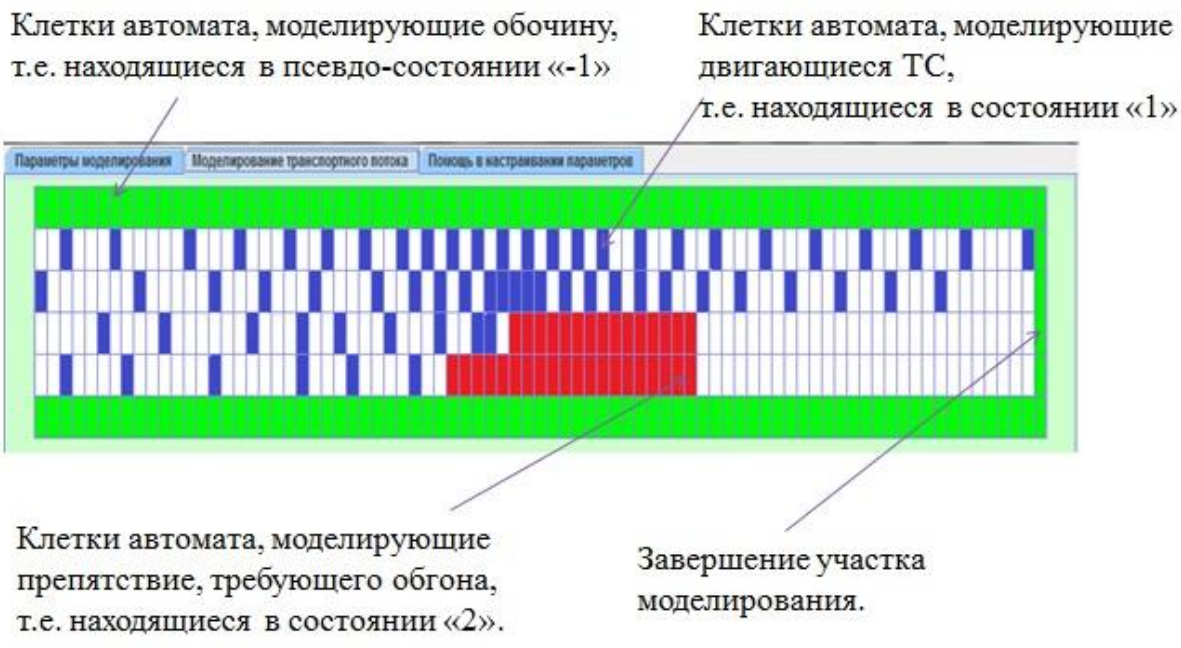

Fig. 1

To understand whether the driver will slow down and let another pass, the characteristic parameter is the degree of "politeness". The indicator of "politeness" $d_{pol} \in [0; 1)$, that is, with the probability d_{pol} the driver will slow down to pass the driver being reconstructed. When checking the safety of a lane change in the case of a risky driver with a probability of $1 - d_{pol}$, he may neglect the safe distance behind, forcing the other driver to resort to emergency braking. If the reaction speed of the driver behind is small, then with the probability p_{acc}, an unsafe maneuver will end in an accident.

There is an emergency situation, in case of a distribution conflict, when two vehicles on the left and on the right intend to occupy the same cell located in the middle row. The conflict can be resolved by giving priority to vehicles, for example, from the right lane (by analogy with the rule of "interference from the right") or priority is given to vehicles one by one. If no priority is allocated with the given probability p_{conf} then the maneuver will lead to an accident.

Another important characteristic is the desired speed [4]. Each driver belongs to one of three groups - “cautious”, “normal”, “aggressive”, and each group is subdivided into subgroups that differ from each other in the degree of “radicalism” - the influence of speed preference on real speed. A lane is considered to be advantageous if the average vehicle speed is close to the driver's desired speed.

Taking into account all the above described rules and parameters, in fig. 2 is shown a block diagram for the algorithm of movement and rearrangement of the vehicle.

Fig. 2

Transport Network Modeling

The network of intersections in the model is considered as a graph with vertices at the intersection nodes. Let us introduce a uniform two-dimensional square grid (i, j), where $i, j = 0, \dots, m$. In fig. 3 is shown a schematic representation of a transport network model and signals on it.

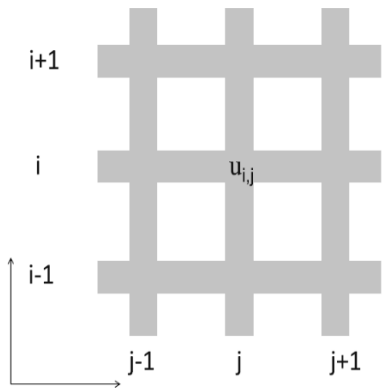

Fig. 3

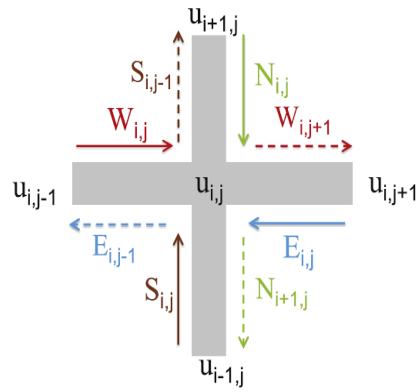

Fig. 4

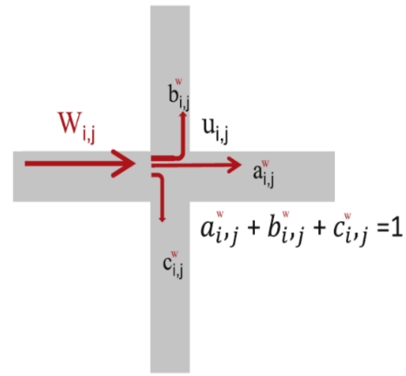

Fig. 5

At each node (intersection) (i,j) the traffic signal $u_{i,j}(t) \in \{0,1\}$. If $u_{i,j}(t) = 1$, then traffic flows pass in the directions “East → West” and “West → East”, if $u_{i,j}(t) = 0$, then traffic flows “South → North ”and“ North → South ”. It is assumed that the signals $u_{i,j}(t)$ remain constant (0 or 1) during the time interval $\Delta t > 0$, which is a priori, i.e.

$$\forall i,j\ u_{i,j}(t) = \begin{bmatrix} 0, \\ 1. \end{bmatrix} for\ t \in [k\Delta t, (k+1)\Delta t), \forall k = 0, \dots, N-1,$$

which is equivalent $u_{i,j}(t) = u_{i,j}^0 \chi_{[0,\Delta t)}(t) + \cdots + u_{i,j}^{N-1} \chi_{[(N-1)\Delta t, N\Delta t)}(t)$,

$$where\ u_{i,j}^k \in \{0,1\}, \chi_{[a,b)}(t) = \begin{cases} 1, if\ a \le t \le b \\ 0,\ \ otherwise. \end{cases}$$

The traffic volumes arriving at the node (i,j) will be denoted by $E_{i,j}$, $W_{i,j}$, $N_{i,j}$ and $S_{i,j}$, respectively, from the direction East, West, North and South. In fig. 4 is shown the definition of the volume of incoming traffic. The distribution of the shares of the turning traffic $W_{i,j}$ flow is shown in Fig. 5:

$$b_{i,j}^W \ge 0\ (turning\ left);\ c_{i,j}^W \ge 0\ (turning\ right);$$

$$a_{i,j}^W = 1 - b_{i,j}^W - c_{i,j}^W \ge 0\ (proportion\ of\ continuing\ to\ move\ straight).$$

The rate of change in traffic volume is proportional to the sum of inflow and outflow flow as follows.

$$\boldsymbol{\frac{d}{dt} W_{i,j} = -\lambda u_{i,j} W_{i,j} + \lambda [a_{i,j-1}^W u_{i,j-1} W_{i,j-1} + b_{i,j-1}^N (1 - u_{i,j-1}) N_{i,j-1} + c_{i,j-1}^S (1 - u_{i,j-1}) S_{i,j-1}]}$$

Where $\boldsymbol{\lambda}$ – proportionality factor to be calibrated according to the length of the signal interval$\Delta \boldsymbol{t}$, that is $\boldsymbol{\lambda \Delta t < 1}$.

It is assumed that at the nodes on the grid border the signal is in the "on" position for $i = 0, m+1$ and in the "off" state for $j = 0, m+1$, if the flow is directed directly, then for these nodes the expression for $E_{i,m}$ takes the form:

$$\frac{d}{dt}E_{i,m} = -\lambda\left(u_{i,m}E_{i,m} - E_{i,m+1}\right).$$

The values $W_{i,0}$, $E_{i,m+1}$, $N_{m+1,i}$ and $S_{0,i}$ $(1 \le i \le m)$ represent inflows to the boundary nodes and are set a priori. Let $x(t)$ denote a column vector of size $4m^2 \times 1$ for traffic volumes $\left(E_{i,j}, W_{i,j}, N_{i,j}, S_{i,j}\right)$ at time t;

$$x(t) = \left(E_{1,1}, W_{1,1}, N_{1,1}, S_{1,1}, \dots, E_{m,m}, W_{m,m}, N_{m,m}, S_{m,m}\right)^T.$$

The dynamics of change $x(t)$ is represented in a compact form using the correspondingly defined matrices *A* and *B* as follows:

$$\dot{x}(t) = \left(A + \sum_{i,j=1}^{m} u_{i,j}(t)B_{i,j}\right)x(t) + s(t), 0 \le t \le T, x(0) = x_0,$$

Where $s(t)$ – source that is due to inflow from boundary nodes. We denote the solution by $x = \Phi(u) \in C[0,T]$, $T = N\Delta t$, u is a column vector:

$$u = \left(u_{1,1}^0, u_{2,1}^0, \dots, u_{m,m}^0, \dots, u_{1,1}^{N-1}, u_{2,1}^{N-1}, \dots, u_{m,m}^{N-1}\right).$$

Various results on similar problems are presented in works [7-16].

Numerical Simulation Results

Consider a software package that implements the described model and the algorithm shown in Fig. 2. The program is written in Java from NetBeans 8.2. The modeling parameters are the initial data on the traffic flow and the roadbed configuration (number of lanes, highway length, number of vehicles, time interval, flow courtesy factor). For a traffic stream, the observation window displays the simulation results with the main investigated characteristics of the stream. Comparison of the results with different parameters allows you to choose the optimal configuration of the road surface (here "optimal" is the configuration that provides the lowest density or the highest flow rate). To select random individual characteristics of drivers, pseudo-random number generators are used. A method for changing the parameters of the model is proposed, which makes it possible to obtain the required distribution of possible velocities. In fig. 6 is shown a special case of the configuration, which simulates the narrowing of the road "bottleneck". Modeling such a situation can offer the organization of the traffic light mode of movement in order to avoid unnecessary traffic jams.

Fig. 6

I simulate a stream of novice drivers with an uncertain driving style, the probability of changing lanes p_{chn} is small, about 0.1 (they will expect a safer maneuver). If the simulated stream is standard, then $p_{chn} \in (0.5; 0.6)$. Taking into account the results obtained in [5] and recommendations for choosing the value of the probability of random slowdown for urban traffic – $p_v \in [0.1; 0.2]$, and for the highway – $p_v = 0.5$.

Conclusion

The proposed model can be used to solve urban planning problems. It can be used to determine the optimal length of the acceleration lane, the length of the braking lane, the optimal length of the dedicated lane for buses, etc. “Optimal” refers to the length or configuration of the road that will result in the shortest travel spent on overcoming a section of the road, as well as to move at the highest speed. The simulation of the results correlates well with the theory of three phases of traffic flow proposed by Boris Kerner [6].

References

Nagel K., Schreckenberg M. A cellular automaton model for freeway traffic. *Journal de Physique I France*. 1992. Vol. 2. No 12. – P. 2221–2229.

Knospe W., Santen L., Schadschneider A., Schreckenberg M. Towards a realistic microscopic description of highway traffic. *Journal of Physics A: Mathematical and General*, vol. 33, no. 48, pp. L477–L485, 2000.

Boboshina A.V., Pegachkova E.A. Accounting for stop signals and turn signal signals when modeling traffic flows based on cellular automata, 17-я Mezhdunarodnaya konferentsiya

«Aviatsiya i kosmonavtika – 2018, November 19-23, 201. Moskow. Abstracts. – Tipografiya «Lyuksor», 2018. – P.423-425.

Xu Qu, Mofeng Yang, Fan Yang, Bin Ran, Linchao Li. An Improved Single-Lane Cellular Automaton Model considering Driver's Radical Feature. *Journal of Advanced Transportation*, Volume 2018, Article ID 3791820, 10 p.

Benjaafar S., Dooley K., Setyawan W. *Cellular automata for traffic flow modeling*. Final report, 2019.

Kerner B.S. Introduction to modern traffic flow theory and control: the long road to three-phase traffic theory. *Springer Science & Business Media*, 2009, 265p.

Bulychev N. A., Kuznetsova E.L., Bodryshev V. V. Rabinskiy L.N. Nanotechnological aspects of temperature-dependent decomposition of polymer solutions, *Nanoscience and Technology: An International Journal*, 2018, Vol. 9 (2), p. 91-97.

Bulychev, N.A., Rabinskiy, L.N. Ceramic nanostructures obtained by acoustoplasma technique. *Nanoscience and Technology: An International Journal*, 2019, 10(3), p. 279–286.

Bulychev, N.A., Rabinskiy, L.N., Tushavina, O.V. Effect of intense mechanical vibration of ultrasonic frequency on thermal unstable low-temperature plasma. *Nanoscience and Technology: An International Journal*, 2020, 11 (1), p. 15–21.

Zagovorchev, V. A., & Tushavina, O. V. (2019). Selection of temperature and power parameters for multi-modular lunar jet penetrator. INCAS Bulletin, 11(Special Issue), 231-241. doi:10.13111/2066-8201.2019.11.S.23

Zagovorchev, V. A., & Tushavina, O. V. (2019). The use of jet penetrators for movement in the lunar soil. *INCAS Bulletin*, 11, 121-130. doi:10.13111/2066-8201.2019.11.S.22

SHA, Minggong; Utkin, Yuri A.; Tushavina, Olga V.; Pronina, Polina F. Experimental Studies of Heat and Mass Transfer from Tip Models Made of Carbon-Carbon Composite Material (Cccm) Under Conditions of High-Intensity Thermal Load 2020 Periodico Tche Quimica vol. 17 (n°35) pp. 988-997

Pronina, Polina F.; Tushavina, Olga V.2; Starovoitov, Eduard I.3; Study of the Radiation Situation in Moscow by Investigating Elastoplastic Bodies in a Neutron Flux Taking into Account Thermal Effects 2020 Periodico Tche Quimica, vol. 17 (n°35) pp. 753-764.

Orekhov, Alexander A.; Utkin, Yuri A.; Pronina, Polina F. Determination of Deformation in Mesh Composite Structure Under the Action of Compressive Loads 2020 Periodico Tche Quimica vol.17 (n°35) pp. 599-608 (70-72).

Kuznetsova, E.L., Makarenko, A.V. Mathematic simulation of energy-efficient power supply sources for mechatronic modules of promising mobile objects. *Periodico Tche Quimica* 15(Special Issue 1), c. 330-338.2018.

Formalev, V.F., Kolesnik, S.A., Kuznetsova, E.L. Analytical study on heat transfer in anisotropic space with thermal conductivity tensor components depending on temperature. *Periodico Tche Quimica*, 2018, 15(Special Issue 1), стр. 426–432