Development of Cellular Automata for Simulation of the Crossroads Model with a Traffic Detection System

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Abstract. Cellular automata are considered by some researchers as one of the computer science areas, which is an artificial intelligence. Even though their history goes back to the forties of the last century, much attention is still paid to the use of cellular automata in the process of testing and simulation of different phenomena. The universality of cellular automata led to their application in many areas such as: physics and traffic modeling. The authors present the achievements in the traffic modeling field and formulate a new traffic model. This new model helps to simulate the traffic at the crossroads of two-lane and two-way roads. In addition, the authors present some aspects of the prepared system, which enables to model any area (intersections and roads) and to carry out the traffic simulations in a microscopic scale.

Keywords: cellular automata, crossroads model, simulation, traffic detection.

1 Introduction

In today's world, almost everybody comes across the problem of street congestion – some as drivers, others as pedestrians. For most of them the only solution to this situation is expanding the network of roads and sidewalks. Unfortunately, there are real limitations to such a policy, due to reduction in the number of densely built-up urban areas and the need to protect the rest of the "green" ones, which are necessary to preserve life on our planet.

Therefore, the need to streamline the existing transportation system is being observed. Of course, this can be interpreted in different ways, e.g. by modeling and controlling the traffic or by continuous education of drivers to show them incorrect behaviors on the roads. For this purpose it is useful to have adequate mathematical models and adequately prepared computer applications (software).

Table 1 shows the existing traffic models using cellular automata. Some of them have been implemented and presented in the form of a system available on website [6]. Another system, which deserves attention is the TrafficSim [7]. It includes a few

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implemented traffic models [8]. According to the information presented on the project website [7], the authors developed a simple simulation environment for the traffic.

Table 1. The traffic models using cellular automata

The model	Description
The model of Chopard-Luth-Queloz	The elementary cellular automaton, defined by S. Wolfram, as a rule number 184; it submit the traffic on the one-way and single-lane road. Cars move in one direction.
The model of Nagel-Schreckenberg [4]	Model describing the cars' movement on the one-lane and one-way road. The lane is divided into sections (cells) with a length of 7.5 meters. Each vehicle moves at a speed no greater than the maximum speed, but not less than zero. The model has an absorbing boundary conditions. Transition function is divided into 4 stages: acceleration, braking, and shifting a random event.
The model of Chowdhury-Schadschneider [1]	The crossroad's model, where traffic is only right or up. The model has periodic boundary conditions. Transition function as a model NaSch.
The model of Treiber: Ring-Road [6]	Vehicles move on the two-lane and one-way road, represented by an array of two rows and *n*-columns. Transition function as a model NaSch, but the vehicles may change lane.
The model of Treiber: On Ramp [6]	The two-lane and one-way road, with one-way run-up way (the third lane). Transition function consists of 5 stages: a lane change, acceleration, braking, shifting and random events.
The model of Treiber: Lane closing [6]	The two-lane and one-way road. The fragment of this road is closed. Transition function consists of 5 stages: a lane change, acceleration, braking, shifting and random events.
The model of Treiber: Uphil Grade [6]	The two-lane and one-way road. The traffic difficulties are simulated: the slow going vehicles moving on the steep climbs obstruct the traffic.
The model of Treiber: Traffic Lights [6]	The network of cells with two rows and columns to provide a two-lane and one-way road with traffic lights. Transition function consists of 5 stages.
The model of Treiber: Lane Changes [6]	The model identical to Ring-Road model, but a few obstacles are placed on both lanes of traffic, forcing cars to change lanes.
A few models of Bartodziej [8]	Development of several models, including Chowdhury-Schadschneider, Ring-Road and On Ramp.
This article	Extending of crossroads' models presented in [1] and [8]. The authors propose to change the functions of transition - the second stage, by considering the inductive loop, which eliminates the possibility of blocking the crossroads.

Unfortunately, the number of existing models (they do not include all aspects of road traffic) and computer applications (particularly those free for the users) is still insufficient. Therefore, relying on the analysis of the available solutions, the authors developed a crossroads model (presented in this paper). Additionally, the idea and some basic elements of an environment based on cellular automata theory are presented, to analyze drivers' behavior in a given situation in a specific structural area. The application is still being developed.

2 Extending the Existing Model

This paper proposes a thesis that developing a theory and mechanism preventing intersection traffic congestion will increase the motor vehicle traffic capacity of cities.

2.1 The Idea

In Poland, there is an appropriate article in the Road Traffic Code [9, Article 25, para. 4], which provides that "…a vehicle driver is not allowed to enter an intersection if there is no place at it or behind it to continue driving…". Unfortunately, the experience of Polish cities shows that Poles have a problem with respecting this rule, consequently increasing the congestion phenomenon.

The easiest way to verify this thesis is to construct a mathematical model and verify its correctness using the computer application.

2.2 The Model of Crossroads with "Inductive Loop"

In the classic model of Chowdhury-Schadschneider concerning traffic at the crossroads [1] and [8], the situation shown in Figure 1 is possible. In order to avoid this phenomenon, the authors worked out a new model, based on models presented in [1] and [8].

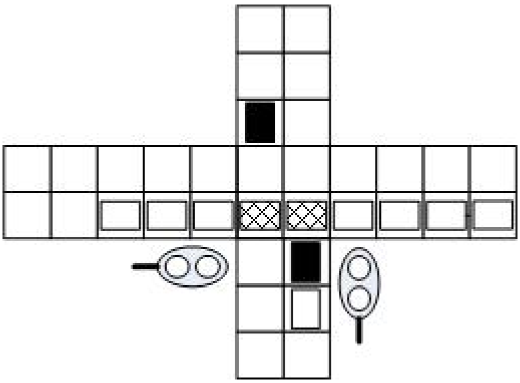

Fig. 1. The models [1] and [8] may lead to the intersection traffic congestion

The model applies to crossroads of two-lane and two-way roads, assuming that the distance between crossroads does not need to be identical. One cell of automata can be free or busy (then it has the numerical value: $V_{j,i} = 0, 1, \ldots, V_{\max}$, where j is the number of ways, i – the number of cell for which the vehicle's speed is set at the road section).

Extending the existing crossroads models concerns the use of the so-called inductive loop behind the crossroads (Fig. 2). The transition function, like in models [1] and [8], consist of 4 stages, but the second one (breaking) was modified; stages: 1, 2 and 4 are consistent with the model [4]:

1. acceleration – vehicles whose speed ($V_{j,i}$) at time t is less than $V_{\max}$, increase it by one:

$$V_{j,i} < V_{\max} \rightarrow V_{j,i} = V_{j,i} + 1\,, \tag{1}$$

   where $V_{j,i}$ – the speed of a vehicle situated on the road number j and the cell number i;
2. braking – if the traffic lights at the next crossroads is on with a color:
   - red and

$$V_{j,i} > \min(d_{j,i}, s_{j,i}) \rightarrow V_{j,i} = \min(d_{j,i}, s_{j,i}), \tag{2}$$

   - or: green and

$$d_{j,i} > s_{j,i} + p_{j,l} \rightarrow V_{j,i} = \min(V_{j,i}, d_{j,i}), \tag{3}$$

   - or: green and

$$d_{j,i} \le s_{j,i} + p_{j,l} \rightarrow V_{j,i} = \min(d_{j,i}, s_{j,i}), \tag{4}$$

   where $d_{j,i}$ – the distance from the vehicle located in the cell number i and road number j to the next vehicle, $s_{j,i}$ – the distance from the vehicle located in the cell number i and road number j to the next traffic lights, $p_{j,l}$ – the distance from the traffic lights on the road number j to the inductive loop placed behind the crossroads;
3. a random event – with a given probability, the cars reduce their speed by one:

$$V_{j,i} > 0 \wedge P < p \rightarrow V_{j,i} = V_{j,i} - 1, \tag{5}$$

   where P – the random variable, p – the probability of appearance of random event;
4. a move – vehicles move through the number of cells as their speed was, the time variable changes the value: t=t+1.

To ensure better intersection traffic capacity in the situation shown in Figure 2, the traffic lights could change to red (according to the formula (4) the vehicle located in the marked field will not enter the crossroads). Then the cars marked in black will be

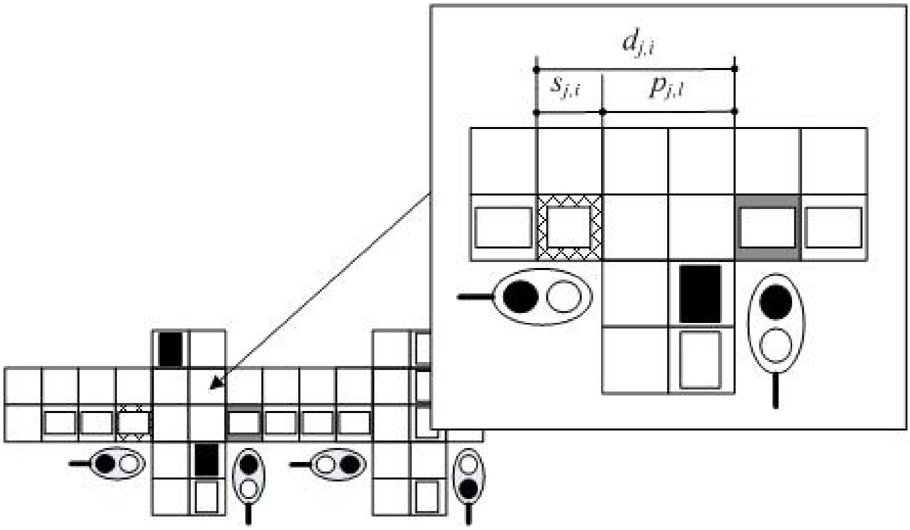

Fig. 2. The models [1] and [8] may lead to the intersection traffic congestion

able to continue their movement a bit earlier. The next change of traffic lights may take place straightaway after the place behind the crossroads is empty (the gray box shown in Fig. 2).

3 The Assumptions of the Traffic Simulation System

The system, which is being developed at the Department of Computer Science at the West Pomeranian University of Technology in Szczecin (Poland), consists of two main applications: TrafficCA (traffic simulation based on cellular automata) and MapGen – the map editor, which allows users to generate any area comprising the roads, traffic lights and surroundings.

The main aim of developing such a system is to provide a tool for analyzing drivers' behavior, depending on the situation on the road, according to the models presented in Table 1. The software will include new models describing other possible events, such as aggression with reference to driving comfort of other traffic participants or the impact of inductive loops on reducing intersection traffic congestion.

The map obtained in the system consists of grid cells with n-rows and m-columns. A single cell may represent a roadway or shoulder (the area closed to vehicles). The pavement cells are used to create paths which cars move along. Each track is a tree structure (Fig. 3), and therefore has one root and n-leaves. The root represents a point at which the vehicles' objects are created (entering the zone shown on the map), the node splits into two subsequent paths (fork of the roads) and the leaves are the points where the cars are "destroyed" (they leave the map). For each node a probability value is assigned. Based on that the vehicle determines the choice of the road (path in the tree). For the root the probability value means to emerge a new car on the map at the point. The leaves are the same facilities as other nodes – they only do not hold a reference to the next node.

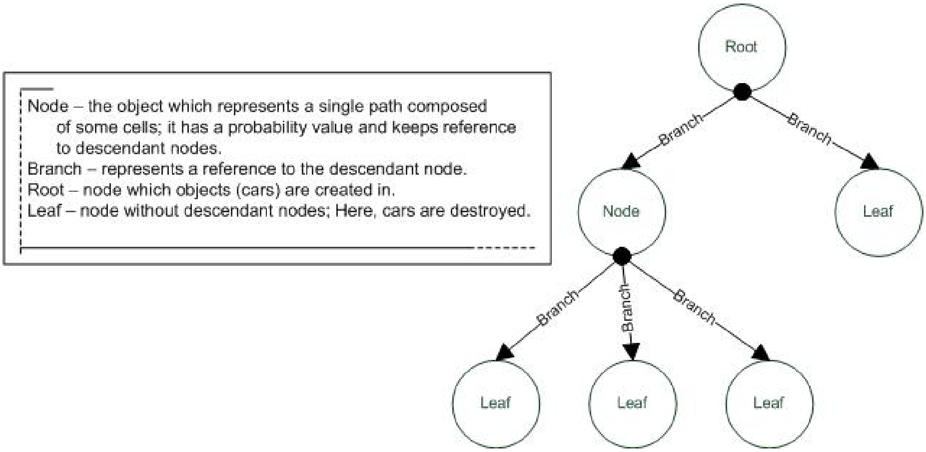

Fig. 3. The tree for the path which the vehicle moves on

Furthermore, any cell typed as "roadway" may contain an object representing the traffic lights. It is defined by three parameters – red and green traffic lights durations and a delay (it is used for proper signals synchronization).

As in the Nagel-Schreckenberg model [4], a simulated car is not bigger than a single cell and keeps references to the cell where it is located and to the cells following it in the path. A car may move to the next cell, if the red traffic light is not on in the current cell and there is not another car in the next cell.

The object "car" holds some values, including information about the current cell and the next cell, the current path (road), the coordinates, speed, maximum speed, acceleration (or delay) and maximum acceleration. Acceleration / delay depends on the distance to another vehicle or traffic lights and random events.

Thanks to the technology and application of new models, the software has great potential to use:

- access through any Web browser;
- map editor that allows to model any area of study;
- a simulation enabling cars differentiation due to the different values of acceleration and maximum speeds, generating random data and modeling of specific situations on the road;
- complex statistics and visualization of data generated by the simulator, such as traffic intensity, average speed, speed and acceleration of vehicles on the road section, the capacity of the area and characteristics of traffic lights;
- and many others.

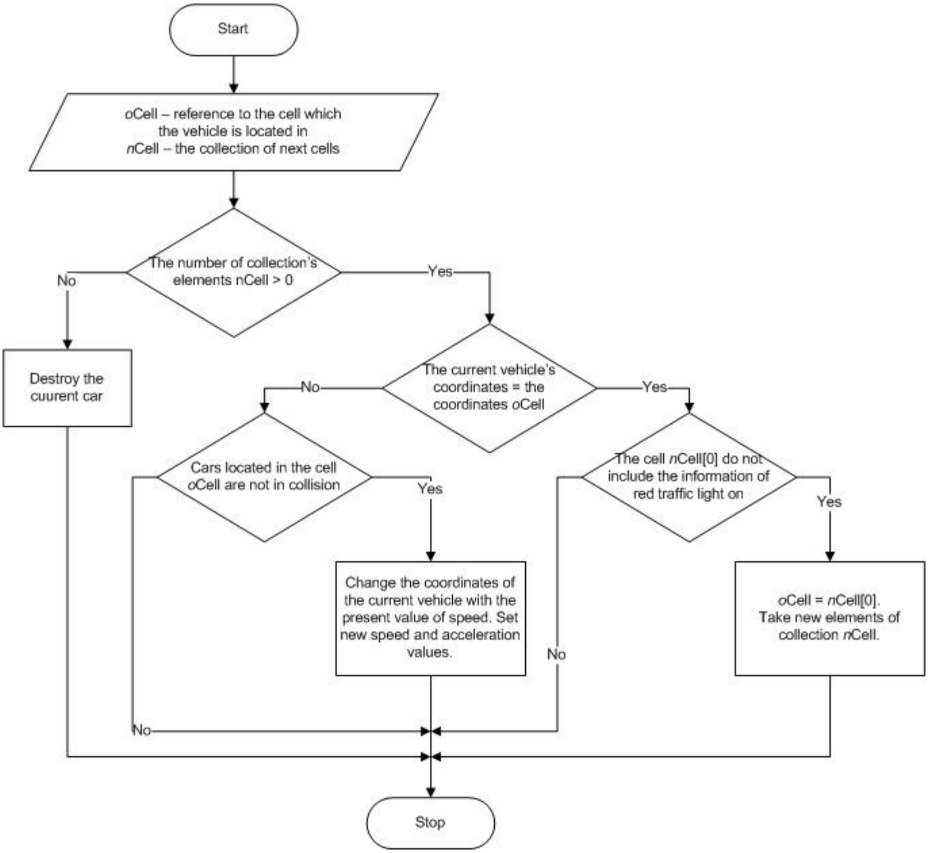

Fig. 4. The algorithm of the vehicle movement

4 Experimental Results

To validate the developed model, the authors implemented two identical crossroads with traffic lights in the simulator. One of the intersections was additionally equipped with a traffic detection system – the induction loops (behind the intersection - to see if the road is passable).

Numerous simulations have shown that the intersection traffic congestion is dependent primarily on:

- –traffic on a given stretch of road,
- –traffic light settings,
- –time periods ("dead zones") between the switching on subsequent traffic lights,
- –the distance between two intersections.

The results of the tests allow to conclude that the detection system (e.g. inductive loops) effectively minimize the risk of conflict situations and prevent blocking of vehicles at crossroads. Obviously, a key aspect is the appropriate location of inductive loops - for this purpose all the above-mentioned factors should be included, and possibly the specific traffic lights durations could be corrected.

5 Conclusion

A new crossroads model which is an expansion of the models presented in [1] and [8], was drawn up. The analysis of the current models has highlighted the phenomenon of intersection traffic congestion, now completely eliminated.

Based on the analysis of the existing traffic models the authors attempted to work out the traffic simulation system and drivers' behavior in various road situations. The basics of the system are presented in this article.

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