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Selected aspects of traffic micro-simulation based on cellular automata and traffic detection system

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ABSTRACT

The authors of this publication provide selected achievements in the field of traffic modelling and simulation based on cellular automata. Presented models and experimental studies carried out on the basis of their application to simulate traffic movement. One of the most important aspects of traffic modelling is to use the motion detection systems. The authors simulate the detectors, which in practice will implement as induction loops. They contribute to the evaluation of queues at the intersection and entered the intersection to determine whether to enter the intersection is possible, from the point of view of possibility of leaving that intersection. Quantitatively characterizations are presented.

KEYWORDS: traffic micro-simulation, cellular automata, detection system

1. Introduction

The problem of street congestion is quite normal, in today's world. 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 (for example: based on cellular automata, graph theory, multi-agent system and so on) and adequately prepared computer applications (software). Publication [4] shows the existing traffic models using cellular automata. Some of them have been implemented and presented in the form of a system available on Martin Treiber's website [6]. This project includes a few implemented traffic models. According to the information presented on the project's website, the author developed a simple simulation environments for the traffic, accurately presenting the dependences in traffic (back traffic jams, etc.).

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.

Hence, in aspect of the analysis of existing models, the authors have carried out a number of simulations for the crossroads model initially introduced by [1] and extended in [4]. The main idea of the research was to check whether the situating of motion detectors can have an influence on the capacity of the crossroads in question. A problem has been specified, whether and how a queue of vehicles after the crossroads can be estimated so as to prevent (with the use of traffic lights) vehicles from entering the crossroads and blocking the road (fig. 1, cars: C1 and C2).

2. Model of crossroads with detectors

In the field of cellular automata, the basic crossroads model is that introduced by [1] which is comprised of a grid of cells of NxN size, with one-way streets parallel to X and Y axes allowing for moving north and east. After a set number of cells (D), the streets intersect, forming crossroads without the possibility of changing direction. Traffic lights are present at these crossroads changing after a set period of time (T), with the cycles synchronized so that at each of the crossroads the lights are the same color for a given driving direction. The transfer function is similar to that of [5]. It varies only in the braking step, where additional factors needed to be considered, such as distance from traffic lights, their color and the time of light change. Further development of this model has led to one of a crossroads with multiple lanes.

In such models, the situation shown in Fig. 1 is possible.

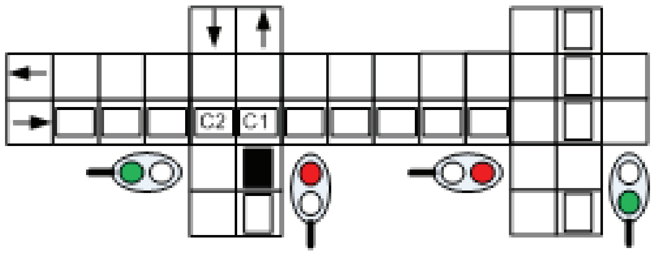
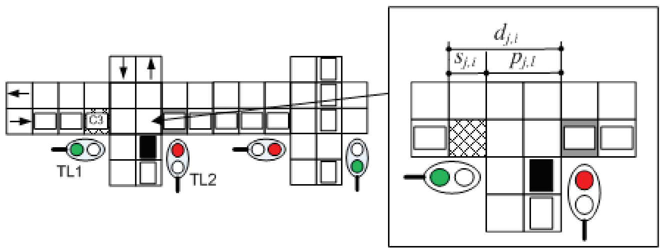
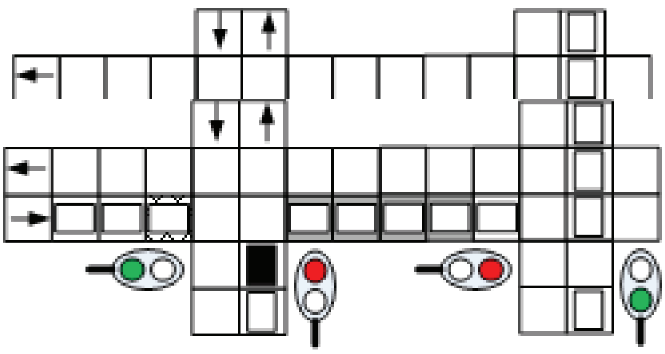


Fig. 1. Model may lead to the crossroads' blocking [1]



(a)



(c)

Fig. 2. Extended crossroads model: (a) with a motion detector situated behind the crossroads (detector marked with a grey field), (b) with two motion detectors situated behind the crossroads (two gray squares), (c) with a system of multiple motion detectors (four gray squares)

In order to avoid this phenomenon, in [4] the authors worked out a model with traffic detection system. This work is the continuation of research carried out in this direction. An extended crossroads model with motion detection has been presented (Fig. 2) and a simulation has been conducted and compared with the basic model. In this case motion detection has been simulated as inductive loops, two-state detectors allowing to detect whether there is an object (vehicle) situated at a certain point.

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 detector (for example: inductive loop) behind the crossroads (Fig. 2). The transition function, like in model [1], consists of 4 stages, but the second one (braking) was modified; stages: 1, 2 and 4 are consistent with the model [5]:

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

$$V_{j,i} < V_{\max} \rightarrow V_{j,i} = V_{j,i} + 1, \qquad (1)$$

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

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

   - or: green and

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

   - or: green and

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

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:

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

   - 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: $t=t+1$.

3. Experimental Results

In order to prove the correctness of the model, experimental research was conducted and its results have been presented as a comparison with model [1].

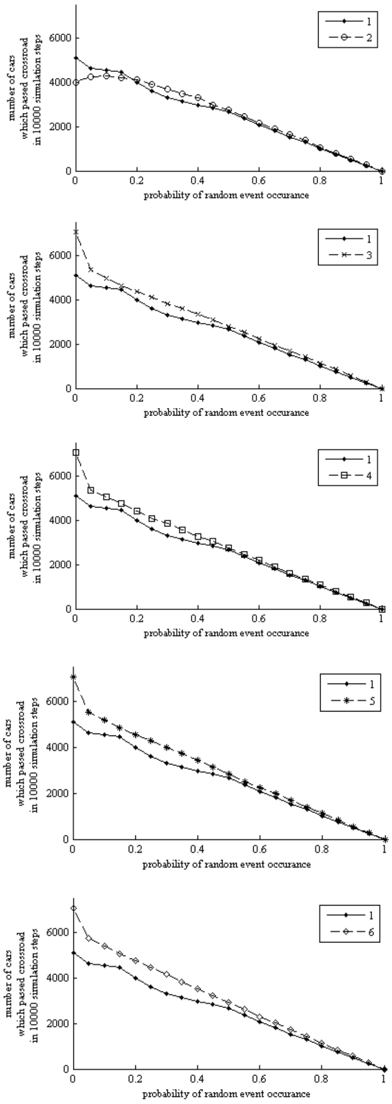


Fig. 3. Comparison of simulation results for all developed models regarding probability of random event occurrence

Various computer simulations have been prepared, focusing on traffic light switching modes (marked 1-6 in fig. 3-5):

1. a basic model based on [1], without motion detectors; vehicles enter the crossroads not checking whether it can be left, which leads to blocking of the crossroads,
2. a model without motion detectors, cars do not enter the crossroads if there is no space behind it,
3. a model with a single motion detector (Fig. 2a), switching traffic light to red (TL1) when for the direction with green light there is no more space behind the crossroads,
4. a model with multiple motion detectors (Fig. 2c); the TL1 light changes from green to red when the average speed on the marked section of the road (grey color) of the direction with green light is lower than the average speed of the other (perpendicular) direction,
5. a model with two motion detectors (Fig. 2b); the TL1 light changes to red when for the direction with green light there are vehicles in the two marked spaces and none in the respective cells for the perpendicular direction,
6. a model with two detectors (similar to model 5), with the difference that based on the marked spots, the sum of velocities in these cells is calculated, and if the sum for the direction with green light is smaller than the one for the other direction, the lights are switched.

Additionally, in all models with detectors, lights are switched after a set period of time if a condition allowing for the change is not met beforehand.

Fig. 3 presents simulation results for all developed models considering the probability of random event occurrence. The analysis showed an improvement in the capacity of the crossroads fitted with motion detectors by c. 2000 vehicles throughout the simulation period.

The next picture (fig. 4) presents the comparison of simulation results for variable cars density (increasing congestion of analyzed crossroads).

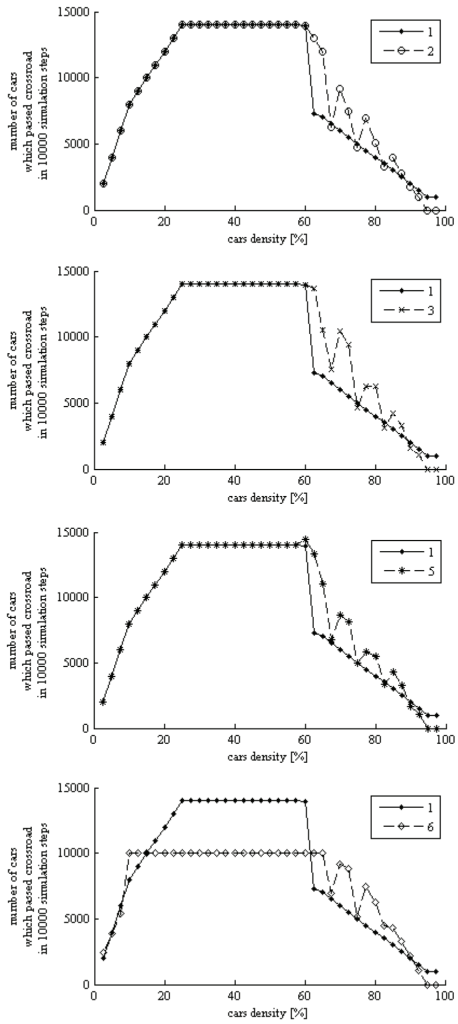


Fig. 4. Comparison of simulation results for developed models for variable vehicle density (increasing congestion of analyzed crossroads)

A cellular automaton of periodic boundary conditions was used for the simulation.

The influence of light switching times has been presented with two examples (model 2 – fig. 5a and model 5 – fig. 5b). In the latter case a situation of reaching full capacity (no vehicle is stuck in a traffic jam) from the value of 10 is visible, whereas models 1 and 5 are convergent in the range 0-10.

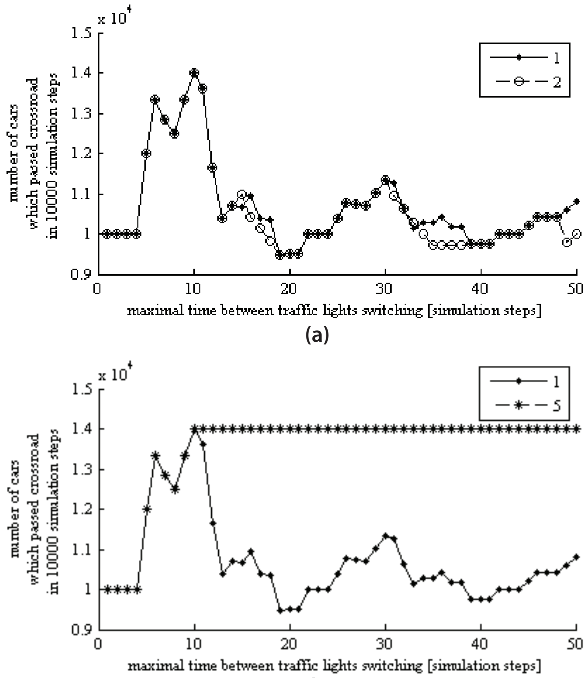


Fig. 5. Results of selected models in terms of maximal time between light switching: (a) comparison of basic model and model 2, (b) comparison of basic model with model 5

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. The developed models and conducted experiments have showed the influence of the placement of motion detectors and the method of interpretation of signals from the detectors on the capacity of crossroads.

4. Conclusion

In this work the problems of traffic simulation on two-lane roads have been presented. A model described in [4], based on cellular automata, including motion detectors as traffic lights controlling mechanisms has been utilized. A novelty in the work was placing the detectors behind the crossroads and checking their influence on the capacity of that crossroads.

A few crossroads models with motion detectors have been developed. All of them have been tested in the simulation process with the results compared. An increase in the capacity with the use of motion detection situated behind crossroads has been proved.

Further research will be conducted in an attempt to estimate the regularities stemming from the use of motion detectors both in front of and behind crossroads.

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