TRAFFIC MODELLING USING CELLULAR AUTOMATA

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Abstract:

Today's traffic models are divided into 3 main categories: microscopic models, mesoscopic models and macroscopic models. Each of them has its own advantages over the others. In this article it will be dealt with the microscopic models. Their main advantage is that they model car behaviour on the most detailed level and are great for modelling smaller traffic networks. Disadvantage of these models is that they require a lot of computing power and are sometimes obscure due to the lots of parameters. There are two types of microscopic models: multiagent systems and cellular automata. The latter one was chosen for this simulation because its rules are simple and well defined for models composed of many parts (for example straight roads, crossroads, traffic circles and so on). Main principle of the cellular automata is that the simulated object is divided into cells with some parameters and hen resolved by examining relations between cells by some logic. The simulation of traffic flow on the two-lane roadway is presented in the article. The traffic flow simulation module is a part of complex automated system for traffic network modelling. The road is broken down into the cells. Each cell is one lane wide and approximately 5 m long and can contain no more than one car. During resolving phase, every cell resolves its relationships with other neighbour cells. For example some cell contains the car with enough speed to get into the resolved cell so it is moved into resolved cell or it has not enough speed and is left to be dealt by another cell and so on. Thorough analysis was performed to analyze all possible situations. Logic for resolving situations is based on the real traffic rules. The simulation was implemented in Java programming language.

Keywords: traffic simulation, cellular automata

1 Introduction

During the last 25 years the traffic situation in Czech Republic has changed rapidly. Earlier there were simply too few cars to cause many problems. Traffic jams and problem with parking places were not so commonplace like today. Many roads and crossroads were built for the much lighter traffic than it is now. Today in rush hours, traffic in many places is jammed. So modelling and solving traffic problems becomes very serious issue. We have chosen to take a closer look on traffic modelling and made our own modelling logic to simulate and analyze various traffic situations. So far we made simulations of single-lane road, two-lane road and two-lane road with a ramp.

2 Types of modelling

Based on level-of-detail of modelling Ch. Mallikarjuna and K. Ramachandra Rao[1]recognized three types of the models:

- Microscopic models (Car following models, cellular automata models)
- Mesoscopic models (Gas Kinetic models)
- Macroscopic models (LWR models)

Microscopic models – Car following models

Microscopic models describe traffic operations during discrete time intervals over continuous time. Amongst Car following models are safe distance models, stimulus response models, psycho pacing, etc. On these models are based many new models concentrating on problems like jams and capacity drop. Problems of these models are multitude parameters making them sometimes obscured and they require a lot of computing power.

Mesoscopic models – Gas Kinetic models

Mesoscopic models are covering the space between macroscopic and microscopic models. They combine the use of traffic flow variables with resolving interaction between vehicles. In kinetic theory, traffic is treated as a gas of interacting particles where each particle represents a vehicle. Instead of describing the traffic dynamics of individual vehicles, gas-kinetic traffic flow models describe the dynamics of the velocity distribution functions of vehicles in the traffic flow.

Macroscopic models – LWR models

LWR model named after Lighthill (L), Whitham (W) and Richards (R) who developed it independently in 1950's. The LWR model describes the traffic on a link using conservation law. The strongest point of the LWR model is its capacity for analytical solutions. LWR model shows, by using diagrams, the relation between flow q and density k when traffic is stationary and homogeneous. Because the real traffic is not ideal the use of this type of modelling is problematic. Some advancement was made to describe non-stationary and heterogeneous characteristics of traffic flow but new parameters increase the input for the model thus losing the analytical value.

3 Cellular automata models

We have chosen cellular automata (CA) model for our traffic simulation. It has many advantages over the former ones. Only a relatively small set of rules is needed for movement of the vehicles and resolving traffic situations. It is also very easy to make new component of the model as the rules for the different types of the road are similar. Due to this similarity updating is also very easy as the components of the model are parallel. CA models are also undemanding for computing power because many processes are done implicitly and are described by relatively few variables (position, speed, time) which all are discrete. Road itself is broken down to cells. Cell can have two states: it's either unoccupied (i.e. there is no car on its position) or occupied (i.e. there is a car on its position). Cars are represented only by states of cells. Every time T automaton resolves next state of all cells (i.e. if they will have a car or not) by using real logic it changes speed and position of cars accordingly. Usually there are also some randomizations added as the traffic is not always ideal (for example it is almost not possible to hold the same speed, some drivers are not obeying traffic rules, etc.). However as

Kai Nagel[3] mentions, the CA models also have some downsides. It's really difficult to simulate precise speed because speeds are counted not in meters passed but in cells passed. And as the cell has fixed length, accuracy of speed is also limited by this length. Longer the cells are, less accurate is the speed. On the other hand if the cells are too short and cars must occupy two or more ones, the accuracy grows but speed of the model decreases dramatically.

4 Our traffic model

Single-lane road

As we mentioned before, we have chosen to make our traffic model by using cellular automata. We started with simple logic for single-lane road. We divided it into cells 5 meters long and lane-wide. Each of the cells has its state, which is determined by presence of car. Should there be no car, cell is empty. But if there is a car, the cell will be full and will have some speed. Model starts as empty road. Cars are entering it every second step (can be changed) with random speed. Each time period, cellular automaton will resolve each cell by its logic. For each resolved cell, the simulation will create array of neighbor cells around the resolved cell. It will be v_{max} ahead and v_{max} backwards of the resolved cell. In the diagram below (figure 1) is shown the logic we made for the resolving the cell.

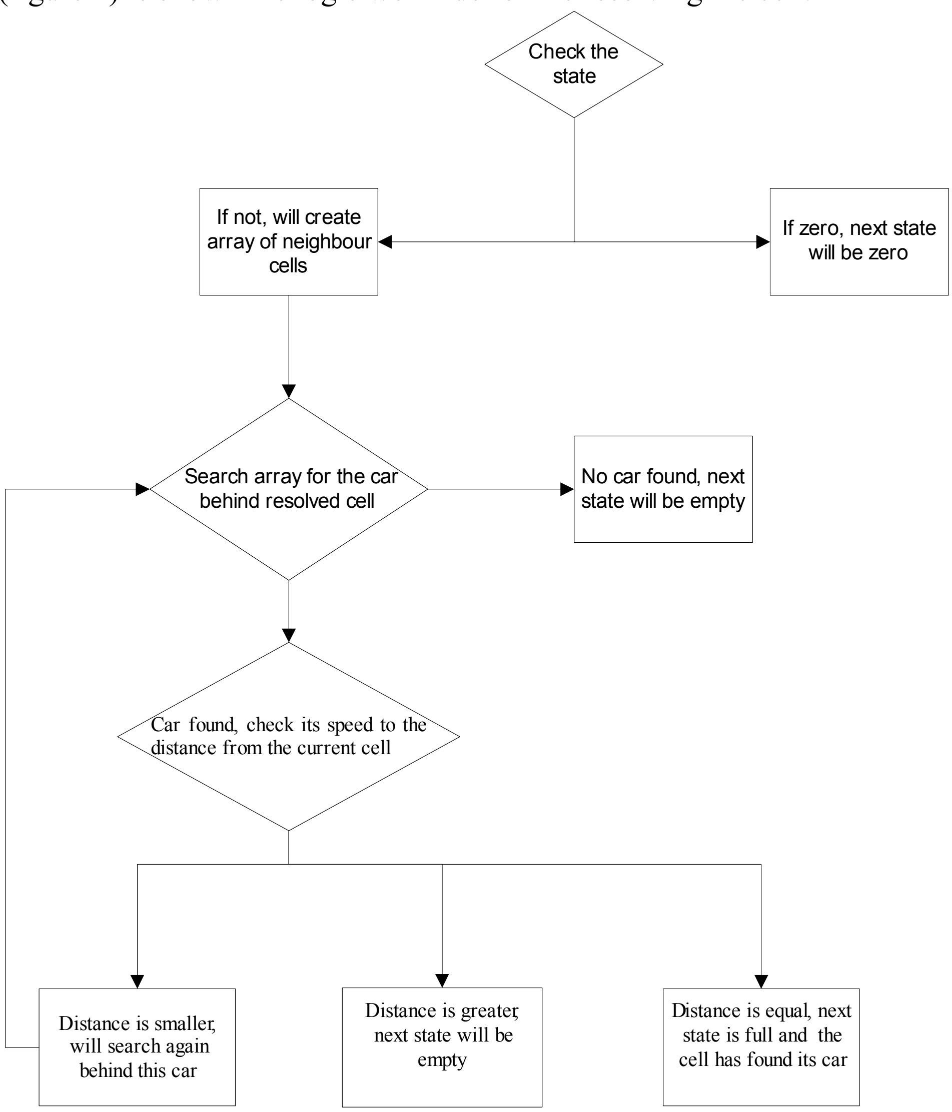

Figure 1: Resolving diagram for single-lane road

Figure 2

After all cells have found their cars, they will adjust their speed accordingly to new situation and their safety. They will try to keep safe distance from car ahead. The speed is defined by nuber of cells that car passes in the next step. The new speed is calculated by this formula:

	C				O		B		

$$v_{future} = v_B + (indexB - indexO) - 1 + round(a)$$

v_{future}........................next speed of the car
v_b.............................speed of first car ahead
indexB.....................index of cell of the first car ahead of the resolved car in the array
indexO.....................index of the resolved cell
a...............................random number from <-1, 1>

We also defined max speed which is (last speed of the car + maximal acceleration). Should the resolved speed be higher, it will be set to max speed. Should the speed be lower than (last speed – max deceleration) the car will crash.

Two-lane road

Two lane roads are similar in most things but bring few changes. The most important thing is that slower cars can be overtaken by faster ones. Another big change is that array of neighbour cells is two-dimensional to cover both lanes. We also included some chance that a car will stop and create an obstacle which must be overtaken by all cars. The logic is slightly more difficult as there are two different logics for the cell resolving, one for the right lane and one for the left lane. Both of them are shown int the folowing diagrams (figure 2, figure 3).

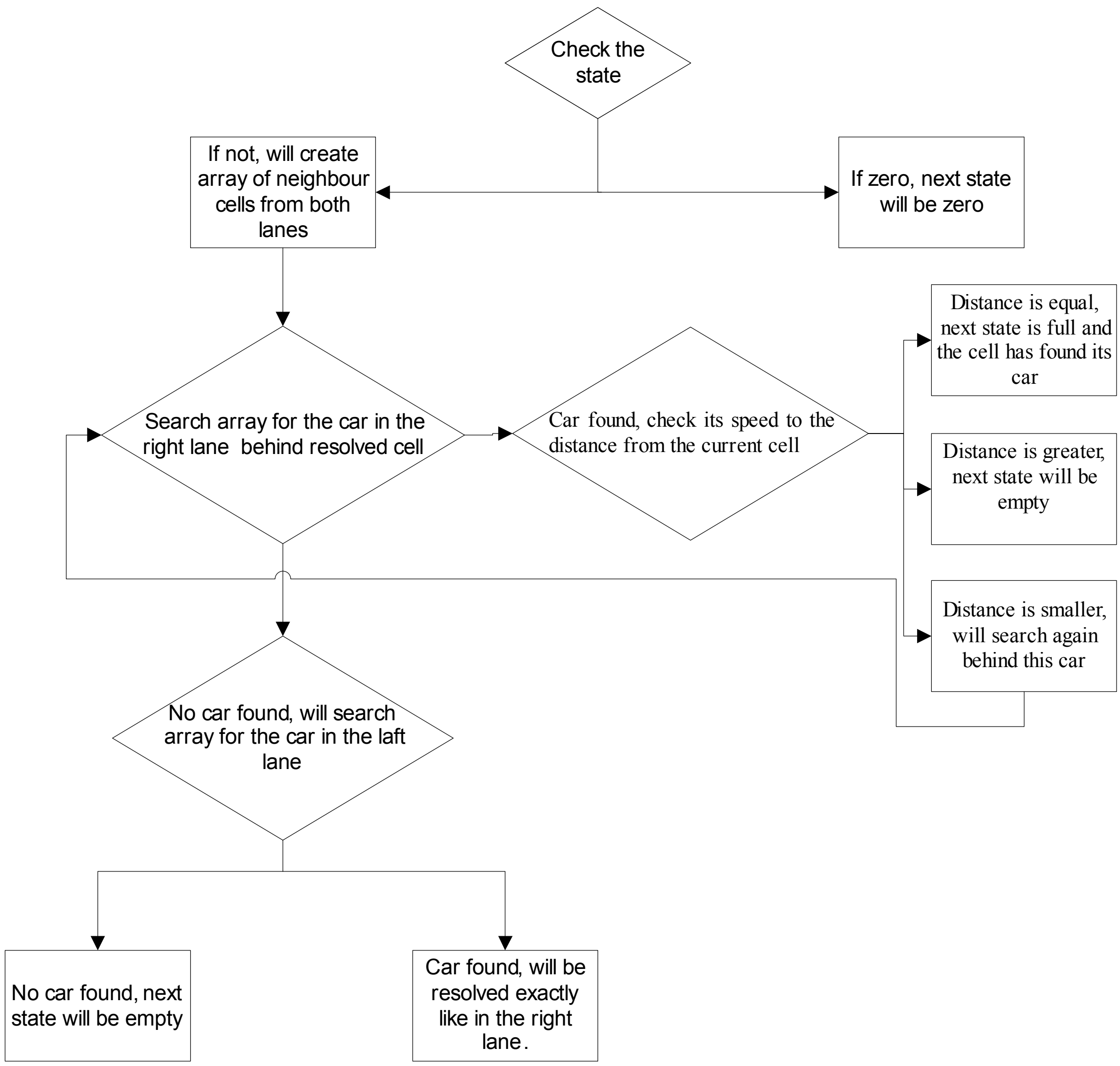

Figure 2: Resolving diagram for two-lane road (right lane)

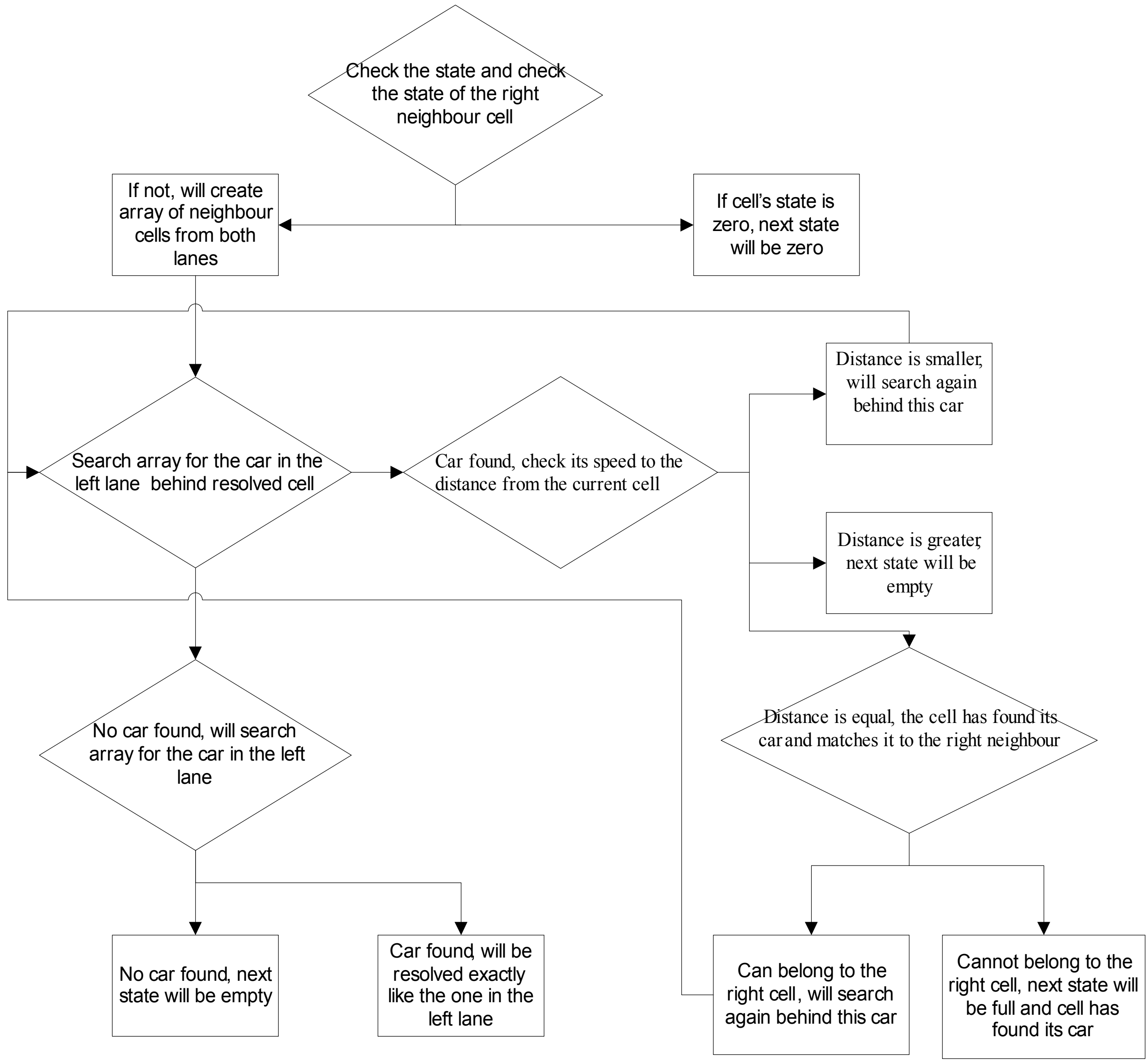

Figure 3: Resolving diagram for two-lane road (left lane)

Speed is determined similary to the single-lane road, with the exception that the car ahead is the first car ahead in the lane of the resoved cell.

Two-lane road with a ramp

Two-lane road with ramp brings several new things. It uses two previous models and adds interaction between them. Generally it shows possibilities of CA based modelling and how it is possible to break down model to smaller components. This model has 3 effective parts: two-lane road which is before and behind the merging with the ramp, single-lane road which is the ramp before the merging and area of merging. In the following diagrams (figure 4, figure 5, figure 6) is shown logic for the merging part, logics for the single-lane road and the two-lane road are described earlier.

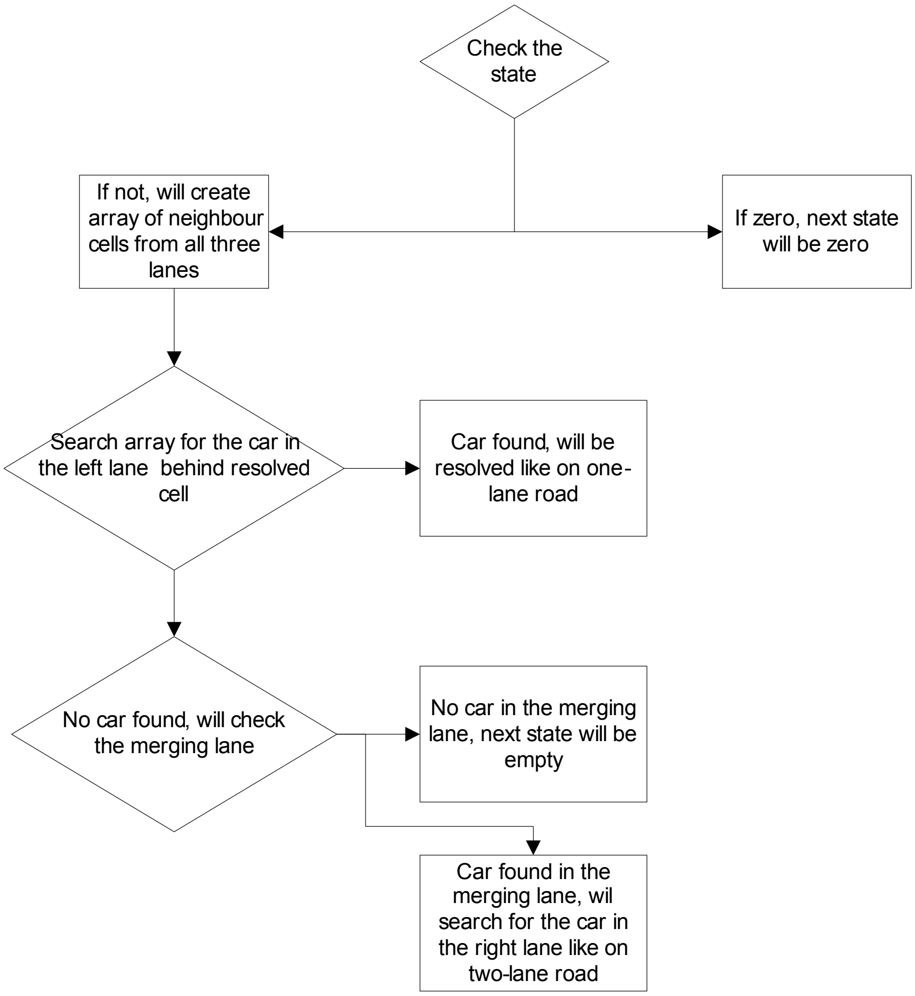

Figure 4: Resolving diagram for two-lane road with ramp (left lane)

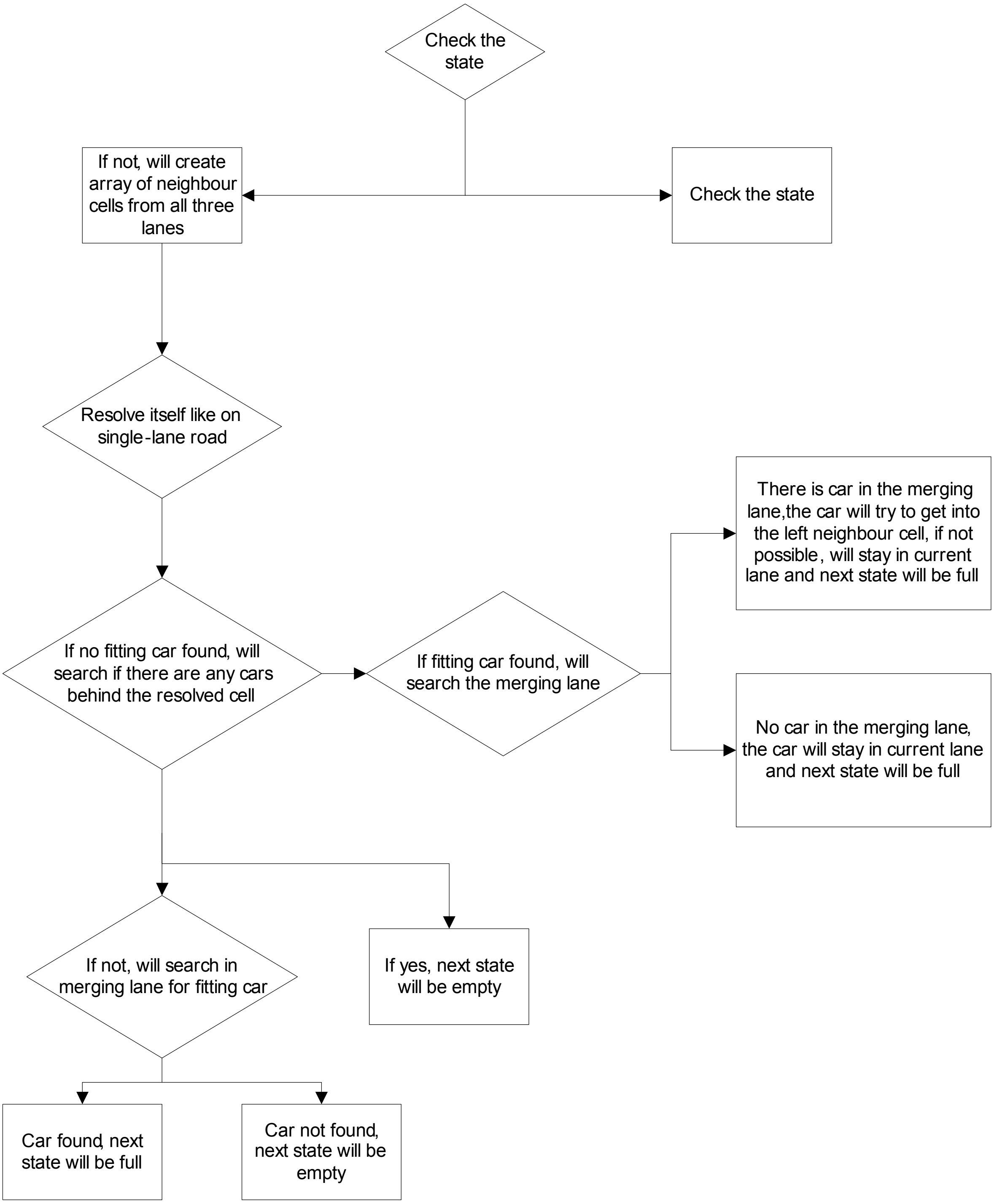

Figure 5: Resolving diagram for two-lane road with ramp (right lane)

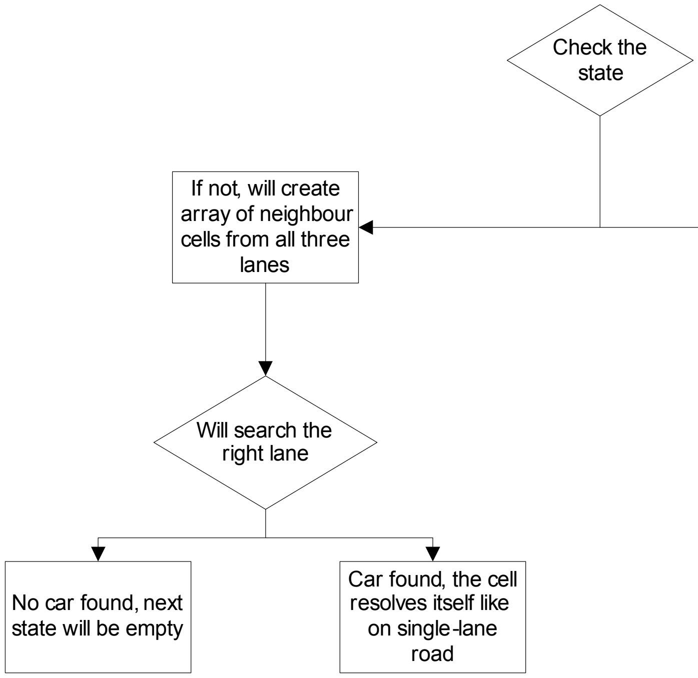

Figure 6: Resolving diagram for two-lane road with ramp (merging lane)

Speeds are counted accordingly to the type of the road. Only exception is that in the area of merging there is a restriction lowering max speed and speed is counted like on single lane road in all three lanes. Finally we will show you results of few steps of simulation (figure 7).

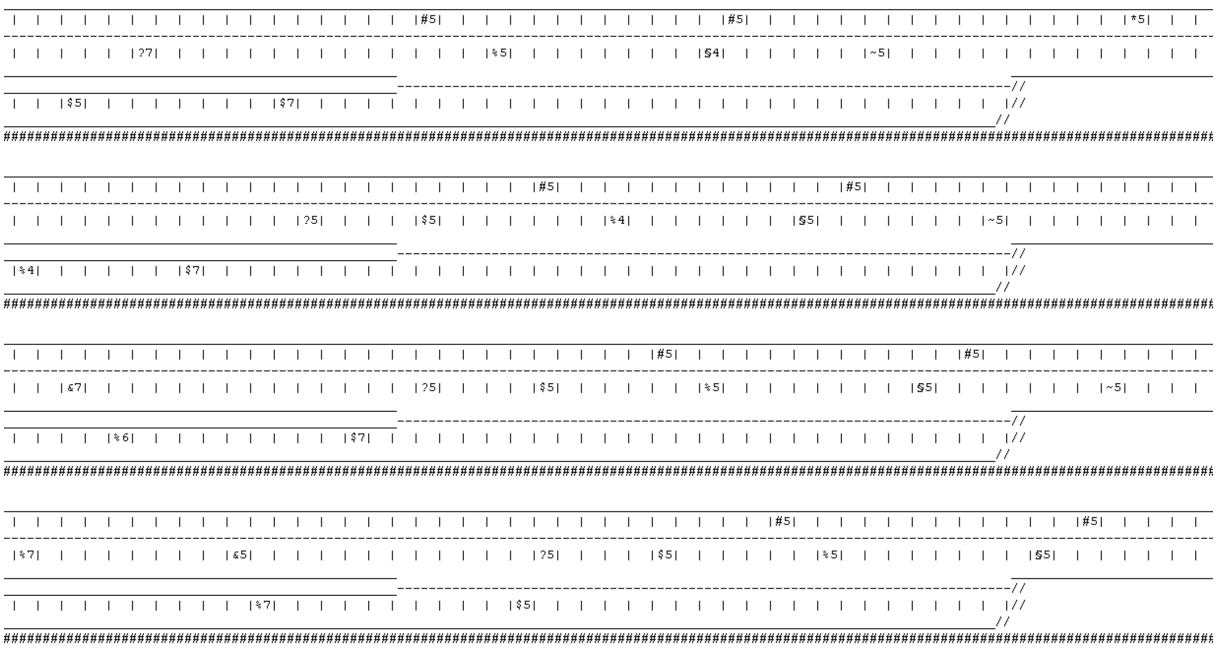

Figure 7: Output of the simulation

5 Conclusion

In this paper, we have showed some approaches to the traffic modelling and presented our own model. For presentation and analyze purposes we implemented it in Java programming language. You can find image (figure 8) from our program below this paragraph. It is only first part of the system we are working on. We will present other parts in the near future. Finally these parts will be put together and will create simulation of the entire traffic network in some area. It will be used to analyze some situations and find best solutions for them. It is also developed as a module for GIS. It will be able to upload data of the traffic network from GIS, simulate the traffic by CA and then send results to GIS to be visualised. It will be used to analyze some situations and find the best solutions for them.

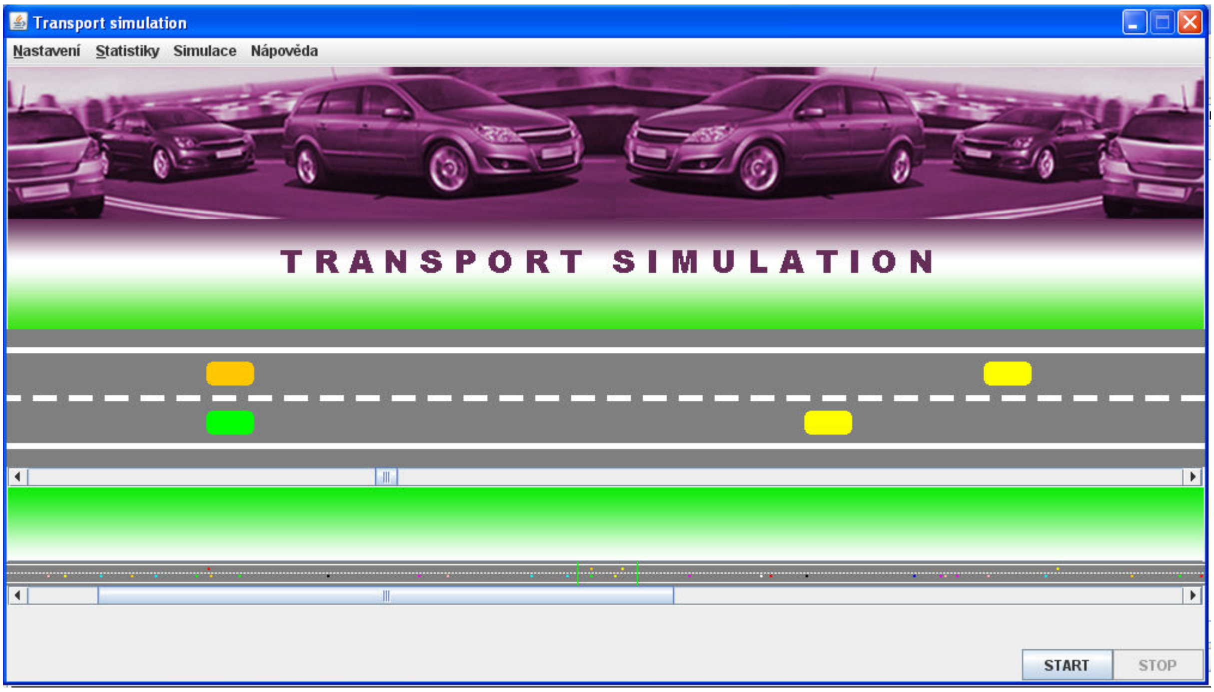

Figure 8: Interface of the simulation

Acknowledgemet

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