General Purpose Road Traffic Simulation System with a Cell Automaton Model

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EXTENDED ABSTRACT

For several years, we have been developing a general purpose road-traffic simulation system to analyze road traffic jam. This paper describes the concept of the system using the running line model, and a case study for general purpose simulation with cell aotpmaton model.

In order to simulate congestion of road traffic system, it is indispensable to describe vehicles having their own decision-making capabilities, and to have detailed and exact road condition data on the road system. The road system is composed of such roads as streets, avenues and highways, and their intersections. In this study, we represent it by a network in which roads are arcs and intersections are nodes.

The road-network itself has two kinds of attributes; the physical attributes and the logical attributes. The former are ones of the roads themselves such as their varying widths, shapes, slopes, running lines of traffic lanes and their channels. The latter are ones which depends traffic regulations such as signals and traffic signs. The former is called road information and the latter is road traffic regulation information in the road-network.

Almost all road traffic simulations using a microscopic model have been carried out through a locally fixed road-network information database system. However, these systems are not effective. A general-purpose road traffic database system is therefore desired to analyze traffic jams in all areas. Because such a general-purpose system is very voluminous, speedy input of road network attributes should be taken into consideration, and the addition of some effective error-correcting method. We propose a new concept whereby the running lines on the various shapes of the road can be represented approximately by a combination of lines, circles and clothoid curves allowing speedy calculation. We developed a general-purpose database system to describe road information except for the road traffic regulation information. It is important to draw quickly and easily any running lines on the road of the database system.

On the other hand, several studies have been done to realize road traffic simulation by a microscopic model. For example, there is a flattery model of a vehicle by a fuzzy theory and various theories such as a neural network work. A model could do movement every one vehicle in detail by using these methods, and high simulation of precision was enabled. However, these models are very complicated, and simulation practice processing time becomes long. Therefore, as a method we simplify a complicated phenomenon as much as possible, and to express, simulation by a cell automaton attracts attention.

A cell automaton assigns one individual to one cell basically and moves a cell in consideration of being affected by the individual which each individual is next to. Modeling for simulation is clear and becomes simple a generous thing called a cell follows a specific rule, and to move. It may be thought that an error grows big when we cut off a small error. However, you should have you just think like the middle of a micro-model and a macro-model. We can realize total movement in form to be almost reality to some extent by doing simulation of a rough model. A cell automaton is applied in a wide field by such a characteristic.

By this study, we changed passing and a traffic lane of it more, and parking vehicle evasion wrestled for realization of the run model that became important by a town area run. We introduce a model general idea to call "a temporary lane" for these run models. And these modeling, we can realize simulation to be almost reality. Because we did systems construction by these theories and the inspection by this thesis, we introduce about it.

1. INTRODUCTION

Many road traffic simulation systems have been developed. But the road databases used in almost all of them were developed only for specific areas and purposes, and so cannot be reused in simulations for other areas.

The need exists for a general-purpose simulation system to analyze road traffic congestion of arbitrary wide areas accurately. Such a simulation requires a microscopic model for the vehicle's behavior. In simulating such a system, it is essential to have detailed and correct data on road conditions, including the road itself, as well as traffic signs and signals. In addition, it is important to reduce a simulation’s execution time to the utmost. A road system is generally described as a network in which the road is an arc and each intersection is a node. It is represented approximately by a combination of lines, circles, and clothoid curves. We built a road network model based on this concept. Moreover, since road information is composed of lanes on which vehicles are running, we also built a running model of vehicles based on our concept of the road network model. Vehicles run approximately along center line on the lane. One lane is directly connected with the other lane on the other road through channels in an intersection. In addition to the lane, we employed the concept of a pseudo-lane set up temporarily in the road network model. The lanes on the various shapes of the road network can be represented approximately by a combination of lines, circles and clothoid curves. Thus vehicles could run freely as if under actual traffic conditions.

On the other hand, a road network has a number of attributes, such as width, form, traffic signs, and signals at intersections. These attributes can be divided into two classes: physical, pertaining to physical features of the road itself and its lanes; and logical, concerned with road traffic regulations. We built models for the former and developed a database system for them. This system includes all the information on physical attributes of the road necessary for road traffic simulation with a microscopic model. This road database system made it possible to simulate any road traffic system for any area. A database should be flexible enough to accommodate changes in road data. Because of the large amount of data, we also had to consider the addition of a graphic user interface for human interaction.

We studied a simulation system by a microscopic vehicle model as a traffic jam analysis system in a general road around a city till now. On that occasion we were similar and went about a study of a flattery model with a fuzzy theory or a neural network work. We can build the driving model that is almost a human sense by introducing these theories, and the simulation that accorded with reality is enabled. However, processing time becomes long because processing is complicated in these models. Therefore a cell automaton we simplify a complicated thing, and to express attracts attention. This simplifies only movement and arrests you, and it is technique to analyze a complicated phenomenon by doing simulation as the aggregate. It is expected that we can express more traffic style by this well.

This paper describes the introduction in chapter1, cell automaton model in chapter 2, concept of road network model in chapter 3, Modeling of road network in chapter 4, running model of vehicles in chapter 5, an experiment and verification of a model in chapter 6, and concluding remarks in chapter 7.

2. CONCEPT OF ROAD NETWORK MODEL

The key point of doing a simulation with a microscopic model for congestion of a road traffic system is building a road network model. The following two points should be taken into account: one is how to reduce the execution time of road traffic simulation with a microscopic model; the other is a method for inputting data correctly, quickly and easily to the database.

The reduction of execution time is the most important requirement in the real time simulation of a road traffic simulation with a microscopic model. On the other hand, an effective human interaction system, using a two and/or three-dimensional graphic display, is another important requirement in the simulation of a large and complex system such as a road traffic system. Detailed and correct information concerning the conditions of the road itself, lanes and running lines, should also be used for the animation on the display screen during simulation.

2.1 Requirement for Road Network Model

An important element controlling the vehicle run in road traffic simulation is information concerning the road itself, as well as traffic signs and signals at intersections. A simulation for analyzing road traffic congestion requires that the two-dimensional behavior of the vehicles be described exactly as it occurs in the actual run. It may also be necessary to represent detailed two-dimensional behaviors of vehicles running on curves. The microscopic model should adjust for that effect.

Thus the model must describe the detailed physical form of the road itself as well as the behavior of the vehicles, which have their own decision-making capability. The way in which the road network model and running model of vehicles are built is the most important point in the development of the road traffic simulation system.

The data for describing physical features, such as the roads form, width and lane configuration are voluminous. Related data should be correctly and quickly input, and easily modified. As a large amount is input through human interface, the data should be organized efficiently and its processing should involve minimal time.

2.2 Principal of Model-building

A road generally has a uniform width as measured from the center line. Also, a road network can be fundamentally defined by the center line using a combination of straight lines and circles. However, we adopt a clothoid curve for more precision in addition to these. The clothoid curve is a locus drawn by the run of vehicles, based on the movement of the steering wheel. Hence, we built our road network model using a combination of straight lines, circles, and clothoid curves. This is the principal concept of our road network model.

The road itself is two-dimensional, but here we employ a modeling concept in which a locus drawn by the run of vehicle on a lane can be approximately replaced by a line centered along a lane. A vehicle runs along this line (Figure 1). This concept is fundamental for our running model of vehicles on the road network model. Therefore movements of vehicles on our model can be changed from two-dimensional space to one-dimensional space. Such a line is described more realistically and exactly by using a combination of straight lines, circles and clothoid curves. This permitted us to model the behavior of actual vehicles in a more natural way. In addition, it reduced remarkably the simulation's execution time.

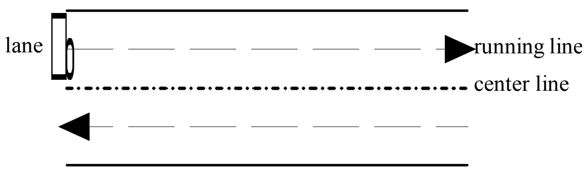


Figure 1. Lane and Running Line of Vehicle

According to this concept, it is possible to describe the behavior of a vehicle passing another moving or parked vehicles by temporarily establishing a pseudo-lane to connect from one lane to the other. The pseudo-lane is established only for representing non-regular vehicle behavior. This pseudo-lane is also used to describe the behavior of a vehicle parked and stopped on the side of the road.
This representation of lanes through a combination of straight lines, circles and clothoid curves makes it possible to organize a more effective road network model with running model of vehicles and road database system.

3. MODELING OF ROAD NETWOK

The important information needed for simulating the congestion of road traffic is the fundamental form of the road network model (Figure 2), the width of the road, and a set of lanes on which the vehicles will travel. In the following sections, we describe our road network model and running model of vehicles on it (Figure 3).

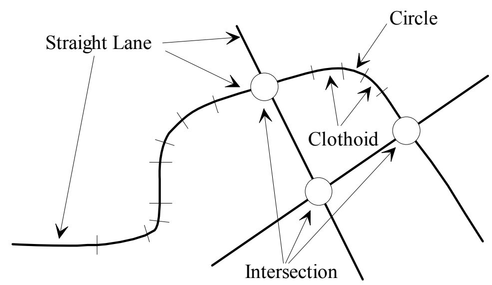


Figure 2. Fundamental Form of the Road Network Model

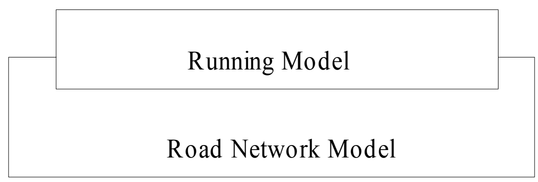


Figure 3. Architecture of Running Model on Road Network Model

The fundamental form of the model is described by a combination of lines (straight and/or curved). The cross point of the fundamental form is the road intersection. A road system has basically uniform widths in relation to the line of the fundamental form. This line is usually called the center line of the road. This is shown in Figure 4 as a basic pattern with a consistent width. Some roads, however, have widths that vary in some places. The roads with such variable width portions are divided into three kinds of subroads as follows :

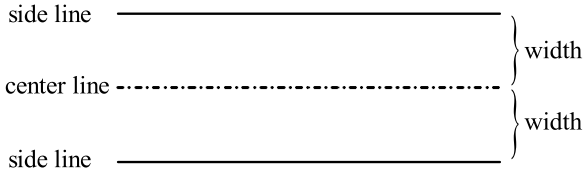


Figure 4. Road with Standard Width

1. Fixed and symmetrical in relation to the center line.
2. Partially varying and not symmetrical to the center line. Example: bus stop, vehicle rest station.
3. Partially varying and symmetrical to the center line.
4. Partially varying and not symmetrical to the center line.

4. RUNNING MODEL OF VEHICLES

We describe relation of lane and running line in this chapter. The vehicle's free travels in a two-dimensional area can be represented approximately adopting the concept of running lines. We call a set of running lines the running model of vehicles.

4.1 Lane

The lanes can be described on the road network model. In general, vehicles travel in a regular manner along the lanes of the road system. We call this a regular lane. But vehicles may also be able to run non-regularly, e.g., by transferring from one lane to another when passing another moving or parked vehicle. This model is built to include the provision of a pseudo-lane (non-regular lane) and a temporary lane for transferring from one lane to another. The combination of these three lanes can easily represent such non-regular running as passing and parking.

Using their lanes, the vehicle's free run in a two-dimensional area can be represented approximately.

4.2 Running Line

In addition to this concept of lanes, we employ model-building in which the vehicles run along a center line of the lane (Figure 5). Vehicles must run along the center line of the lane. We call this a running line (Figure 6). This fundamental concept is our running model of vehicles. This model is built to include the provision of pseudo-lines (non-regular lines) and a temporary line for transferring from one line to another (Figure 7 and Table 1). Of course, the running line of vehicles is represented using a combination of straight lines, circles and clothoid curves, and their application. It can represent approximately the behavior of vehicles. This model contributes considerably to the reduction of the execution time in the road traffic simulation with a microscopic model.

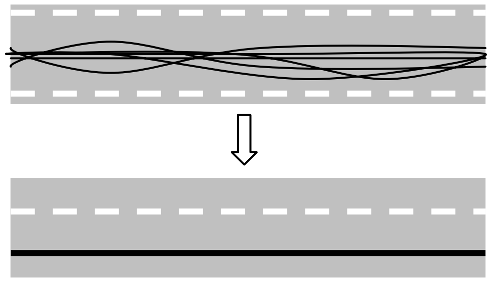


Figure 5. Locus of Vehicle's Run and Running Line

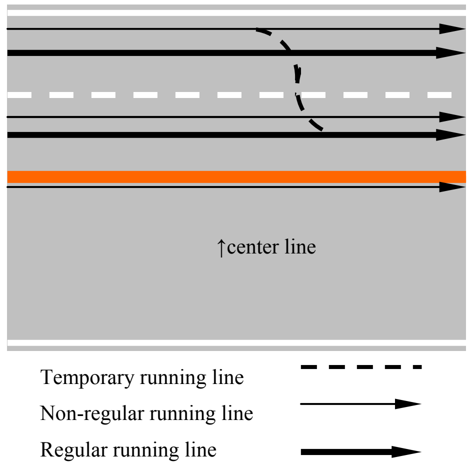
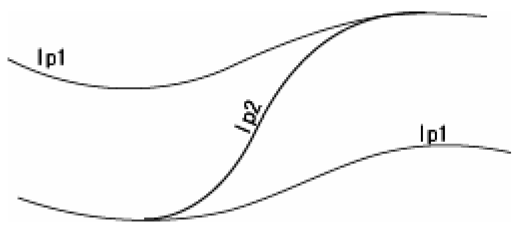


Figure 6. Running Line and its Locus of Vehicle



lp1 : Regular or non-regular running line
lp2 : Temporary running line

Figure 7. Temporary Line to Transfer from One Running Line to the Other

Table 1. Architecture of Running Line

running line		
non-regular running line	regular running line	temporary running line
locus of vehicle's run		

5. CELL AUTOMATON MODEL

5.1 About Cell Automaton

Cell automaton (CA) is a method to decide a state of a cell of the next time by a state of an adjacent cell. Though we decide a value of the next time of the cell which there is when we thought about the cell which formed a line in one line wide in 1 dimension of cell automaton, it is it with a big factor when we decide a state change where we consider a cell next to each other to. We consider a state of a cell of the next-door houses on both sides then when we assume company list of a cell, t the time in i, and it is given a cell of the next time by following function F if decided.

$$a_{t+1}^{i} = F(a_t^{i-r}, a_t^{i-r+1}, \Lambda, a_t^{i}, \Lambda, a_t^{i+r-1}, a_t^{i+r})$$

We assume the state that we can take of each cell 0 and 1-2 kind here and think about a case to consider two three state neighborhoods that is the right and left next-door houses on both sides. There are eight patterns to show it in next in a row of cells and the state that I can take of a central cell in the next time.

$$\frac{111}{1} \quad \frac{110}{0} \quad \frac{101}{1} \quad \frac{100}{1} \quad \frac{011}{1} \quad \frac{010}{0} \quad \frac{001}{0} \quad \frac{000}{0}$$

It becomes 10111000 then in the lower berth. This calls the 184th rule neighbor, this with rule 184 when we make 184 neighbors, a number of the decimal a rule number when we convert this number 2 into the decimal from the binary. In addition, in the case of two three state neighborhoods, there is this rule 2 according to 256 from a combination of eight columns of numbers of the decimal. Generally there can be a rule according to S. But K is the number of states.

5.2 The Model of Cell Automaton

It is the model that used rule 184 that it explained in a foregoing paragraph that firstly it was thought as the road traffic model who used a cell automaton. This model "divide a road into a cell, and a vehicle expresses the cell which there is not a vehicle with existing cell 1 with 0". And if a cell in front of a progress direction becomes vacant, one cell gets worse with one clock and remains in the place without can move if a vehicle is forward. With a simple thing, a run of a vehicle is the same as the state that applied rule 184. Now a model by various cell automatons was thought about, but most improved this rule 184. There is a NS model suggested with an in that well-known thing by Nagel and Schreckenberg. A vehicle of each cell has speed made v=0,1,2 / v and disintegration, and this model is expressed for a number of a cell advancing with one clock. Then each vehicle obeys the next rule within the maximum speed and runs with number of speed v, maximum speed Vmax, the forward empty cells (distance between the vehicles) g.

(1) $v > g$ and $v < v_{\max}$ $\rightarrow$ $v = v + 1$ (acceleration)

(2) $v < g \rightarrow v = g$ (slow down)

(3) $v > 0 \rightarrow v = v - 1$ with 0.3 probability. (random break)

(4) Each vehicle goes ahead through v cells between one clock (running).

In addition, when they really do simulation, one cell assumes it 7.5m, and Nagel propose that one clock does it with one second.

However, it seems that it is difficult for this to apply to a road in an urban region in the case of a large-scale road such as a highway. Therefore we thought that we improved a model so that there was the run that was suitable for a general road.

5.3 The Model that We Propose in a Cell Automaton

There is you for the purpose of doing road traffic simulation in a city by this study. Therefore we built the model that enabled run simulation in a city by improving a NS model more. Therefore we let speed in simulation and real speed support like a list to show below.

Table 2. Speed and cells

Speed in cell(cells when 1 simulation clock)	Speed (km/h)
1	5
2	10
3	15
4	20
5	25
6	30
7	35
8	40
9	45
10	50

And we assumed chopping fine 1 of simulation time 0.1 seconds per a clock and assumed real speed 5km/h distance. In this way it is necessary to assume length of one cell 0.14m to make it high simulation of precision. One vehicle is to sit astride plural cells when we compare size of a vehicle with this size. In addition, it gets possible to support model of a vehicle whether you occupy several cells.

We changed it with a rule with (1) (2) in the NS model that we described in a foregoing chapter as follows to realize these new methods.

(1) $(v+1)*a \leq g$ and $v < v_{\max} \rightarrow v = v+1$ (acceleration)

(2) $v*a < g \rightarrow v = g/a$ (slow down)

In addition, a assumes distance between the vehicles (the number of the cells) that was suitable for speed with a value to decide distance between the vehicles at the minimum v*a. In other words we are to decide speed from distance between the vehicles (the number of the cells) that was suitable for distance between the vehicles (the number of the cells) with the former in a vehicle with a certain time and speed of a vehicle at that time. By this study, we assumed a value of this a 20.

6. AN EXPERIMENT AND VERIFICATION OF A MODEL

We experimented on a vehicle run, and we verified a model. With these theories, we inspected it with a program experiment. Inspection of an experiment displayed simulation result 3 dimensions that we did with a cartoon film, and each vehicle confirmed that we did a lane change smoothly. In addition, the inspection did the evaluation from the traffic volume that was a macroscopic traffic index, traffic density, a correlation of space average speed in the same way as the simulation that the model that we built was usual effectively.

In statistics value used as a traffic style characteristic, there is usually a Q-V characteristic to characterize K-V characteristic to characterize space average speed V(km/h) corresponding to traffic density K(vehicles/km), K-Q characteristic to characterize traffic volume Q corresponding to traffic density K, space average speed V corresponding to traffic volume Q. And K, V, Q, is

$$Q = KV_s$$

It has these relation. In addition, as a mathematics model expressing relation of speed V and density K, the following under Wood models are well known.

$$V_s = V_f e^{-K/Kc} (V_f, K_C : parameter)$$

In addition, free speed, K are critical speed V.

By our experiment, we did simulation for a road in a certain specific place. And, in search of K, V, Q, we tried inspection by comparison with under Wood model. But going straight at a crossing, a right turn, the ratio of a left turn generated 80%, 10%, the traffic that became 10% by simulation. At first we made expression 3 linear shape and we recurred from K - V data of a simulation result and analyzed it, and parameter V and K were provided, and it seems to have become figure 3.

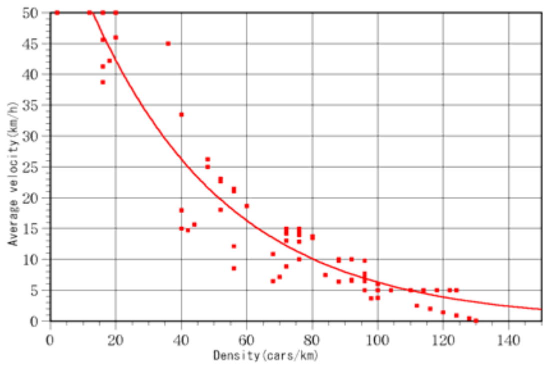


Figure 8. K-V Graph

In addition, about K-Q, a Q-V characteristic, the following relation is concluded than the above-mentioned expression.

$$Q = KV_f e^{-K/K_c}$$

$$Q = K_c \ln(V_f / V)V$$

And we used a recurrence analysis result and was able to get figure 4 and figure 5.

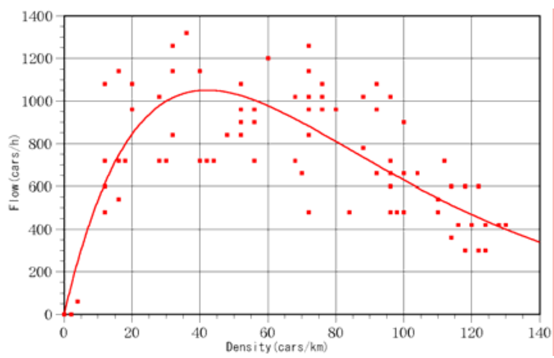


Figure 9. K-Q Graph

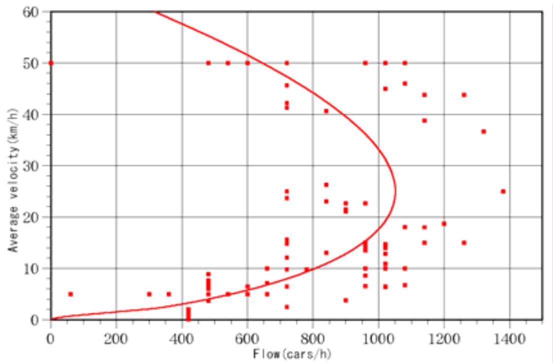


Figure 10. Q-V Graph

With a K-V characteristic, a general tendency of the traffic style characteristic that was expressed by under Wood model so that it was shown by figure 3 was seen. It was similar about a K-Q characteristic of figure 4, a Q-V characteristic of figure 5.

7. CONCLUSIONS

By this thesis, we used a model of a cell automaton as one technique to realize microscopic model road traffic simulation in a city. By this, we were able to work as a model simply. In addition, about a divergence junction model, we get possible to do modeling to be smooth about shoulder parking of a vehicle, a traffic lane change, parking vehicle evasion in what we introduced an associate run line into. In addition, about the model that we introduced a virtual vehicle in junction divergence into, we understood that I could run from three-dimensional cartoon film indication smoothly.

And, about mutual relations of traffic volume and density the speed that was a macroscopic traffic index, it was similar to a graph from general actual survey value and finally understood that appropriate road traffic simulation was done by these results.

However, because we were simple about movement of an individual vehicle, an awkward point was seen, and it seemed that acceleration, modeling at the time of slowdown was particularly insufficient. About these, we sentence you to a problem of a future study and want to build a better model.

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