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City Traffic Simulation Using Cellular Automata with Stochastic Velocity Model

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This paper describes the cellular automata simulation based on the stochastic velocity model for the city traffic flow. The cellular model of the city road network, the local rules to control the vehicle velocity and behavior are defined. The simulation results are compared with the real data of the traffic flow in Nagoya city in order to discuss the validity of the present model.

1. Introduction

The simulation model for the traffic flow can be classified into the macro- and the micro-models. Since the computational cost for the macro-model simulation is much cheaper than the micro-model simulation, the macro-model simulation has been employed for the traffic flow simulation in the wide areas. However, Tanahashi *et. al.*[1] pointed out from the comparison of the macro-model simulation results with the real traffic data that the traffic flow strongly depends on the individual characteristics of individual vehicles. The individual characteristics of the vehicles can be represented easily in the cellular automata simulation[2)~4)] and therefore, some researchers have been studying the traffic flow simulation based on the cellular automata. In the other studies, the vehicle velocity is represented with the number of cells which the vehicle moves at each time step. When a vehicle moves over many cells at one time step, the movement rules of the vehicle often become very complicated. For overcoming this difficulty, the authors have presented the simulation model named as "stochastic velocity model (SV model)"[5]. In the SV model, the movement of the vehicle is controlled with the random variable. Since the moving range of each vehicle is restricted up to one cell, the local rule for the vehicle movement can be simplified. In the previous study[5], the SV model has been successively applied to the simulation of the traffic flow on the highway. In this paper, the present model is applied to the traffic flow simulation in the Nagoya city of Japan and the results are compared with the real data.

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2. Back Ground

We shall introduce here the simulation models for the traffic flow and show the feature of the present model.

2.1 Rule-184 CA Model

The first traffic simulation model, which was based on the rule-184 named by Wolfram[2], simulated vehicles moving on one-lane freeway. The vehicles move at constant velocity and do not accelerate even when the distance between vehicles is very large. Therefore, the rule-184 CA model cannot simulate the actual traffic flow well.

2.2 Nagel–Schreckenberg Model

The Nagel–Schreckenberg (NaSch) model is composed of the rule-184 CA model and the rules for acceleration and deceleration of vehicles[3]. The vehicle velocity in the NaSch model is represented with the number of cells v that the vehicle moves over at a time step. When the model is applied to the freeway traffic flow simulations, the fact that vehicles move over multi-cells at a time step results in the reduction of computational cost. When, however, it is applied to urban city traffic flow, the behavior rules of the vehicles become very complicated due to the existence of the traffic signals, the intersections and the branch lines.

2.3 Vehicle (Car) Following Model

In the vehicle (car) following model, the vehicle velocity v or the acceleration a is determined from the distance or the velocity difference between a vehicle and the forehand one[6),7)].

In the vehicle following models, the velocity or the acceleration is represented as a continuous functions. Therefore, the velocity can be represented much smoothly than the NaSch model. Note that, however, there exits the same difficulty as the NaSch model in the case of the traffic flow simulations in urban cities.

2.4 Biham-Middleton-Levine Model

Biham *et. al.* have presented the cellular automata model for simulating the traffic flow in urban cities[4]. The roads in an urban city are expressed as a tetragonal lattice and vehicles can move only in upward or rightward directions. Three different traffic control models are presented in the BML model.

The BML model is the first idea for the traffic flow simulations in urban cities. Note that, however, it is too simple for actual traffic flow simulations in urban cities.

2.5 Stochastic Velocity (SV) Model

The vehicles driving at velocity of $v_{\max}$ move by one cell at each time step. The movement of the vehicles at velocity of $v(< v_{\max})$ is determined according to the stochastic variable. Since the maximum movable distance of vehicles is restricted up to one cell, the behavior rules of the vehicles are defined as only the relationship between a vehicle and its neighbor vehicles. Therefore, the behavior rules of the SV model are much simpler than them of the other models, which is very attractive in the case of the traffic flow simulation in the urban cities.

3. Simulation Model

3.1 City Road Network

A city road network is constructed with several road parts such as one-lane, two-lane and three-lane roads and the intersections and so on. The road parts are defined with the cells of length $3m$ and width $3m$ and each vehicle is expressed with two cells. One time-step is equivalent to $0.1s$ in the real traffic.

3.2 Stochastic Velocity Model

Referring the feasible maximum velocity of a vehicle in the object domain as v_{def}, the vehicle driving at the velocity $v(< v_{def})$ move as follows.

(1) Estimate the parameter P_0 as

$$P_0 = v/v_{def}. \quad (1)$$

(2) Generate uniform random number $P(x)$ within the bounds of 0 to 1.

(3) Move the vehicle by one cell when $P(x) < P_0$.

3.3 Local Rules

Local rules are composed of the behavior and the velocity local rules. We shall assume that vehicles always keep the safety distance from the forehand vehicle in order to avoid traffic accidents.

3.3.1 Vehicle Movement and Local Rules

The distance between a vehicle and its forehand vehicle is referred as "the following distance" G and the safety following distance for the vehicle is as G_s. The behavior of vehicle driving on the three-lane road is determined as follows.

(1) Calculate the safety vehicle distance G_s from the velocity v.

(2) Estimate the following distance on the current lane G_0, the following distance on its left-hand lane G_l and the following distance on its right-hand lane G_r.

(3) Apply behavior local rule.

(4) Apply velocity local rule.

(5) Move ahead according to the stochastic velocity model.

3.3.2 Behaivour Local Rule

Through-driving Vehicle

In the following, the safety following distance for the vehicles driving at the maximum velocity is expressed as G_{max} and the function $\max(val_0, val_1, val_2)$ gives the maximum value among val_0, val_1 and val_2.

(1) If $G_{\max} < G_0$, the vehicle keeps the current lane.

(2) If $G_0 < G_{\max}$ then:
 - (a) If $\max(G_r, G_l) < G_0$, the vehicle keeps the current lane.
 - (b) If $\max(G_r, G_l) > G_0$ and $G_l < G_r$, the vehicle moves right-hand lane.
 - (c) If $\max(G_r, G_l) > G_0$ and $G_r < G_l$, the vehicle moves left-hand lane.

(3) $G \leftarrow G_0$

Left-turning Vehicle

(1) If a vehicle is on the cell adjacent to the intersection cell:
 - (a) The vehicle turns to the left.
 - (b) $G \leftarrow \max(G_0, G_l, G_r)$

(2) If the vehicle is on the other cell:
 - (a) If there exists the left-hand lane, the vehicle moves to the left-hand lane.
 - (b) Otherwise, the vehicle moves ahead.
 - (c) $G \leftarrow G_l$

Right-turning Vehicle

(1) If a vehicle is on the cell adjacent to the intersection cell:
 - (a) The vehicle turns to the right.
 - (b) $G \leftarrow \max(G_0, G_l, G_r)$

(2) If the vehicle is on the other cell:
 - (a) If there exists the right-hand lane,

the vehicle moves to the right-hand lane.

(b) Otherwise, the vehicle moves ahead.

(c) $G \leftarrow G_r$

3.3.3 Velocity Local Rule

Velocity local rules are composed of the relative and the absolute velocity local rules.

Relative Velocity Local Rule

(1) If $G_s > G$, $v \leftarrow v + \alpha$. (Acceleration)

(2) If $G_s < G$, $v \leftarrow v + \beta$. (Deceleration)

(3) If $G_s = G$, the current velocity v is unchanged.

(4) If $v > v_{max}$, $v \leftarrow v_{max}$.

(5) If $v < 0$, $v \leftarrow 0$.

where v_{max} means the maximum velocity and α and β denote the acceleration and the deceleration rates, respectively.

Absolute Velocity Local Rule

(1) If $G_i < G_s$, $v \leftarrow v - (v - v')/G_i$.

where G_i denotes the distance from the vehicle to the object such as the traffic signal, the stopped vehicle, obstruction and so on and v' is the velocity when the vehicle reaches to the object (usually, zero).

3.4 Safety Following Distance and Acceleration Rate

The estimation of the real traffic data gives the safety following distance G_s and the acceleration/deceleration rate $\alpha(m/s^2)$ and $\beta(m/s^2)$ as follows.

$$G_s = 0.0029 \times v^2 + 0.3049 \times v$$
$$0 < \alpha < 3$$
$$-3 < \beta < 0$$

4. Evaluation

4.1 City Road Network

The present model is compared with the real traffic data along Nagakute-Hongo way in east Nagoya city[8]. The simplified road network is shown in Fig.1. The point 0 to 13 denote the measurement points of the traffic amount and the lines connecting between the points mean the roads. The points (a), (b), ..., (h) denote the intersections, which are controlled with the traffic signals. The road between point 8 to point 12 (the road 8-12) and the road between point 0 to point 1 (the road 0-1) respectively denote the Nagoya-Nagakute way and the Higashiyama avenue. The road 0-1 is three-lane two-way road and the other ones are one-lane two-way roads. The traffic amount running out from the intersections is estimated at the measurement points. Short lanes for right- and left-turning vehicles are attached at the intersections depending on the traffic amount. Since the Higshiyama avenue is one of main streets in this area, the short lanes for right- and left-turning vehicles are attached at the intersection (e) in both east- and west-directions. There are the short lanes for right-turning vehicles at all intersections in both north- and south-directions along the road 8-12. The short lanes for right-turning vehicles are attached in the east- and west-directions at the intersections (a), (e), (f) and (g). The traffic amount has been estimated from 6:30 AM to 9:30 PM on November 19, 2001.

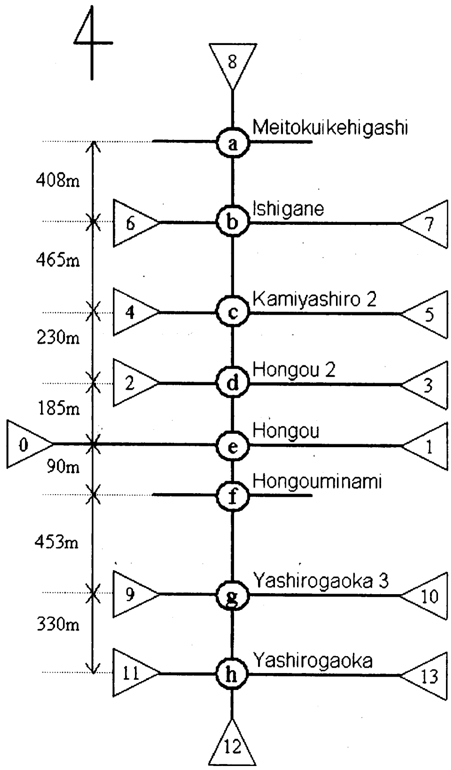

Fig. 1 City Road Network

Table 1 Simulation parameters

Cell size	$3m \times 3m$
1 time step	0.1s
Max. velocity	$60km/h \sim 80km/h$
G_s	$0.0029v^2 + 0.3049v$
Acceleration	$0.6 < \alpha < 2.4(m/s^2)$
Deceleration	$-3.0 < \beta < -1.2(m/s^2)$

4.2 Simulation Parameters

Simulation parameters are shown in Table 1. The maximum velocity for the vehicles driv-

Table 2 Traffic signal schedule

Int.	North-South (Blue:RT:Red)	East-West (Blue:RT:Red)
(a)	101s:Non:3s	33s:Non:3s
(b)	62s: 9s:3s	35s: 8s:3s
(c)	71s:10s:3s	33s:Non:3s
(d)	71s:10s:3s	33s:Non:3s
(e)	61s: 9s:5s	66s:16s:3s
(f)	124s:Non:3s	28s:Non:3s
(g)	49s: 7s:3s	28s:Non:3s
(h)	57s:Non:5s	25s:Non:3s

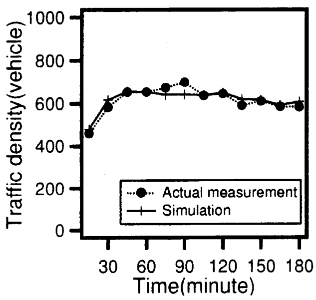

Fig. 2 Traffic density at point 0

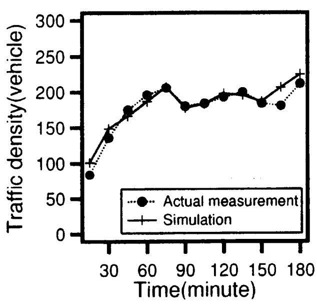

Fig. 3 Traffic density at point 12

ing on the Higashiyama avenue is specified as $80km/h$ and that for the other vehicles is as $60km/h$.

Table 2 shows the schedule of the traffic signal at each intersection. The columns labeled with "North-South" and "East-West" means the schedules of the traffic signals for the traffic flows in the North-South and East-West directions, respectively. Besides, the items "Blue", "RT" and "Red" denote the blinking-intervals for blue signal, the signal for right-turning vehicles and red signal, respectively.

The traffic amount of the vehicles running into the domain and the rate of the through and right- and left-turning vehicles are determined according to the real data.

4.3 Results

The comparison of the real data and the simulation results are compared in Figs.2 and 3. The abscissa and the ordinates denote the time (minute) and the traffic density (number of vehicles), respectively. The solid and the broken lines denote the real data and the simulation results, respectively. We can say that the simulation results well agree with the real data.

5. Conclusions

This paper described the traffic flow simulation in the urban city by using the cellular automata with stochastic velocity model. The area along Nagakute-Hongo way in east Nagoya city Japan is considered as the object domain and the simulation results has been compared with the real traffic data. The simulation results well agree with the real data. In the future plan, we are going to apply the present model to evaluation of effectiveness of Intelligent Transportation System (ITS) in the urban city.

References

1) I. Tanahashi, H. Kitaoka, M. Baba, H. Mori, S. Terada, and E. Teramoto. Wide area traffic flow simulator NETSTREAM. In *IPSJ, ITS*, Vol. 9-2, pp. 9–14, 2002. (in Japanese).
2) S. Wolfram. *Cellular Automata and Complexity*. Adison-Wesley Publishing Company, 1 edition, 1994.
3) K. Nagel and M. Schreckenberg. Cellular automaton model for freeway traffic. *Journal of Physics I france*, Vol. 2, pp. 2221–2229, 1992.
4) O. Biham, A. A. Middelton, and D. Levine. Self-organization and a dymnamical transition in traffic-flow models. *Physical Review A*, Vol. 46, No. 10, pp. R6124–R6127, 1992.
5) T. Tamaki, S. Yasue, and E. Kita. Traffic flow simulation using cellular automata. In *Proceedings of Civi and Structural Engineering Computing*, 2003.
6) S.Yukawa and M.Kikuchi. Coupled-map modeling of one-dimensional traffic flow. *Journal of the Physical Society of Japan*, Vol.64, No.1, pp. 35–38, 1995.
7) Y. Sugiyama. Optimal velocity model for traffic flow. *Computer Physics Communications*, Vol. 121-122, pp. 399–401, 1999.
8) Transport Lab. Hongo area benchmark dataset. *http://www.i-transportlab.jp/ bmdata/HongoBM/*, 2001.