An Analysis on Mixed Traffic Flow of Conventional Passenger Cars and Micro-Cars Using a Cellular Automata Model

Rui MU[1] and Toshiyuki YAMAMOTO[2]

[1]Doctor candidate, Dept. of Civil Eng., Nagoya University
(Furo-cho, Chikusa-ku, Nagoya, Japan 464-8603, Japan)
E-mail:muruimarie@hotmail.com
[2]Member of JSCE, Professor, EcoTopia Science Institute, Nagoya University
(Furo-cho, Chikusa-ku, Nagoya, Japan 464-8603, Japan)
E-mail: yamamoto@civil.nagoya-u.ac.jp

In this study, characteristics of traffic with micro-cars in traffic flow are analyzed by using a cellular automata simulation model. 400m of arterial road with two lanes are supposed. The cellar automata model assumes that the vehicles running with cycling boundary on the road, and there is an intersection delay with a signal cycle in the middle of the road. Two kinds of vehicles which are conventional car and micro-car are defined in the traffic stream, they have different maximum speed and occupy different amount of cells in the simulation. It is also assumed that vehicles can accelerate, decelerate and change lane every time unit under certain rules. The changing lane behavior is considered which can make vehicles have more opportunity to higher their speed. The rules are all based on actual driving behaviors. Traffic flow with different rates (from 0.0 to 1.0) of micro-cars is investigated in the simulation. The traffic flows counted by the number of vehicles per hour and PCE (Passenger Car Equivalent) as well as average speed are put out as results of the simulation. Density-Flow graphs are drawn to analyze and compare the characteristics of traffic flow without micro-cars and that with different rates of micro-cars. Appropriate micro-cars rates which can relieve congestion and make trip more convenient is found. The results demonstrate that using micro-car instead of traditional car will relieve traffic congestion somewhat, and vehicles passing through per hour in the have-micro-cars traffic flows are more than that in have-not-micro-cars ones.

Key Words : *micro-car, traffic flow, cellular automata model, simulation*

1. INTRODUCTION

As we know, traffic congestion has a number of negative effects. It waste time of motorists and passengers ("opportunity cost"). And as travel is kind of non-productive activity for most people, congestion reduces regional economic health. Delays, which cause in late arrival for employment, meetings, and education, may result in lost business, disciplinary action or other personal losses. The inability to forecast travel time accurately leads drivers to allocate more time to travel "just in case", and then less time on productive activities. Waste of fuel, increased air pollution and carbon dioxide emissions owing to increased idling, acceleration and braking are only a part of negative effects caused by traffic jam, which cause many losses to human.Nowadays, traffic congestion is a widespread problem. Traffic during peak hours in major Australian cities, such as Melbourne, Sydney, Brisbane and Perth, is usually very congested and can cause considerable delay for motorists. The Texas Transportation Institute estimated that, in 2000, the United States' 75 largest metropolitan areas experienced 3.6 billion vehicle-hours of delay, resulting in 5.7 billion U.S. gallons (21.6 billion liters) in wasted fuel and $67.5 billion in lost productivity, or about 0.7% of the nation's GDP. It is also estimated that the annual cost of congestion for each driver was approximately $1,000 in very large cities and $200 in small cities. Traffic congestion is increasing in major cities and delays are becoming more frequent in smaller cities and rural areas. It is concluded that problems of traffic jam can be solved in several aspects: road infrastructure, urban planning and design, travel demand management, traffic management.

Micro-car is the smallest automobile classification usually applied to standard small car (smaller than city cars). As micro-car has some similar characters with conventional car, also has some ones with motorcycle, we can say it is a kind of vehicle between the compared two, whatever the compared aspects are size, or speed, or some other characters. As micro-car has lower maximum speed and smaller size than conventional car, it will be more convenient to use micro-car for short distance trip. For short distance trip, individuals do not need high speed. If there is not micro-car, they mostly choose motorcycle, which have lower speed but more mobility, but the latter one cannot protect people from rain, as the micro-car can meet all three requirements mentioned for short distance trip, it is the most appropriate vehicle for such kind of trip.

Until now, no effects about which will be brought to traffic flow or aspects derived from traffic are analyzed. As micro-cars have different characters with traditional cars, such as maximum speed, acceleration, and bulk, there are many differences between the have-micro-cars traffic flow and the have-not-micro-cars one. So series of simulation with both conventional cars and micro-cars running on road are done to analysis characteristics of traffic with micro-cars in traffic flow.

The rest of this paper is organized as follows. Section 2 gives a brief introduction of micro-car. Section 3 describes the celluar automata model designed in this study. The results of the simulation was listed and analysed in section 4. Finally, conclusions are summarized along with a discussion about future research issues in the last section.

2. MICRO-CAR CHARACRISTIC

Micro-cars which were produced in Europe immediately after World War I were often motorcycle-based and were referred to as cycle-cars. Many micro-car designs flourished in post-World War II Europe, particularly in Germany, where prominent micro-car makers were former military aircraft manufacturers, so some micro-cars even had aircraft-style bubble canopies, giving rise to the term bubble car to refer to all these post-war micro-cars. France also produced large numbers of similar tiny vehicles called voiturettes, but unlike the German makes, these were rarely sold abroad. Very small cars have also been popular in Japan, where again they attract various tax and insurance benefits when compared to other vehicles. These are known as light cars(The current regulations in

Fig.1 Electric M.GO produced by microcar UK

Fig.2 Series 11 M.GO produced by microcar UK

Japan state that a light car is a vehicle less than 3.4 m long, 1.48 m wide, 2 m high and with an engine under 660 cc. Extra small micro-cars are available with an engine size no larger than 49 cc, identified with a light blue license plate and blue text) and differ from most of the European micro-cars in that they are typically designed and built as scaled-down versions of very traditional car configurations, while European micro-car designs tend to be unorthodox and sometimes bizarre.

Most micro-cars have a 60km/h top speed. Typical micro-cars usually have some of the following features:

(1)Two seats only for the driver and a single passenger

(2)A 1 cylinder 49cc - 500cc engine

(3)1 wheel drive

(4)Cable operated brakes on 2 or 4 wheels (no longer permissible in countries such as the UK)

(5)Simple suspensions

(6)Three wheeled

(7)Less than 3m in length (sometimes less than 8', 2.440m)

There are many advantages using micro-car. Firstly, in some countries, micro-cars with a certain maximum weight are considered motorcycles and therefore car driving license is not needed (Austria, France, Germany, Spain, Italy). This assures a certain market for elder people who do not want to or who cannot pass a car driving license. Another advantage is the ease of parking. Some micro-cars can be parked perpendicular, where other cars park parallel, or be lifted by hand, like a motor scooter, to get into a tight spot. Thirdly, the small size improves handling by reducing the angular inertia. The Messerschmitt and Spatz have been described as much better than ordinary cars on snow and ice. Spare room on the road and ease of missing obstacles are also improved.

3. SIMULATION MODEL

A cellular automata model is founded here for the simulation. An arterial road which have the length of 400 meters with two lanes are supposed. Vehicles running with cycling boundary on the road. And the original positions of vehicles are distributed on the road probabilistically.

(1) Parameters set in simulation

As mocro-cars mostly have the length of 2 to 3 meters, which is commonly half of that of conventional cars, one micro-car is defined to occupy one length unit(4 meters) in the simulation, and one conventional car is set to occupy two cells. The maximum speed of conventional cars and micro-cars are set as 6 and 4 unit length/s with the actual speed of 86.4 and 57.6km/h. Table 1 and table 2 list the attributes of vehicles both in reality and simulation.

(2) Variables set in simulation

Variables set in the simulation are showed in table 3. The speed and location of vehicles was update second by second, so the unit time is one second. The total steps of time is 10000, while results calculated from the last 600 seconds are print out as output. A signal cycle which result in intersection delay with an 60 seconds cycle and 30 senconds green time is designed in the middle of simulating path.

(3) Rules for driving

The acceleration rules are the same with the NaSch model (Nagel and Schreckenberg, 1992), and the vehicles will decelerate probabilistically.

a) Rule of speed changing

There are three steps to change speed, the details are shown as follows.

Step 1. Acceleration

$$v_n \rightarrow \min(v_n + 1, v_{\max}) \quad (3a)$$

Step 2. Limited speed

$$v_n \rightarrow \min(v_n, d_n) \quad (3b)$$

Step 3. Lower speed(with a probability of 0.3)

$$v_n \rightarrow \max(v_n - 1, 0) \quad (3c)$$

Where,

v_n : speed of vehicle n

$v_{\max}$: maximum speed of vehicle n

d_n : space headway of vehicle n and its front vehicle

b) Rule of lane changing

If vehicle n meets the following three conditions, it can change lane

Table 1 Attributes of vehicles in reality

Attribute	Conventional car	Micro-car
Length(m)	4.0~5	2~3
Maximum speed(km/h)	200~260	60
Maximum speed on road(km/h)	80	60

Table 2 Set attributes in simulation

Attribute	Conventional car	Micro-car
Length(unit length, one unit length=4m)	2	1
Maximum speed on road(unit length/s)	6	4
Maximum speed on road(km/h)	86.4	57.6
Acceleration and deceleration(unit length/s^2)	1	1

Table 3 Set variables in simulation

Variable	Value
Unit time	1s
Time steps(s)	10000
Count time(s)	600
Total length(unit length)	100
Total length(m)	400
Signal cycle(s)	60
Green time(s)	30

A. $d_n < l$, $l = \min(v_n + 1, v_{\max})$ (3d)

B. $d_{n,other} > l_o$, $l_o = \min(v_n + 1, v_{\max})$ (3e)

C. $d_{n,back} > l_{o,back}$, $l_{o,back} = \min(v_{back} + 1, v_{\max,back})$ (3f)

Where,

d_n : space headway of vehicle n and its front vehicle

$d_{n,other}$: space headway of vehicle n and its front vehicle of the other lane

$d_{n,back}$: space headway of vehicle n and its back vehicle of the other lane

v_{back} : speed of the back vehicle in the other lane of vehicle n

$v_{\max,back}$: maximum speed of the back vehicle in the other lane of vehicle n

Condition A is a motivation standard, if the space headway between vehicle n and its front vehicle is not long enough for vehicle n to accelerate or keep its maximum speed, vehicle n have the willing to change lane. Condition B is used to check whether the driving condition in the other lane is better. Condition C is used to check if the condition of the other lane permits vehicle n to change lane.

4. SIMULATION AND RESULTS

The input data are occupancy rates of the road by vehicles with different rates of micro-car whose range is 0 to 1 with step 0.1, from 0 to 1, and the step is 0.01. The output results are average traffic flow(vehicle/h) of the two lanes by both vehicle and PCE(Passenger Car Equivalent), average speed of vehicles on the road, as well as average vehicle density (vehicle/unit length) of the two lanes. As there are probability elements, each simulation was ran ten times to calculate the average values of the results to avoid randomness somewhat.

(1) Accuracy of model

The accuracy of the model is tested first. The rules designed in the model are all based on actual driving behaviors. Fig. 3 is a carve speed and flow when micro-car rate equals 0.5, compared to fig.4, the main trends of two curves are similar. It is proof that the model is mostly identical with the traffic flow in reality.

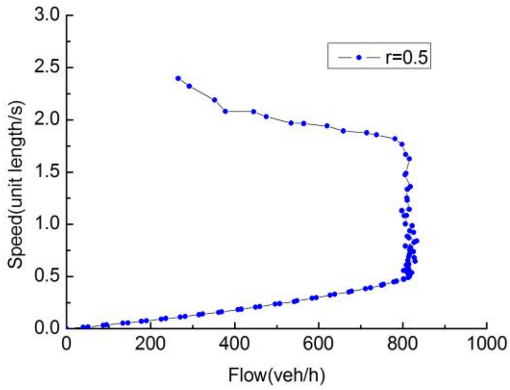

Fig.3 Curve of speed and flow when micro-car rate equals 0.5

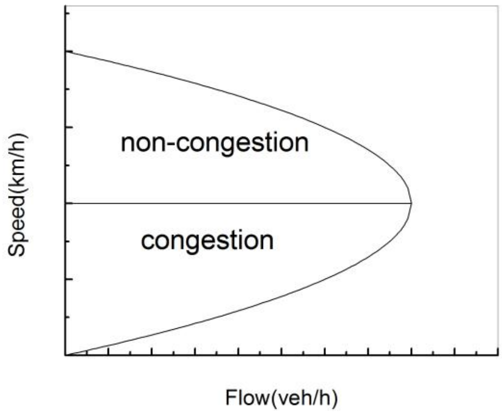

Fig.4 Greenshields speed-flow parabola

(2) Simulation results

Rates of micro-car are calculated by PCE, if calculated by vehicle, the rates will be different. In this paper, the ones counted by PCE are used.

Fig.5 is flow-density curves under different micro-car rates, where the flows are counted by vehicle, From the figure, we can see that the flow is the highest when micro-car rate is 1.0, the flow comes up as r comes up especially when density is from 0.21 to 0.60, but not so consonant for some points. Also because of the figure's ambiguous definition, fig. 6 and 7 show more clear curves where density is from 0.00 to 0.20 and from 0.61 to 1.00. In these two ranges, the order of flow is not the same as the range from 0.21 to 0.60. From 0.00 to 0.20, curves can be sorted into three groups, see table 4. From 0.61 to 1.00, curves are also sorted into three groups, see table 5.

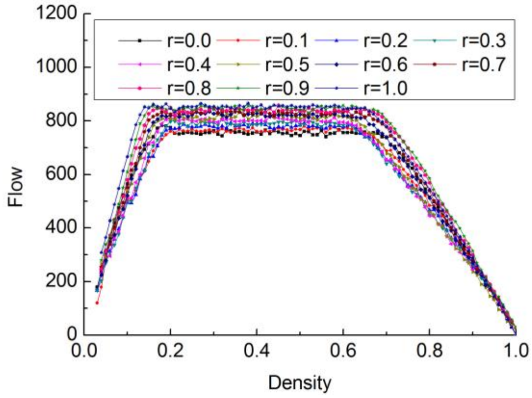

Fig.8 Flow-density curves by vehicle under different micro-car rates

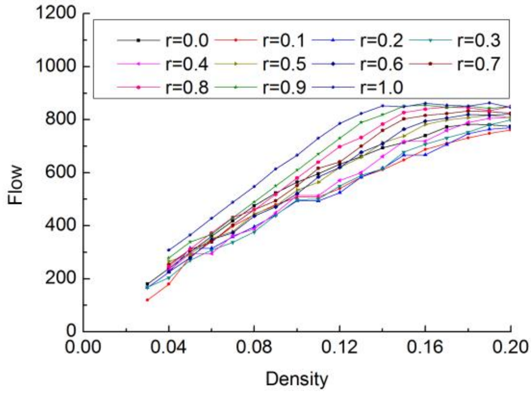

Fig.9 Flow-density(from 0.00 to 0.20) curves by vehicle under different micro-car rates

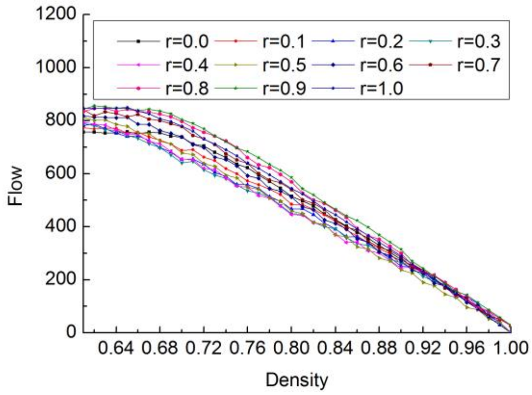

Fig.10 Flow-density(from 0.61 to 1.00) curves by vehicle under different micro-car rates

Table 4 Grouping situation of flow-density curves by vehicle with density from 0.00 to 0.20

Group	Micro-car rate	Flow
1	0.1~0.4	lowest
2	0.0,0.5~0.9	medium
3	1.0	highest

Table 5 Grouping situation of flow-density curves by vehicle with density from 0.61 to 1.00

Group	Micro-car rate	Flow
1	0.2~0.5	lowest
2	0.0,0.1,0.6,0.7,1.0	medium
3	0.8,0.9	highest

5. CONCLUSION

Micro-car is more and more popular for its small size and good mobility especially in high population density areas. Research on characristic of traffic flows with micro-cars is necessary nowadays.

By using a celluar automata model, several simulations which are aimed to see characristics of traffic flow with different rates of micro-car are excuted. Three kind of parameters which is the basic parameters of traffic flow are got as output of the simulation. The simulation results manifest that the arterial road can pass through more vehicles if there are more rate of micro-cars when the density is from 0.21 to 0.60. When the density is from 0.00 to 0.20, roads with only micro-car are the best, and roads without micro-cars or with 50% to 90% micro-cars are also good choice. When the density is from 0.61 to 1.00, roads with 80% and 90% micro-cars are the best, and roads without micro-cars as well as with 10%, 60%, 70%, 100% micro-cars can also pass through more vehicles than ones with 20% to 50% micro-cars. In conclusion, it is better to drive micro-cars to avoid and relieve traffic congestion, the more micro-cars in traffic flow, the better.

This paper is a try to analysis the effects which the micro-cars bring to traffic flow. Furthermore, the model can be improved by setting more detailed rules to simulate the reality traffic flow as possible as it can. For example, in the applied model, the furthest cell vehicle n in time step i+1 can drive to is the one behind vehicle n+1, which in reality can be further.

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