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

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Abstract

Characteristics of traffic with microcars in traffic flow are analysed by using a cellular automata simulation model. 400m of urban highway and arterial road segment both with two lanes are supposed respectively, including an intersection delay with a signal cycle in the middle of the latter. Two kinds of vehicles, conventional car and microcar are defined in the traffic stream. The changing lane behaviour which can make vehicles have more opportunity to higher their speed is considered. Traffic flow with different rates of microcars is investigated in the simulation. Traffic flow and average speed are computed for congestion point of view. The results demonstrate that introduction of microcar will relieve traffic congestion to some extent, and vehicles passing through per hour become more than those without microcars.

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Key Words: microcar, traffic flow, cellular automata model, simulation

1. Introduction

It is clear that we are entering into a new era when the ability of the automobile cannot sustainably fulfill its function as a primary provider of personal powered mobility, given that many issues threatening

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the car's autonomy, such as peak oil concerns and rising fuel prices, legislation to reduce carbon emissions and other factors concerning climate change, increasing congestion and parking limitations. Alternative vehicles have been developed and produced by niche manufacturers for decades, and will enjoy the mainstream popularity in years to come. For a culture accustomed to the conveniences of mobility, it will be difficult to find a direct replacement that provides the speed, carrying capacity, comfort, weather protection and personal safety of a car (Richardson and Rose 2010). Although one conventional car can carry at most 5 people while one microcar carrying 2, however, the average occupancy is usually less than 2. In the US, car occupancy has fallen from 1.95 in 1960 to 1.38 p-km/v-km in 2009. In Japan, it is even lower than in the US, having fallen from 1.45 in 1990 to 1.39 p-km/v-km in 2009. Thus the carrying capacity can be ignored, especially in high motorised countries.

Microcar is the smallest automobile classification usually applied to standard small car (smaller than city cars). As microcar has some similar characteristics with conventional car, and also has some with motorcycle, we can say it is a kind of vehicle between the compared two, where the compared aspects are size, speed, and some other characteristics. Until now, no effects about which will be brought to traffic flow or aspects derived from traffic if microcars are driven on road are analyzed. As microcars have different characteristics from traditional cars, such as maximum speed, acceleration, and dimension, there are many differences between the traffic flows with and without microcars. Introduction might cause traffic congestion. Thus, a series of simulation with both conventional cars and microcars running on urban highway and arterial road is carried out to analyze characteristics of traffic flow with microcars.

Among the approaches for investigating the traffic flows, cellular automata (CA) has become an excellent tool for simulating real traffic flow, because of its efficient and fast performance when used in computer simulations (Maerivoet and De Moor 2005). It can simulate large traffic systems many times faster than real time which makes predictions feasible, so CA model is computationally extremely efficient. Traffic phenomena such as the transition from free to congestion flow, lane inversion and platoon formation can be accurately reproduced using CA model. CA is a discrete model both in time and space. We can define unit time and unit length of cell depending on different requirement. According to these advantages, CA is chosen for the simulation in this study.

2. Literature review

Richardson and Rose (2010) gathered the information of alternative personal mobility, concluded that an increasingly diverse range of alternatives are becoming available, promising to provide more diverse transport opportunities, given the climatic, social and financial issues facing society. Recent international motor shows have demonstrated a marginal increase in OEM alternative vehicle concepts that have trend towards two vehicle types: microcars and PMDs (Personal Mobility Devices). As PMDs have many limits, microcars, however, provide a small spatial footprint to ease congestion and parking concerns, greater fuel efficiency, weather protection and some luggage capacity. So microcars are the most likely alternative vehicle of cars.

In 1992, Nagel and Schreckenberg proposed the well-known Nagel-Schreckenberg (NaSch) model (Nagel and Schreckenberg 1992). The NaSch model is a minimal model in sense that any further simplification of the model leads to unrealistic behaviour. Following NaSch, several extensions of the model are put forward, such as Fukui-Ishibashi (FI) model, TT model, VDR model, VE model, etc. The previous are single-lane models. In order to simulate real-traffic, two-lane models have been proposed. Rickert et al. (1996) examined a simple two-lane cellular automata model based on the single-lane CA proposed by Nagel and Schreckenberg. Wagner et al. (1997) proposed a set of lane changing rules for CA simulating multi-lane traffic, and asymmetric lane changing rules were introduced. Chowdhury et al. (1997) developed particle-hopping of two-lane traffic models with two different types of vehicles, and

investigate effects of lane changing rules. Nagel et al. (1998) summarized different approaches to lane changing and their results. Knospe et al. (1999) discussed the effect of slow cars in two-lane systems. Li et al. (2006) proposed a realistic two-lane CA model considering aggressive lane changing behaviour of fast vehicles. Gao et al. (2007) proposed a CA model for traffic flow in the framework of Kerner's three-phase traffic theory. Chen et al. (2008) presented a new CA model, in which randomization effect is enhanced with the decrease of time headway. Tonguz et al. (2009) introduced a new CA approach to construct an urban traffic mobility model. Sukanta (2011) proposed a CA based traffic model that allows the cars to move with a small velocity during congestion.

For multi-class traffic using CA, Moussa and Daoudia (2003) presented computer simulation results of traffic flow utilizing CA model on a two-lane roadway with two different types of vehicles, cars and trucks. The importance of braking noise and the proportion of trucks on the traffic flow of a two-lane roadway were investigated. Chen et al. (2004) put different kinds of vehicles, cars and trucks, with different driving behaviour on the highway to investigate traffic flow on a 3-lane highway using a CA method. Zhang et al. (2006) attempted to solve hyperbolic conservation laws with spatially varying fluxes, applied the weighted essentially non-oscillatory method to solve a multi-class traffic flow model for a heterogeneous highway. Zhang et al. (2008) extended the d-mapping algorithm to solve a multi-class traffic flow model on a heterogeneous highway, which is characterized by spatially varying fluxes and very complex waves.

3. Model

A two-lane CA model is founded for the simulation. In CA models, space, time and velocity is discrete. Roads are divided into unit cells locating one by one, and each cell is either occupied by a vehicle or empty.

3.1. Basic parameters

In this study, there are 100 cells counting as 400-meters in length on a highway and an arterial road both with two parallel lanes, the length of a cell is 4 meters. According to the attributes of vehicles in reality as shown in Table 1, Table 2 is the assumed ones in simulation.

Table 1. Vehicle attributes in reality

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

Table 2. Vehicle attributes in simulation (unit length = 4 m)

Attributes	Conventional car	Micro-car
Length with minimum headway	2 (8 m)	1 (4 m)
Maximum speed per second	6 (86.4 km/h)	4 (57.6 km/h)
Acceleration and deceleration per second	1 (4 m/s ²)	1 (4 m/s ²)

Table 3. Simulation parameters

Variable	Situation
Boundary	Periodic
Unit time	1 s
Time steps (s)	10000
Used last time (s)	600 or 3600
Total length (unit length)	100
Total length (m)	400

Vehicles run with periodic boundary on the road, and the original positions of vehicles are distributed on the road probabilistically. A signal cycle which results in intersection delay with a 60 seconds cycle and 30 seconds green time is arranged in the middle of arterial road. The total time steps is 10000, while results calculated from the last 600 s for some outcome or 3600 s for the other outcome are print out as output as shown in Table 3.

3.2. Rules of speed updating

We have the following setting of speed updating rules, which are proposed by Nagel and Schreckenberg. The situation is updated in parallel for all vehicles:

$$v_n = \min(v_{t-1,n} + 1, d_{b,n} - 1, v_{max,n}) \tag{1}$$

$$v_{t,n} = \max(0, v_n), \text{ with probability } p_{brake} \tag{2}$$

$$v_{t,n} = v_n, \text{ with probability } 1 - p_{brake} \tag{3}$$

$$x_{t+1,n} = x_{t,n} + v_{t,n} \tag{4}$$

where

- t : current time step;
- $v_{t,n}$: velocity of vehicle n at time t ;
- $x_{t,n}$: position of vehicle n at time t ;
- $v_{max,n}$: maximum speed of vehicle n ;
- $d_{t,n}$: space headway of vehicle n and its front vehicle at time t ;
- p_{brake} : brake probability.

3.3. Rules of lane-changing

Rickert et al. (1996) have assumed a symmetric rule set where vehicles change lanes if the following criteria are fulfilled:

$$A. d_{t,n} < \min(v_{t,n} + 1, v_{max,n}) \tag{5}$$

$$B. d_{t,n,other} > \min(v_{t,n} + 1, v_{max,n}) \tag{6}$$

$$C. d_{t,n,back} > 5 \tag{7}$$

$$D. rand() < P_{n,change} \tag{8}$$

where

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

$d_{t, n, back}$: space headway of vehicle n and its back vehicle of the other lane at time t
 $rand ()$: a random number between 0 and 1

$P_{n, change}$: lane-change probability of vehicle n

Referring to a comprehensive examination of realistic lane changes by Lee et al. (2005), drivers of fast vehicles are willing to change lane even when a vehicle is approaching from behind in the adjacent lane. So in this paper, the trigger criterion that the space headway between vehicle n and its succeeding vehicle of the other lane is modified, which is aimed to be more conformed with reality. Here if vehicle n meets the following four conditions, it can change lane.

$$A. d_{t, n} < \min(v_{t, n} + 1, v_{max, n}) \tag{9}$$

$$B. d_{t, n, other} > \min(v_{t, n} + 1, v_{max, n}) \tag{10}$$

$$C. d_{t, n, back} > \min(v_{t, n, back} + 1, v_{max, n, back}) \tag{11}$$

$$D. rand () < P_{n, change} \tag{12}$$

where

$v_{t, n, back}$: speed of the back vehicle in the other lane of vehicle n at time t

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

4. Simulation results

4.1. Input and output

The input data of the simulation are the number of vehicles on the road ranging from 10 to 100 with step 10 with different rates of microcars (mentioned as r in following expression) whose range is from 0% to 100% with step 10% as shown in Table 4. Simulations in which brake probability (mentioned as p in following expression) equals 0.2 and lane changing probability equals 0.8 are done. As the simulation includes stochastic elements, each simulation was ran ten times to calculate the average values of the results to avoid randomness to some extent.

Table 4. Simulation parameters

Attributes	Range	Step
Rates of microcar	0%~100%	10%
Vehicle quantity	10~100	10
Brake probability	0.2~0.2	0
Lane changing probability	0.8~0.8	0

The output results are as follows:

average traffic flow (vehicle/h) of the two lanes by the number of vehicles crossed the segment in one hour

average speed of all vehicles in the last counted 600 time steps

4.2. Results

Figure 1 shows traffic flow by the number of vehicles and microcar rates on the highway. From the figure, we can see that the flow comes up as r increases especially when the number of vehicles is from

Fig. 2. Traffic flow by the number of vehicles and microcar rates on highway

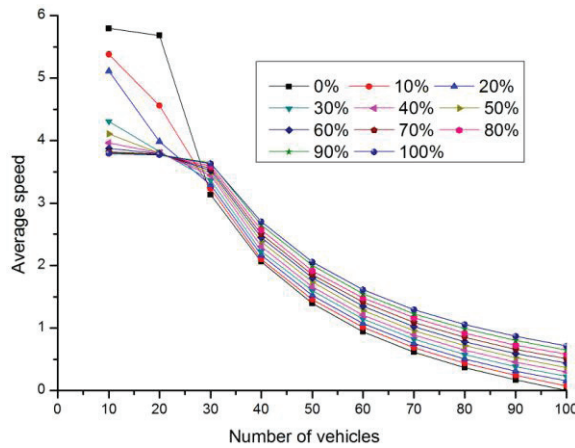


Fig. 3. Average speed by the number of vehicles and microcar rates of highway

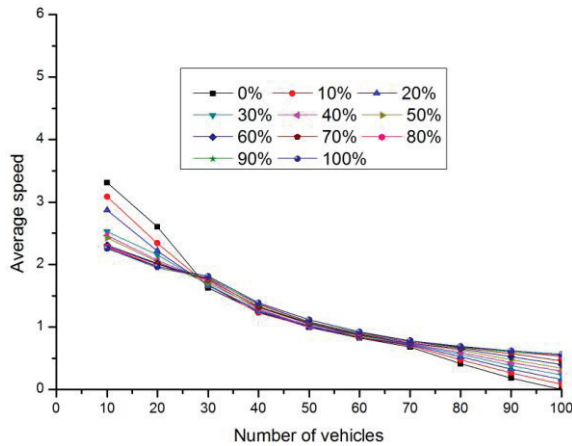


Fig. 4. Average speed by the number of vehicles and microcar rates on arterial road

From Fig. 3, we can see that, the average speed in traffic flow goes down as the number of vehicles increases. When vehicle quantity is more than 30, the more microcars ratio gives the higher speed. The speed of all-normal-car flow is highest when vehicle quantity is less, but when there are more than 30 vehicles, the situation changes, the speed of all-normal-car flow becomes the lowest one.

On the arterial road (Fig. 4), trends of curves mostly share the same characteristics with those of highway. For details, speed of all-normal-car flow becomes the lowest one when vehicle quantity is more than 30, but the characteristic that the more microcars ratio gives the higher speed is not so obviously under condition of number of vehicles being 30 to 70. The average speed of traffic flow mixed less microcars goes down faster than the ones with more microcars which causing the phenomena that higher rate of microcar gives higher speed obviously when there are more than 70 vehicles on road.

For the traffic flow analysis, the observations can be summarized as follows:

- In the relationship between traffic flow and number of vehicles, more microcars give more driving

through vehicles especially when there are more than 30 vehicles.

- In the relationship between average speed and number of vehicles, more microcars give less driving through time in the same condition of the above.

5. Conclusions

A two-lane cellular automata model on a highway segment and an arterial road with traffic signal was founded and validated in this paper, and series of simulations which are aimed to get several characteristics of traffic flow with different rates of microcar are computed. Traffic flow and average speed which are the basic parameters of traffic flow are obtained as output of the simulation, the two which are considered as very important representations of traffic flow by academics and experts were analyzed. The simulation results suggest that both the highway and arterial road can pass through more vehicles if there are more microcars when the vehicle quantity is from 30 to 100, the more, the better, roads with only microcars is the best situation. The average speed will be higher if there are more microcars when vehicle quantity is more than 30. In conclusion, it is better to drive microcars to avoid and relieve traffic congestion.

This paper is a try to analyse the effects which the microcars bring to traffic flow. Furthermore, the model can be improved by setting more detailed rules to simulate the realistic traffic flow as much as you need. For example, in the applied model, the furthest cell vehicle n in time step $i + 1$ can drive into is the one behind vehicle $n + 1$, which in reality can be further.

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