Simulation Setup and Optimization of Driverless Behaviour Based on Cellular Automata

Xiaoyi Wang¹, Danhong Chen²*, Taoliang Wang² and Guodong Zhao¹

¹College of Safety Engineering, Shenyang Aerospace University, Shenyang, China  
²College of Economics and Management, Shenyang Aerospace University, Shenyang, China  
³College of Aeronautics and Astronautics, Shenyang Aerospace University, Shenyang, China

*Corresponding author e-mail: chendanhong@stu.sau.edu.cn

Abstract. In this paper, aiming at the influence of human-machine mixed traffic flow on traffic efficiency, based on the traditional cellular automata (CA) model, several vehicle safety driving rules are established under different conditions. This paper explores the influence of the proportion of autonomous vehicles in the human-machine mixed traffic flow on the traffic efficiency in different road environments. Taking MATLAB as the simulation experimental platform, this paper carries out virtual programming simulation on the actual man-machine mixed traffic road under various conditions, collects and analyzes the data, and draws the following conclusion: in the future, a large number of unmanned vehicles will enter the existing traffic system, which is bound to change or even overturn the existing traffic management system from many aspects. In order to provide a reliable reference for the formulation of scientific and effective management methods of future man-machine mixed traffic network, this paper considers the influence of the proportion of autonomous vehicles in man-machine mixed traffic flow on traffic efficiency under different traffic conditions.

Keywords: Human-machine Mixed Traffic Flow, Cellular Automata (CA) Model, Traffic Efficiency

1. Introduction

With the growth of car ownership year by year, the existing transportation system is under great pressure. In order to improve the traffic safety, the automatic driving vehicle system has become one of the important development trends of future traffic vehicles. "Unmanned driving" is a cutting-edge technology derived from a new round of technological development such as 5G, big data and artificial intelligence. It is not only conducive to reducing logistics costs and improving efficiency, but also a key technology that is likely to trigger future business changes[1-3]. At present, the world's major developed countries are actively deploying driverless technology, some countries have moved towards practical. At the same time, driverless plays a certain role in ensuring road traffic safety: for road
emergencies, it reduces the reaction time and reduces the incidence of traffic accidents to a certain extent; it solves the problem of traffic congestion and improves the road accommodation; it is conducive to regulating the car ownership while sharing the economy in real time.

In this context, it is particularly important to explore the impact of the proportion of autonomous vehicles in mixed traffic flow on traffic efficiency under different traffic task conditions in the future traffic system. Therefore, it is necessary to establish an appropriate traffic flow model -- traffic flow cellular automata (CA) model. Based on the analysis of the characteristics of driverless behavior and the influence of driverless on manned driving behavior in question 1, the model parameters are set, the simulation and data processing are carried out by MATLAB, and the traffic efficiency is judged according to the parameter -- average flow ($\bar{J}$). Finally, the experimental conclusion is obtained through comparative analysis [4, 5].

Many traditional automobile enterprises and Internet technology enterprises have been carrying out relevant technology research and development and commercialization exploration. Uber has used smart logistics trucks to deliver goods all over Arizona. Suning, Jingdong and other domestic e-commerce enterprises have also launched their L4 level completely unmanned heavy truck R & D plan. However, based on the cellular automata (AC) model, the research on the characteristics and management methods of future complex man-machine mixed traffic flow is relatively less [6].

2. Simulation Setup of Unmanned Driving Behavior Based on CA Model

2.1. The Connotation of CA Model

Cellular automata is essentially a dynamic system which is defined in a cellular space composed of discrete and finite cells and evolves in discrete time dimension according to certain local rules.

Cell, also called unit or cell, is the most basic component of cellular automata.

The cell has the following characteristics:

1) The most basic unit of cellular automata.
2) Cell has the function of memory storage.
3) All cell states are updated according to cell rules.

2.2. Simulation Setup of Unmanned Driving Behavior Based on CA Model

2.2.1. Traffic Efficiency. The average flow represents the number of vehicles passing through the highway in unit time (as defined below). In this paper, the average flow value is selected as the standard to judge the traffic efficiency under the condition of different proportion of autonomous vehicles. The larger the average traffic flow is, the higher the traffic efficiency is; on the contrary, the lower the traffic efficiency is [7].

$$ J = \rho \times V $$

(1)

$\rho$ is the total vehicle density on the road; $V$ is the total average speed of all vehicles on the road.

2.2.2. Safe Distance. Definition: time headway (TH) is the time difference between the front and rear vehicles passing the same position, which is usually obtained by the ratio of the front distance between the front and rear vehicles and the speed of the rear vehicle. Record as variable $g_t$. 

IOP Publishing
Journal of Physics: Conference Series 2037 (2021) 012120 doi:10.1088/1742-6596/2037/1/012120
In Figure 1, $V_n(t)$ represents the speed of the rear vehicle; $V_{n+1}(t)$ represents the speed of the front vehicle; $d_{n+1}(t)$ represents the distance between the front and rear vehicles. According to the above definition of Headway, we obtain:

$$g_t = \frac{d_n(t)}{v_n(t)}$$

(2)

The shortest distance between the front and rear vehicles is represented by $\min\{g_t\}$. The results are as follows:

$$I_{n_{\text{safe, } n}}(t) = v_n(t) \times g_t - l_i$$

(3)

$l_{i-1}$ means the length of the vehicle in front of a manned vehicle, $l_{i-2}$ refers to the length of the vehicle without driving; the shortest safety vehicle distance $I_{n_{\text{safe, } n}}(t)$ indicates the shortest distance required to avoid rear end collision when the current vehicle is in emergency braking when the manned vehicle is driving at a speed $v_n(t)$ under the condition that the front and rear vehicles have fixed headway.

2.2.3 Establishment of manned driving model. Based on the traditional NaSch model, this paper uses the relationship between $I_n(t)$ and $I_{n_{\text{safe, } n}}(t)$ as the condition to judge the movement state of the rear vehicles. Therefore, the rules of manned driving model in man-machine mixed traffic flow are as follows:

(1) The velocity distribution of the car behind at time t is as follows:

A. $I_n(t) > I_n(t + 1)$, The rear car behind accelerates but does not exceed the maximum speed.

$$v_n(t + 1) = \min\{v_n(t) + 1, v_{\text{max}}\} \quad I_n(t) = I_n(t + 1)$$

(4)

The car behind runs at a constant speed.

$$v_n(t + 1) = v_n(t)$$

(5)

C. $I_n(t) < I_n(t + 1)$, The car behind slows down but the speed is not negative.
\[ v_n(t+1) = \max \{ \min(v_n(t) - 1, I_{n_t}), 0 \} \] (6)

Considering the influence of other road random factors (such as the change of driver's mental state, poor road condition, etc.), the random slowing down probability p is used to slow down the car behind.

\[ v_n(t+1) = \max \{ v_n(t) - 1, 0 \} \] (7)

(2) The location distribution of the car behind at time \( t+1 \):

\[ X_n(t+1) = X_n(t) + v_n(t+1) \] (8)

The above model rules consider the influence of road uncertainties. \( I_{\text{safe,n}}(t) \) can judge driving safety according to \( d_s(t) \). the safety distance \( I_{\text{safe,n}}(t) \) that must be kept to avoid collision between front and rear vehicles is shown in formula (2).

### 2.2.4 Establishment of unmanned driving model

Car following model, as an important part of micro traffic flow model, assumes that in the driverless fleet, each workshop maintains a certain vehicle spacing, so as to avoid collision. Chandler initially considered the speed difference between the front car and the following car, and proposed the approximate equation of the stimulus response car following model.

\[ \Delta X_s(t+T) = \delta[\Delta X_{n+1}(t) - \Delta X_n(t)] \] (9)

\( T \) is the reaction time of the driver; \( \delta \) is the intensity coefficient of the driver's response to sudden changes in road conditions (constant by default); \( \Delta X_n(t) \) and \( \Delta X_{n+1}(t) \) are the positions of the nth vehicle and the nth + 1 vehicle at time t, respectively [8].

Considering that the vehicle speed can be measured by the vehicle sensor, and then the difference between the two vehicles is obtained, based on the following model, the traffic flow cellular automata (CA) model is introduced to describe the characteristics of the unmanned vehicles. Therefore, the rules of unmanned driving model in the mixed traffic flow are as follows:

\[ \Delta v_n = \Delta X_{n+1}(t) = \delta[\Delta X_{n+1}(t) - \Delta X_n(t)] = \delta(v_{n+1}(t) - v_n(t)) = \delta \Delta v_n(t) \] (10)

(1) The velocity distribution of the car behind at time \( t+1 \) is as follows:

Let \([\Delta v^*]\) represent the minimum integer not less than \( \Delta v^* \):

\[ [\Delta v^*] > 0 : \quad v_n(t+1) = \min \{ v_n(t) + [\Delta v^*], v_{\text{max}}, I_{n_t}(t) \} \] (11)

\[ [\Delta v^*] < 0 : \quad v_n(t+1) = \max \{ \min(I_{n_t}(t), v_n(t) + [\Delta v^*]), 0 \} \] (12)

\[ [\Delta v^*] = 0 : \quad v_n(t+1) = \begin{cases} \max \{ v_n(t), I_{n_t}(t) \} , & v_{n+1} = 0 \\ \min \{ v_n(t), I_{n_t}(t) \} , & v_{n+1} \neq 0 \end{cases} \] (13)

(2) The position distribution of the car behind at \( t+1 \):
\[ X_n(t+1) = X_n(t) + v_n(t+1) \]  \hspace{1cm} (14)

According to the hypothesis, the technology and facilities of autopilot's own hardware and software are complete, and there is no road interference. Therefore, the influence of random slowing down on location distribution is ignored in the process of establishing the driverless vehicle model.

2.3. Model Parameter Value and Model Simulation Setting
Model simulation settings: assume that the road is a one-way road with a length of L, and the total number of vehicles on the road is N, in which the number of manned vehicles is N1, and the number of unmanned vehicles is N2. Obviously, N = N1 + N2. The total vehicle density on the road is 
\[ \rho = \frac{N}{L} \]
the total average speed of vehicles on the road at any time is:
\[ v = \frac{1}{N} \sum_{n=1}^{N} v_n(t) \]
(15)

In order to represent the mixing degree of autonomous vehicles and manned vehicles in mixed traffic flow, the mixing proportion coefficient \( r \) is introduced. That is, the proportion of vehicles driven on the one-way road. Clearly, the proportion of driverless vehicles
\[ r = \frac{N - N_1}{N} = \frac{N_2}{N} \]
In order to highlight the more realistic driving characteristics of vehicles in single lane mixed traffic flow, the cell length and time step are further refined: the unit cell length is 3.5m, each vehicle occupies two cells, and the actual space length is 7m. The time step \( \frac{1}{3} \) s is set to 3 steps per second. The maximum vehicle speed \( v_{\text{max}} = 9.5 \text{cell/s} \), equivalent to the actual speed, is 119.7 km/h. Driven vehicles and driverless vehicles are evenly and randomly distributed in a single lane according to their respective proportions, and the initial speed is set as 0.

Each simulation is carried out in 30000 time steps, in which the speed of 3 and the multiple of 3 in the last 3000 steps are recorded. Finally, the average time of 1000 groups of data measured by the simulation is calculated, and the total average speed of a movement is obtained:
\[ V = \frac{1}{T} \sum_{t=1}^{T} v_t \]
(16)

Combined with the above formula and experimental data, the average flow of highway can be obtained:
\[ J = \rho \times V \]
(17)

3. Simulation Results and Basic Graph Analysis of Unmanned Driving Behavior Based on AC Model
The figure shows the change trend of the traffic flow of this one-way street with the total vehicle density under the traffic flow conditions of different man-machine mixing ratio.

It can be seen from the figure that when \( r \) and \( \nu \) it means that when the one-way road is full of self driving vehicles, and the total vehicle density is about, the flow reaches the maximum, because the safety distance between the front and rear vehicles of self driving vehicles is shorter than that of manned vehicles, so the peak value of flow is the largest; longitudinal observation: under the same vehicle density, the flow decreases with the increase of the vehicle density, and this difference is
With the increase of the total vehicle density, the proportion difference first increases and then decreases. Transverse observation: with the increase of the total vehicle density, the traffic flow under different mixing ratios first increases and then decreases.

**Figure 2.** Analysis of simulation results

4. Conclusion

Through the simulation setting and experiment of driverless behavior based on cellular automata, the following optimization results are obtained:

First, one-way street: under the same vehicle density, the flow decreases with the increase of traffic volume, and the difference between different proportions increases first and then decreases with the increase of total vehicle density. With the increase of the total vehicle density, the traffic flow under different mixing ratios first increases and then decreases [9, 10].

Secondly, the T-shaped cross network system based on the two-dimensional traffic flow cellular automata model is established: with the increase of the proportion of autonomous vehicles, the traffic flow increases with the increase of the proportion of autonomous vehicles in the human-machine mixed traffic flow. Under the same proportion of autonomous vehicles in the human-machine mixed traffic flow, the traffic density can promote the traffic flow in a certain range.

Acknowledgments

This research was supported by the college students' innovative entrepreneurial training plan of Shenyang Aerospace University under grant S202010143041. Danhong Chen is the corresponding author and instructor of this paper.

References

[1] J.Xing H.H.Li, Y.Duan, et al. The effectiveness analysis of the automatic driving vehicle in the transportation network. Mathematical modeling and its application, 2017, 6 (2), pp. 65-75.
[2] Y.L.Wang, H.L.Yang, Z.L.Liu, et al. Analysis on the function and influence of "overtaking on right and left" rule based on cellular automata. Mathematical modeling and its application, 2014, 3 (2), pp. 32-4.
[3] M. Taieb-Maimon. Learning headway estimation in driving. Human Factors, 2007, 49(4),
pp.734-44.

[4] F.X.Meng, L.Zhang, W.Zhang. Research on driver headway. Industrial engineering and management, 2013, 018 (002), pp. 131-135.

[5] W. Knospe, L.Santen, A.Schadschneider, etal. Towards a realistic microscopic description of highway traffic. Journal of Physics A General Physics, 2000, 33(48), pp.L477.

[6] L.Q.Sun, R.F.Li, Real-time visibility of CAD models into VR models, computer engineering and applications, 2008(06), pp.117-120.

[7] R.E.Chandler, R.Herman, E.W.Montroll. Traffic Dynamics, pp. Studies in Car Following. Operations Research, 1958, 6(2), pp.165-184.

[8] Z.G.Dingo, X.Y.Zhang, C.B.Wang, Q.Li. Decision making method for intelligent collision avoidance of unmanned ship based on driving practice. China Ship Research, 2021, 16 (01), pp. 96-104 + 113.

[9] Q.Wang, Q.N.Zhang, J.Yang, Z.H.Cong, Tu min. Study on decision making model of inland river pilotless ship driving behavior. Journal of Wuhan University of Technology (traffic science and Engineering), 2021, 45 (01), pp. 44-48 + 53.

[10] Y.W.Liu. On the application of "motion control" in driverless vehicles. Time automotive, 2020 (20), pp. 25-26.