# Analysis on Traffic Conflicts of Two-lane Highway Based on Improved Cellular Automation Model

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***Abstract*—Based on microscopic traffic characteristics of two-lane highway and different driving characteristics for drivers, the characteristics of drivers and vehicle structure are introduced into Cellular Automation model for establishing new Cellular Automation model of two-lane highway. Through computer simulation, the paper analyzes the effect of the promotion of different vehicles, drivers and arrival rates on traffic conflicts of two-lane highway, which gets the relationship between the parameters such as road traffic and velocity variance and collision. The results indicate that the frequency of traffic conflicts has close relationship with the product of traffic flow and velocity variation. When the traffic flow and velocity variation are great, the frequency of the conflict is the greatest, and when the traffic flow and velocity variation are little, the frequency of the conflict is the least.**

***Index Terms*—traffic flow, traffic conflict, cellular automaton model, numerical simulation**

## I. Introduction

The concept of traffic conflicts was first proposed by Perkins and Harris who defined a traffic conflict as any potential accident situation leading to the occurrence of evasive actions such as braking or swerving. This definition has since been refined and an internationally accepted definition is 'an observable situation in which two or more road users approach each other in space and time for such an extent that there is a risk of collision if their movements remain unchanged' [1]. The essence of traffic conflict is the manifestation of unsafe factors of traffic behavior. It not only can cause traffic accidents, but also can avoid traffic accidents because of taking safety measures. So accident is similar to conflict. The unique difference between them is if there is direct damaging consequence. In the second international conference about traffic conflict, all traffic engineering scholars considered that traffic conflict technique is an effective measure to identify accident black-spots [2-3].

The application of traffic conflict techniques in assessing the safety of a road entity (intersection, road segment, etc.) has been continuously gaining attention among safety researchers and practitioners. Several studies have demonstrated the feasibility of collecting conflict data using three ways: field observers [4], simulation models [5], and video-camera [6-9].

There are also several studies demonstrated how to assessing the safety of a road entity by using traffic conflict. Lord and Mannering summarized the various types of statistical crash frequency (count) models [10]. Gary et al. discussed an alternative approach to linking traffic conflicts with accidents by estimating the probability of unsuccessful avoidance maneuver by given the initial conditions [11]. Andrew P. Tarko discussed recent developments in safety modeling oriented towards the use of microscopic observations of vehicle interactions and better representation of crash causality [12].

Look through the researches on traffic conflict at home and abroad, they are focus on the relationship between conflict and accident, discriminated method and prediction on conflict. But in practical application, simple distance discrimination method, time criterion method and even rough ocular estimation are used to obtain conflict data [13].

These methods are suitable for fixed point observation on specific objects. Obtaining large-scale conflict data not only is difficult, but also has high cost, which is not applicable for observing large-scale road network with highway network as the representative.

The cellular automat model began to receive wide attention from the traffic and transportation community only after the simple formulation by Nagel and Schreckenberg, which is known as the NaSch model [14]. Daganzo presented how under some specific assumptions, a CA is equivalent to the kinematic traffic flow model and the car-following model [15]. Furthermore, the CA has been generalized to slow-to-start phenomena, traffic with high speed vehicles, signalized intersection, multilane multi- class traffic flow, inhomogeneous mixed traffic flow [16] and large traffic networks. The CA model flexibly introduces various parameters describing real traffic condition and can effectively simulate microscopic motion of vehicles in traffic flow, which is

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easy for studying interaction mechanics between vehicles. So it is widely applied in the studies of traffic flow theory.

Recent years, many jobs have been done to modify the CA model to make it more realistic. On the study of the modification cellular automaton model, Nagatani and Takashi presented a deterministic cellular automaton model to simulate the traffic flow in a two-lane roadway. It is shown that the exchange of cars has an important effect on phase transition between maximal velocity phase and the high-density phase [17]. Nagel et al. summarized different approaches to lane changing and classified the multitude of possible lanechanging rules for freeway traffic. They used a cellular automaton model for two-lane traffic to generate the density inversion, and found in many European countries, the densities somewhat below the maximum flow density [18]. Li et al. proposed a symmetric two-lane cellular automata model to investigate the aggressive lane-changing behavior of fast vehicle and the effect of different lane-changing probability [19]. Tang et al. proposed a car-following model by considering the anticipation effect of the lane changing probability of the leading vehicle on the car-following behavior of the following vehicle on single lane [20]. Wei Lv et al. extended the continuous single-lane models (OV model and FVD model) to simulate the lane-changing behavior on an urban roadway that consists of three lanes. The simulation results indicate that lane-changing behavior is not advisable on crowded urban roadway [21]. Peng et al. presented a new lattice model, and found that the consideration of lane changing probability in lattice model can stabilize traffic flow [22-23].

The objective of this paper is to explore the potential traffic conflict on different traffic condition of normal highway especially two-lane highway, which involved different type of drivers, different kinds of traffic structure, and different vehicle arrival rate. And then new CA rules with road traffic characteristics parameters and traffic conflict parameters are proposed. Using the new CA model, we set up different traffic scenarios, simulate the road traffic characteristics and analyze the attributive characters of highway traffic conflicts for realizing the highway risk criterion with the conflicts as the index.

## II. Improved Cellular Automat Model of Two-lane Highway

In two-lane highway, the vehicles can be divided into cart and car according to climbing performance. And the divers can be divided into the radical and the conservative according to the characters of drivers in the past studies. Compared with the conservative drivers, the radical drivers are easy to overtake under the condition of congestion and may speed up as long as there is enough space between vehicles. But the conservative drivers keep great distance with the vehicle, and they nearly overtake. According to the above conditions, the rules of the radical drivers and the conservative drivers can be differentiated in the driving evolution rules, which can get CA rules of two-lane highway.

### *A. Evolution rules of positive driving vehicles*

(1) The conservative vehicles are on the basis of NaSch model evolution rules, and the evolution rules of positive driving vehicles are:

(a) at $t+1$, the velocity of vehicles is:

①If $V_i(t) < gap_i(t)$, $V_i(t) < V_{i\max}$,

$$V_i(t+1) = \begin{cases} V_i(t) & \text{Uniform probability } \rho_u \\ V_i(t)+1 & \text{Accelerate probability } \rho_a \\ V_i(t)\text{-}1 & \text{Deceleration probability } \rho_d \end{cases};$$

②If $V_i(t) < gap_i(t)$,

$V_i(t)=V_{i\max}$, $V_i(t+1) = \begin{cases} V_{\max}(t) & \text{Uniform probability } \rho_u \\ V_{\max}(t)\text{-}1 & \text{Deceleration probability } \rho_d \end{cases}$;

③If $V_i(t) \ge gap_i(t)$ satisfies the rule of overtake, it is obeyed. And if it doesn't satisfy the overtake rule,

$$V_i(t+1) = \begin{cases} \max(gap_i(t)-1,0) & \text{probability } \rho \\ gap_i(t) & \text{probability} 1-\rho \end{cases};$$

(b) at $t+1$, the position of vehicles is:

$X_i(t+1) = X_i(t) + V_i(t+1)$.

(2) The radical vehicles are on the basis of FI model evolution rules [24], and the evolution rules of positive driving vehicles are:

(a) at $t+1$, the velocity of vehicles is:

①If $V_i(t) < gap_i(t)$, $V_i(t) < V_{i\max}$,

$$V_i(t+1) = \begin{cases} V_i(t) & \text{Uniform probability } \rho_u \\ V_i(t)+a & \text{Accelerate probability } \rho_a \\ V_i(t)\text{-}1 & \text{Deceleration probability } \rho_d \end{cases},$$ a is the maximum acceleration of vehicles;

②If $V_i(t) < gap_i(t)$, $V_i(t)=V_{i\max}$,

$$V_i(t+1) = \begin{cases} V_i(t) & \text{Uniform probability } \rho_u \\ V_i(t)\text{-}1 & \text{Deceleration probability } \rho_d \end{cases};$$

③$V_i(t) \ge gap_i(t)$, if it satisfies the overtaking rule, the following car overtakes. If it doesn't satisfy the overtaking rule, $V_i(t+1) = gap_i(t)$.

(b) at $t+1$, the position of vehicles is:

$X_i(t+1) = X_i(t) + V_i(t+1)$.

### *B. Overtaking Rules*

In the overtaking process, when the overtaking velocity is less than the maximum velocity of the vehicle, the radical drivers directly use the maximum velocity of vehicle, and the conservative drivers speed up 1 every hour and drives with the maximum velocity. Meanwhile, if the vehicles with low velocity satisfy the overtaking rules in the overtaking process, they can follow the overtaking vehicles. The overtaking process is shown in Figure 1.

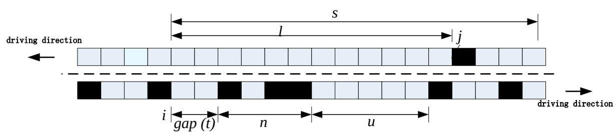



Figure 1 Overtaking Process

And the overtaking rules are as follows:

(1) When the car in front is hindered by the low-velocity cars, $gap_i(t) \le V_i(t)$ and $V_{i+1}(t) < V_{ihope}$;

(2) When the low-velocity cars have enough space within overtaking sight distance, $u \ge T_1 V_{i+m}(t)+1$;

(3) When the neighboring trace has enough space, $T_2>T_1$;

(4) If the above three conditions are satisfied, the car overtakes by changing track with the probability $\rho_T$

Speed of changing lane:

(1) The conservative vehicles:

$V_i'(t+1) = \min(V_i(t)+1, V_{i\max})$

(2) The radical vehicles: $V_i'(t+1) = V_{i\max}$

Position of changing lane: $X_i'(t+1) = X_i(t) + V_i'(t+1)$

$V_{ihope}$ is the expected speed of the car, $X_i'(t+1)$ is the position of the *i* car entering the opposite lane at $t+1$.

*C. Overtaking Retrograde Evolution Rules*

In the overtaking process, the overtaking car and the following car make uniform motion within the overtaking sight distance, and the following car can't overtake it. When the car driving in the opposite direction may hinder the overtaking car, it should slow down.

And the overtaking retrograde evolution rules are:

Retrograde velocity: $V_i'(t+1) = V_{i\max}$

Location of vehicles update: $X_i'(t+1) = X_i'(t) + V_i'(t+1)$

*D. Overtaking Conditions*

As the opposite lane is needed to overtake in two-lane highway, which belongs to retrograde motion, it is not good to stop for too long time in the opposite lane. So the time of vehicles retaining in the opposite lane has a time upper limit and time lower limit.

(1) The shortest time of overtaking retrograde vehicle in the opposite lane, time upper limit $T_1$:

When $\gamma > 0$, if $\delta \ge \dfrac{m-0.5\gamma(\gamma+1)+1}{\gamma}$,

$$T_1 = \text{ceil}\left\{\left[\left(\delta+\frac{1}{2}\right)^2 + 2(m+1)\right]^{1/2} - (\delta+\frac{1}{2})\right\}.$$

And if $\delta < \dfrac{m-0.5\gamma(\gamma+1)+1}{\gamma}$,

$$T_1 = \text{ceil}\left[\frac{0.5\gamma(\gamma-1)+m+1}{\delta+\gamma}\right];$$

When $\gamma = 0$, $T_1 = \text{ceil}\left[(m+1)/(V_{i\max} - V_{i+m}(t))\right]$, in which $\delta = V_i(t) - V_{i+m}(t)$, $\gamma = V_{i\max} - V_i(t)$, $m = n + gap_i(t)$, $n$ is the length of the cars in front, and $ceil(x)$ is greater than the smallest positive integral of $x$.

(2) The longest time of overtaking retrograde vehicle in the opposite lane, time lower limit $T_2$:

When $l \le \dfrac{1}{2}\gamma^2 + \gamma\left(\eta+\dfrac{1}{2}\right)$,

$$T_2 = \text{floor}\left[\sqrt{\left(\eta+\frac{1}{2}\right)^2 + 2l} - \left(\eta+\frac{1}{2}\right)\right],$$

When $l > \dfrac{1}{2}\gamma^2 + \gamma\left(\eta+\dfrac{1}{2}\right)$,

$$T_2 = \text{floor}\left[(\frac{1}{2}\gamma(\gamma-1)+l)/(\eta+\gamma)\right].$$

$\eta = V_i(t) + V_j(t)$, when there is no vehicle in the opposite lane within the sight distance, $V_j(t) = 0$. Function $floor(x)$ is less than the smallest positive integral of $x$.

*E. Identification of Overtake Completing*

When the vehicle reaches $T_1$ on the opposite lane, the overtaking is completed and the vehicle returns the original lane.

The past researches indicated that the relationship between accident and conflict can be described by the severity of conflict. According to the severity, the traffic risk events can be divided into non-disruptive pass, non-serious conflict, and serious conflict and accident, and the quantitative relation between them distributes like a tower. There is direct relationship between serious conflict and traffic accident, so the paper focuses on studying the attributive character of serious conflicts.

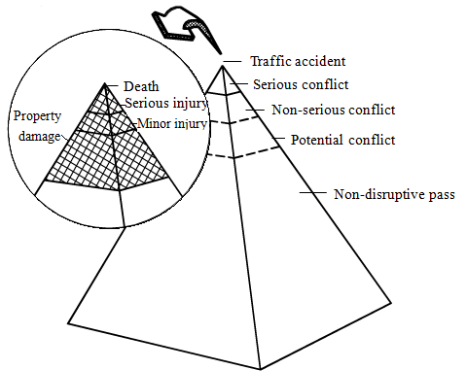



Figure 2 Classification Relationship Between Traffic Conflict and Traffic Accident

According to braking process formula of car and national standard, the incomplete braking distance of different vehicles with different velocities [11], as shown in Table 1.

TABLE 1 INCOMPLETE BRAKING DISTANCE WITH DIFFERENT SPEED

| ***Speed* (km/h)** | ***Critical distance Ds(s)*** | | |
|---|---|---|---|
| | ***Small car*** | ***Midsize car*** | ***Large car*** |
| 5 | 0.3 | 0.4 | 0.47 |
| 10 | 0.87 | 1.12 | 1.21 |
| 15 | 1.72 | 2.14 | 2.22 |
| 20 | 2.83 | 3.47 | 3.49 |
| 25 | 4.21 | 5.11 | 5.04 |
| 30 | 5.86 | 7.06 | 6.96 |
| 35 | 7.78 | 9.31 | 8.95 |
| 40 | 9.98 | 11.88 | 11.31 |
| 45 | 12.44 | 14.75 | 13.94 |
| 50 | 15.17 | 17.93 | 16.84 |
| 55 | 18.17 | 21.42 | 20.01 |
| 60 | 21.44 | 25.22 | 23.44 |

| | | | |
|---|---|---|---|
| 65 | 24.99 | 29.33 | 27.15 |
| 70 | 28.8 | 33.75 | 31.13 |
| 75 | 32.88 | 38.47 | 35.38 |
| 80 | 37.23 | 43.51 | 39.9 |
| 85 | 41.86 | 48.85 | 44.69 |
| 90 | 46.75 | 54.5 | 49.75 |
| 95 | 51.91 | 60.46 | 55.08 |
| 100 | 57.35 | 66.37 | 60.68 |
| 105 | 63.05 | 73.31 | 66.55 |
| 110 | 69.02 | 80.19 | 72.69 |
| 115 | 75.26 | 87.39 | 79.1 |
| 120 | 81.78 | 94.89 | 85.78 |

## III. Numerical Simulation

### *A. Parameter Calibration*

In consideration of the type of vehicles in highway and great difference for length between carts and cars, in order to really describe the practical situation, the basic conditions of the model are set as follows: the length of cellular is 3.5m, the maximum speed of cars on two-lane highway and is $V_{max}$ =8, and the maximum speed $V_{max}'$ of carts is the speed of vehicles driving with uniform velocity, and the simulated 1 time step is 1 second. The other simulated parameters include:

The length of lane is 1000 cellular (3.5km). Open boundary conditions are used, and the lane under the initial condition is empty. The first cellular at the entrance of the road is set as the grid, and the arrival of vehicles follows Poissonian distribution, and the arrival coefficient is $\lambda$ .

The initial speed of vehicles entering the road section: large cars satisfy the positive distribution that the mean value is 1 and variance is 1.3, and the small cars satisfy the positive distribution that the mean value is 4 and variance is 1.84. (The data is from S230 road section in Pinggu Beijing).

Output results of model: the average density, speed and flow of lane continue to use the macro definition of model. At time *t*, the average density of lane is $\rho_t = N_t / L$ , the average speed is $\bar{V}_t = \frac{1}{N_t}\sum_{i=1}^{N_t} V_i(t)$ , and the average flow is $J_t = \rho_t \bar{V}_t$ . In addition, the paper introduces variance of lane speed and the calculation formula is $Var_t = \sqrt{\frac{1}{N_t - 1}\sum_{i=1}^{N_t}(V_i(t) - \bar{V}_t)^2}$ , which is used to describe the fluctuation of travel speed on the driveway.

Number of conflicts: the vehicles satisfying table 1 is recorded as one conflict, and the number of all conflicts on the road section is as the number of conflicts on the road section at time t. In order to eliminate the random influence of the system, the mean value of the model from 4000 to 8000 is selected, and 4000 mean values are for system average based on the time.

### *B. Symmetry of Lane Flow*

The arrival coefficient $\lambda$ of vehicles is from 0.1 to 1.0. The highway traffic characteristics with the proportions of different vehicles and different drivers are simulated according to the growth of 0.1 for figuring out the times of conflicts.

On simulating highway traffic characteristics with the proportions of different vehicles, the proportion of drivers is calibrated according to the proportion that the conservative and radical respectively accounts for 50%. On simulating highway traffic characteristics with the proportions of different driver, cars and carts respectively accounts fro 50%. As the arrival rates of vehicles on two lanes are same, and the traffic characteristics of lanes are similar, the traffic parameter of 1 for lanes is selected to be analyzed. And the analysis results are shown in Figure 3 and Figure 4.

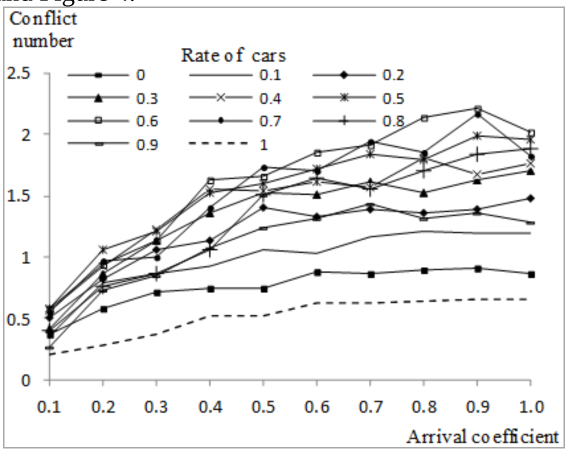



Figure 3. Relationship between the Number of Conflicts and Arrival Coefficient – Vehicles

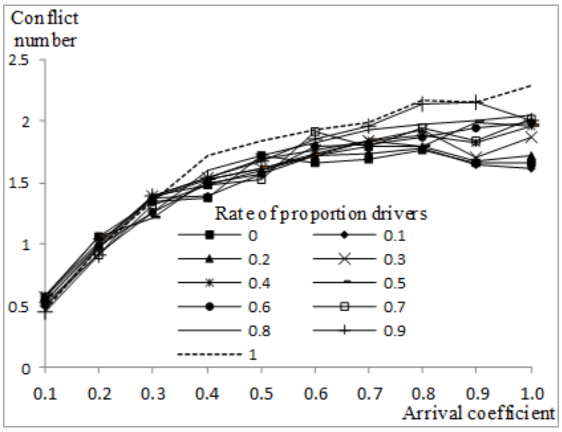



Figure 4. Relationship between the Number of Conflicts and Arrival Coefficient – Drivers

Figure 3 and Figure 4 is respectively the relationship between the number of conflicts and arrival coefficient with the proportion of different vehicles and different drivers.

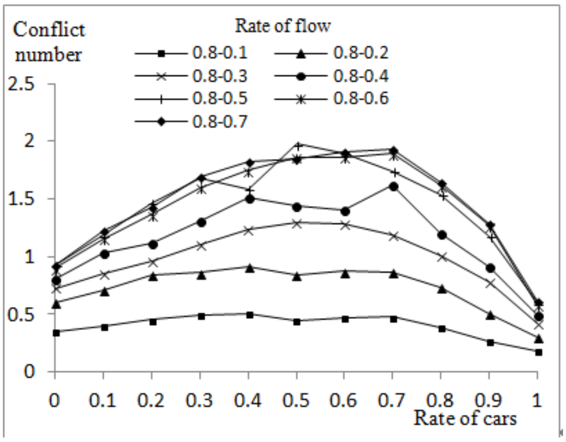
In Figure 3, the number of conflicts increases with the increase of arrival coefficient, and the curve for the number of conflicts of different small cars is very evident. In the situation of single vehicle, the number of conflicts is the smallest, and the number of conflicts is the greatest when the proportion of vehicles is 0.6 and 0.7, which shows that the probability of traffic accidents when the vehicles are not stable is greater than that when the vehicles are stable. With the increase of arrival coefficient, the vehicles increase, the times of vehicles influencing increases, and the times of conflicts increases, which conforms to the reality.

In Figure 4, the number of conflicts increases with the increase of arrival coefficient. For the proportion of different drivers, the curve begins to diverge when the arrival rate is greater than 0.3. And when the proportion of radical drivers is 1, the number of conflicts is the greatest and increases with the rapidest speed with the increase of arrival rate.

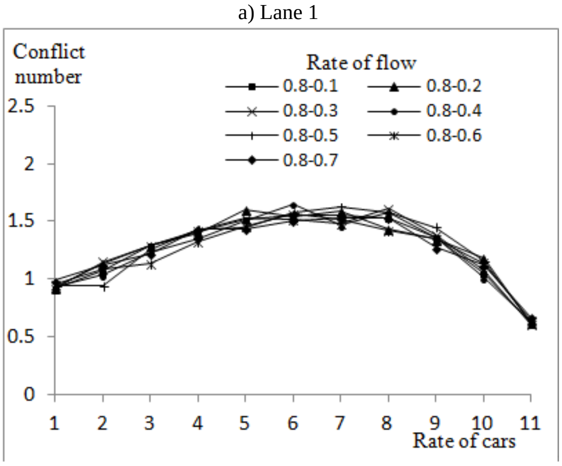
*C. Asymmetry of Lane Flow*

The arrival rate λ of lane 2 keeps 0.8, and the arrival rate λ of lane 1 is from 0.1 to 0.7. The highway traffic characteristics with the proportions of different vehicles and different drivers are simulated according to the growth of 0.1 for figuring out the times of conflicts.

On simulating highway traffic characteristics with the proportions of different vehicles, the proportion of drivers is calibrated 70% according to the proportion of the radical drivers, and the conservative drivers account for 30%. On simulating highway traffic characteristics with the proportions of different driver, small cars account for 70%, and large cars accounts for 30%. And the analysis results are shown in Figure 5 and Figure 6.

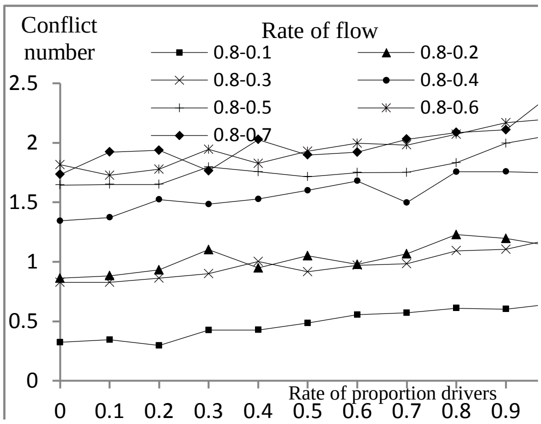



a) Lane 1

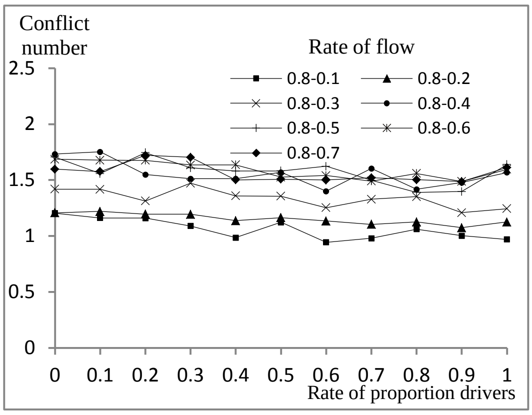



b) Lane 2

Figure 5. Relationship between the proportion of vehicles and the number of conflicts




a) Lane 1




b) Lane 2

Figure 6. Relationship between the proportion of vehicles and the number of conflicts

Figure 5 and Figure 6 is respectively the relationship between the number of conflicts and arrival coefficient with the proportion of different vehicles and different drivers.

In Figure 5, for the lane 1 with low arrival rate, the number of conflicts increases with the increase of arrival coefficient, and the curve is like parabolic. For the curve whose arrival rate is greater than 0.3, the proportion of small cars corresponding to the vertex of parabola is 0.7. And when the arrival rate is less than 0.3, the proportion of small cars corresponding to the vertex of parabola increased from 0.5 to 0.7. In addition, with the increase of arrival rate, the increase of the number of conflicts is very evident. For the lane 1 with high arrival rate, the number of conflicts increases with the increase of the proportion of small cars, the curve is parabolic, the proportion of small cars corresponding to the vertex of parabola is 0.7, and the curves with different proportions of flow are similar. We can see that the proportion of small cars has evident influence on the number of conflicts under different proportions of flow, but has not evident effect on the road with high flow.

In Figure 6, for the lane 1 with low arrival rate, the number of conflicts increases evidently with the increase of the proportion of radical drivers. When the arrival rate is 0.1, there are few vehicles, although there are many people overtaking, the times of severe conflicts is lower than the lowest level. When the arrival rate is 0.2 and 0.3, the number of conflicts increases greatly compared with the lowest level, but two curves which are similar are in the medium level. When the arrival rate is greater than 0.3, the number of vehicles increases to certain extent, the mutual function of vehicles increases, it is difficult for vehicles to speed up, slow sown and overtake, and the number of conflicts increases again. And with the increased of radical drivers, the times of vehicles overtaking increases, the number of conflicts increases. Although the lane 1 has little traffic flow, the number of conflicts is higher evidently than that on lane 2. As for the lane 2 with high arrival rate, the fluctuation of curve is stable. With the change the proportion of flow and the increase of arrival rate on the opposite lane, the number of conflicts on the lane increases.

### *D. Coupling Relationship*

From the above analysis, we can know that the number of conflicts on road not only is influenced by the traffic flow, but also has close relationship with the fluctuation of speed. The chapter focuses on analyzing the coupling relationship between the number of conflicts and other traffic parameters.

The number of conflicts, velocity variance and the mean flow of lane are drawn into scatter diagram, as shown in Figure7 and Figure8.

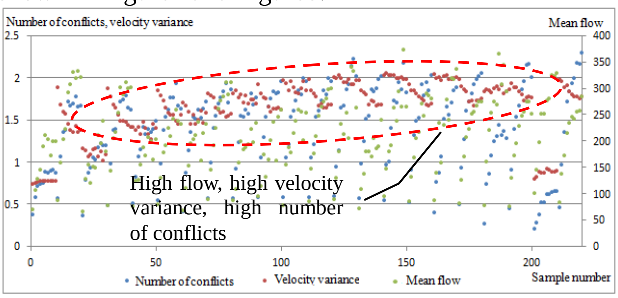



Figure 7. Scatter Diagram of Number of Conflicts, Velocity Variance and the Mean Flow of Lane under Symmetric Flow of Lane

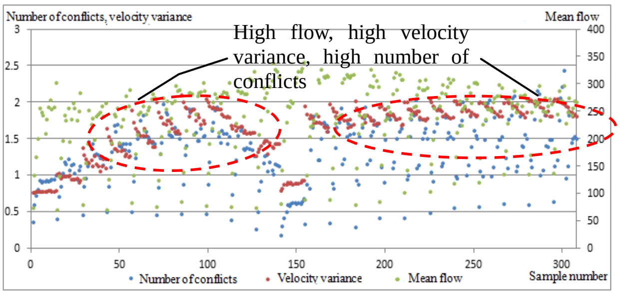



Figure 8. Scatter Diagram of Number of Conflicts, Velocity Variance and the Mean Flow of Lane under Asymmetric Flow of Lane

In Figure 8 and Figure 8, the number of conflicts is high under the condition of high speed variation and high mean flow of lane, which is consistent with the real situation that it is easy for traffic accidents when the fluctuation of velocity and the traffic flow are great.

We can deduce from the preamble analysis results that when the traffic volume or the speed fluctuation is great, it is easy for traffic conflicts. And we can summarize the logic relationship among the average flow of lane, speed variance and the number of conflicts, as shown in Figure 9. The paper introduces a new parameter, the product of the average flow of lane and speed variance. When the flow or speed fluctuation is great, the product of flow of lane and speed variance is great.

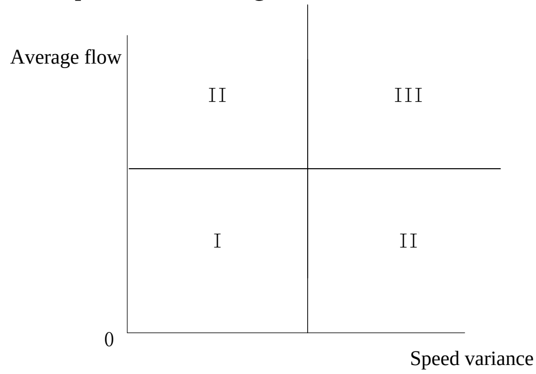



Figure 9. Relationship diagram among the average flow of lane, speed variance and the number of conflicts

In figure 9, I area means the condition of low speed variance and low average flow of lane, in which the number of conflicts is the smallest. II area is the condition of low speed variance and high average flow of lane, or the condition of high average flow of lane and low speed variance, in which the number of conflicts is greater evidently than that in I area. III area is the condition of high speed variance and high average flow of lane, in which the number of conflicts is the greatest.

The product of flow and speed variance and the number of conflicts are drawn into scatter diagram, as shown in Figure 10 and Figure 11.

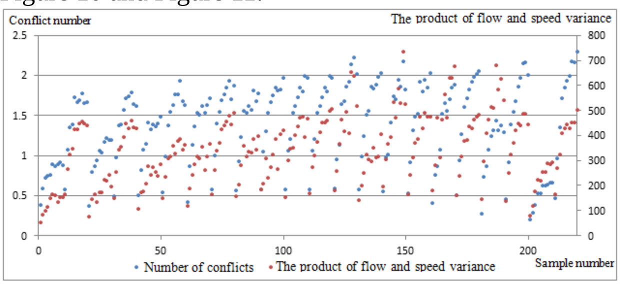



Figure 10. Scatter Diagram of the Product of Flow and Speed Variance and the Number of Conflicts under Symmetric Flow of Lane

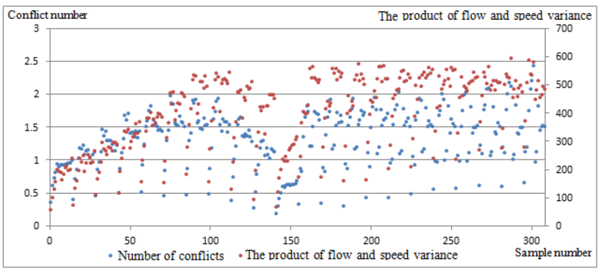
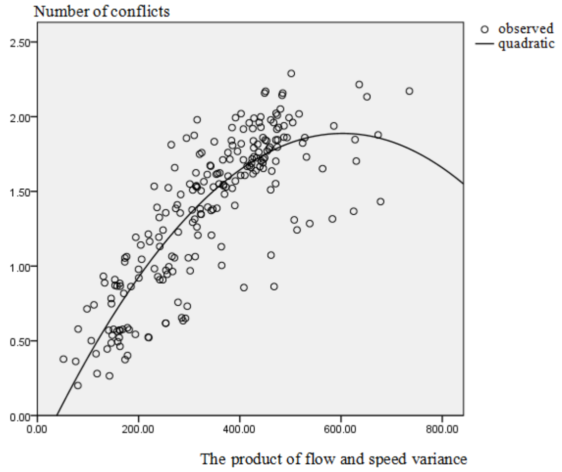
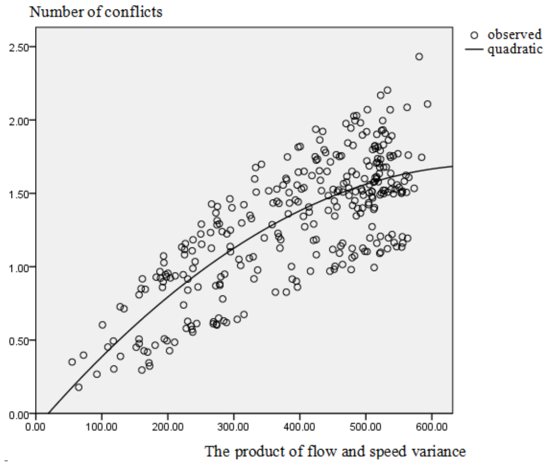



Figure 11. Scatter Diagram of the Product of Flow and Speed Variance and the Number of Conflicts under Asymmetric Flow of Lane

From Figure 10 and 11, we can see that there is close relationship between the product of flow and speed variance, and the number of conflicts. SPSS statistical data analysis software is used for correlation analysis, and the results are as follows:




a) Symmetric Condition of Traffic Flow




b) Asymmetric Condition of Traffic Flow

Figure 12. Regression Curve of the Product of Flow and Speed Variance and the Number of Conflicts

The goodness-of-fit index of curves（$R^2$） in Figure 12 is respectively 0.715 and 0.601. From the goodness- of-fit index, we can see that there is close relationship between the flow and speed variance and the number of conflicts, but the goodness-of-fit index under symmetric condition is higher than that under asymmetric condition, the reason for which is that the vehicles are influenced greatly by the vehicles on the opposite lane under asymmetric condition. And we can see that the number of conflicts is also influenced by other complicated factors.

## IV. Conclusion

Based on microscopic traffic characteristics of two-lane highway and different driving characteristics for drivers, the characteristics of drivers and vehicle structure are introduced into CA model for establishing a new CA model of two-lane highway. Meanwhile, open boundary conditions are used for numerical simulation, which really realizes the traffic condition with the proportion of different characters and different drivers. The results indicate that the frequency of traffic conflicts has close relationship with the product of road traffic and velocity variation. When the road traffic and velocity variation are great, the frequency of the conflict is the greatest, and when the road traffic and velocity variation are little, the frequency of the conflict is the least.

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