Influence of Reckless Jaywalking on Urban Road Traffic Capacity

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Abstract: A modified cellular automaton (CA) model based on the NaSch model is proposed to simulate the typical reckless jaywalking which can cause serious traffic jam and even traffic accident. Incorporating traffic psychology, the walking characteristics such as customary activity, randomness, conformity and tendency are analyzed. Two parameters reflecting the influence degree of human factor is introduced with the global consideration of the above walking characteristics. The numerical simulations are carried out under the periodic boundary conditions. Different cases including the reckless jaywalking at a fixed position and other stochastic positions are taken into account, respectively. The relationship between the traffic states and weight of human factor is investigated. The corresponding fundamental diagrams and the spatio-temporal patterns are given. Furthermore, the formation mechanism of traffic jam is explored and the measures for decreasing the negative influence of human factors are discussed.

Keywords: Cellular automaton model, reckless jaywalking, traffic flow, traffic psychology.

1. INTRODUCTION

Recently, traffic has become a global exasperating problem, and the increasing traffic jams and traffic pollution are exerting great pressure on society and causing enormous economic losses. Many researchers from different disciplines have been trying to understand the fundamental principals governing the traffic based on three different approaches, namely: the macroscopic, mesoscopic and microscopic description [1-3]. Within the conceptual framework of the microscopic approach, the cellular automata (CA) have become popular for modeling traffic because it is conceptually simple, with high computer efficiency. Much effort has been concentrated on stochastic CA models of traffic flow first proposed by Nagel and Schreckenberg [4] and subsequently studied by other authors using a variety of techniques. Now this model has been widely used in investigating different kinds of traffic situations such as blockages, multi-lanes traffic, mixed traffic, etc [5-9].

As we know, another significant reason to form jams is human factors, including reckless jaywalking, non-motor vehicles moving on the motorway, motor vehicles changing lanes or making a U-turn randomly, taxies stopping casually, etc [10]. A recent survey revealed that the influence of human factors on traffic has exceeded over 30% [11]. Moreover, the traffic nodes and blockage from human factors are becoming an increasingly key reason influencing traffic. Especially in China, with a large population and mixture traffic, pedestrians compete with vehicles to cross the road, and thus the influence of human factors on traffic is more serious.

The answer to this question requires a deep investigation. Unfortunately, most of literatures have focused on the interaction between vehicles and other vehicles, or pedestrians and other pedestrians, while the effect of human factors on vehicles have rarely been discussed. In this paper, our primary aim is to propose a modified NaSch model by analyzing the characteristics of human factors from traffic psychology, which can contribute to a better understanding of the properties of traffic. The study is focused on the reckless jaywalking in branch of main roads, where the walkers’ behaviors are more casual. Once traffic jam appears, it would quickly expand to urban street networks.

This paper is organized as follows: Section 2 is devoted to explain the model. In Sections 3 and 4 we will present the main results obtained by simulation with a detailed discussion. Finally, a general conclusion is drawn.

2. MODEL

2.1. Behavior Analysis of Reckless Jaywalking

The citizens’ consciousness degree of obeying traffic regulations has a direct effect on vehicles’ speed and road capacity. Investigations show that nearly all traffic participants including drivers, cyclists and walkers understand traffic from the viewpoint of his self-convenience. The only main aim is to save time and strength, thus decrease time in transit and physical exertion. Traffic psychology, as a branch of psychology, is primarily concerned with the study of behavior in people driving on the roads and how that behavior influences their actions on the road. It aims to shed some light on some of our more interesting behavior tendencies and to improve safety and comfort and increase efficiency of transport system. It tells us that though the people’s behavior is complicated, there are some common characteristics as follows:
First, the behavior of reckless jaywalking is a customary activity, often characterized by crossing the road from not the sidewalk but other positions for his / (or her) convenience.

Second, the behavior is random, e.g., the irregular crossing position, crossing time and the time interval for the next crossing. Compared with traffic lights, the crossing position is unfixed and the time consists of crossing time and the time interval for the next crossing. Compared with traffic lights, the crossing position is unfixed and the time consist of crossing time and the time interval for the next crossing. It is more stochastic.

Besides, another important characteristic is conformity or following effect. In many cases, one walker’s jaywalking would lead to blind following. Consequently, the crossing time increases inevitably.

2.2. The CA Model Considering Jaywalking

Generally, the pedestrian’s crossing time is one of the most important factors affecting traffic capacity. Stochastic variables t, t1 are introduced to describe the crossing time and the time interval for the next crossing, respectively. They reflect the influence degree of human factors. Some modifications based on NaSch model are performed as follows:

1) The jaywalking behavior is added to the NaSch model. It is set to one and some lattices randomly.

2) The moving rules for normal vehicles would change when confronted with the jaywalking. Let dstop denote the empty sites in front of the nth vehicle with the crossing position. When \( d_{stop} \in [0, 5] \), \( v_n(t+1) \rightarrow 0 \). In other cases, vehicles move as updating rules of the NaSch model. Generally, in urban areas, pedestrian behavior is always more “aggressive” than vehicles, which means that vehicles always decelerate voluntarily while pedestrian always cross the street as soon as possible when they feel the situation is safe. Considering safety, theoretically, we assume the vehicle’s velocity decelerates to zero once the distance between the vehicle and pedestrian is not more than 5.

3. SIMULATION AND RESULTS

The numerical simulations are performed according to the above updating rules under the periodic boundary condition. A one-dimensional lattice of \( L \) sites and vehicles moving unidirectionally are considered. Each site is set to be 7.5m long, \( L \) to be 200, one time step to be 1s, being the order of the reaction time for humans, and the maximum velocity to be \( v_{max} = 3 \), corresponding to 81km/h. In order to characterize the behavior of the model, we determine globally the macroscopic quantities, including the global density \( \rho \), the mean speed \( V \), the mean flow \( J \) defined as

\[
\rho = \frac{N}{L} \tag{1}
\]

\[
V = \frac{1}{T} \sum_{t=0}^{T-1} \frac{1}{N} \sum_{n=1}^{N} v_n(t) \tag{2}
\]

\[
J = \rho V \tag{3}
\]

In numerical simulation, the first \( 5 \times 10^4 \) time-steps of each run are put away in order to remove the transient effects, and then the data are recorded in successive \( 1 \times 10^4 \) time-steps. The mean velocity is obtained by averaging over 30 runs of simulations. Two typical situations are considered.

Case 1: Jaywalking at a fixed crossing position

The fundamental diagram for different crossing time \( t \) with the fixed time interval for the next crossing \( t_1 = 120s \) is shown in Fig. (1a). As \( t \rightarrow 0 \), the flow increases linearly with density at low densities, but it is lower than that of \( t=0 \). Then the flux saturates at the first critical density and keeps a constant value till the occurrence of the second critical density. Moreover, as \( t \) increases, the saturated flow plateau decreases, too. As \( \rho \) is larger than the second critical density, the flow decreases with the increase of density. Especially, when \( t=60s \), the saturated flow declines to 70%. Considering the effect of crossing time, with the increase of \( t \), the flow decreases except for the consequence in a higher density \( (\rho > 0.6) \). The first critical density decreases but the second critical density increases with the increase of \( t \). This means for a larger crossing time \( t \), the density range corresponding to the saturated flow also increases. A possible explanation is that with the increase of crossing time, more and more vehicles can not move at an expected speed, which leads the critical density from the free flow to the saturated flow to decrease. At the same time, the decreasing flux requires more vehicles for the occurrence of congested phase, so the second critical density increases. The results are in agreement with the real traffic.
The spatiotemporal patterns, with different density \( \rho = 0.05, 0.2, 0.4 \) and crossing time \( t_c = 10s, 60s \), are shown in Fig. (2), where \( t_1 = 120s \) is constant. The abscissa denotes the spatial position, i.e., the position of the cells in the lane, while the ordinate denotes the simulation time steps. Black points denote vehicles while white point represents blank spaces. The crossing position is at location 100 on the abscissa and the vehicle is moving left to right. In the spatiotemporal map, the jaywalking leads to a line of waiting vehicle in front of the pedestrians, which evolves with time as the black area in the map. The blank area behind the crossing position is the vacant area when some walkers begin to cross the road. Far from the crosswalk, the vehicle density tends to be sparse and stable. Comparison of Fig. (2) under different density and crossing time shows how the map characteristics change with \( \rho \) and \( t_c \). Even in a low density, the increasing crossing time lead to a big jam.

The fundamental diagram with fixed \( t_c = 10s \) and variable \( t_1 \) is given in Fig. (1b). With the increasing time interval of crossing, the saturated value of flow and the mean velocity both increase obviously. When the crossing frequency is high, e.g., \( t_1 = 10s \), the saturated flow is only 0.28, declined 50%. A conclusion can be drawn that the frequent crossing has a more negative influence on the traffic flow compared with the increasing crossing time in the low density. The spatiotemporal patterns under different \( \rho \) and \( t_1 \) are shown in Fig. (3). It is clearly that the increase of crossing frequency makes the vehicle accelerate and decelerate more frequently. All these further validate the former fundamental diagram.

**Case 2: Reckless jaywalking at some stochastic positions**

In the real traffic, the randomness of pedestrian’s behavior is universal. This randomness mainly includes stochastic crossing position, different starting crossing time under different positions and different time interval for the next crossing,
4. OTHER ANALYSIS AND DISCUSSION

In real traffic, how to reduce the influence of human factors is still a tough work. To some extent, the proper management strategies and road design would be helpful to ease traffic congestion. Three typical questions are worth further discussing.

1) Influence of crossing frequency. Under the same conditions, let pedestrian cross the road in a long time or a short time but with the high frequency, which is better? Fig. (5a) gives the fundamental diagram under different crossing frequencies with constant total crossing time $t_{\text{total}}=120s$ and time interval for the next crossing $t_{1\text{total}}=240s$. During the total time, pedestrian would cross the road with different $t$ and $t_1$. The crossing time length directly determines the crossing frequency. At lower density ($\rho<0.05$), both vehicle flow and velocity with $t=10s, 20s$ are larger than that of other cases, which implies that the short crossing time have little influence on vehicle flow since the probability for vehicle to decelerate or stop is reduced obviously. An interesting phenomenon is found that the velocity of $t=40s$ is larger than that of $t=30s$ although still lower than that of $t=60s, 120s$; while $0.05<\rho<0.18$, its velocity drops distinctly, less than that of $t=30s, 60s, 120s$. All these reflect in low density re-

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**Fig. (4).** The spatiotemporal patterns with five random crossing positions.

**Fig. (5).** The fundamental diagrams with different crossing frequencies (a), Uniform and random crossing positions (b) and different numbers of crossing positions (c)
region, traffic is under the double influence of crossing time and frequency. In the middle and high density, mean flow and velocity of $t=120s$ is much lower than that of others. Broadly, compared with the crossing frequency, the influence of crossing time of each cross on traffic capacity and efficiency is much greater, especially in crowded areas, so policies are needed to restrict the behaviors of jaywalking. For example, crossing the street partially under the guidance of traffic light or police may be required.

2) Influence of distribution of crossing position. Crossing positions can be random or uniform. But which is more proper? The corresponding fundamental diagram is shown in Fig. (5b), where five crossing positions and three random cases are selected. It can be seen the distribution of crossing position has little influence on vehicle flow under fixed $n$. An important enlightenment to the road construction can be taken that in constant road length, the settings of the traffic light mainly depends on real circumstances instead of doing that apart same.

3) Influence of the number of crossing positions. Under the same conditions, let pedestrian cross the road through a position or several positions with a short time, which is better? Fig. (5c) gives the fundamental diagram under different crossing position number $n=1, \ldots, 6$ with fixed road length. Here, $t_{\text{total}}=60s$ and $t_1=120s$ remain constant. It is easily seen that larger $n$ could lead to relatively larger flow and velocity, especially in low and middle density region, and the saturated flow plateau gradually disappears. In comparison with the case of $n=6$, the maximum flow of $n=1$ drops nearly 30%. On the one hand, to some extent, the decreasing crossing time in every position reduces the possibility of brake or deceleration; on the other hand, vehicle starting delay time in a long queue is much more than that in a short queue. Whereas it should be noted that in the high density ($\rho>0.4$), the mean velocity and flow of $n=2$ are a litter lower than other cases, which means in such case, it is very necessary to consider the influence of both the crossing time and the number of positions.

CONCLUSION

Based on the numerical investigation and discussion presented in this paper, some important conclusions can be drawn as follows: (1) The saturated flow appears in the fundamental diagram. Its value depends obviously on the increasing crossing time and crossing frequency, which lead to the sudden drop in mean velocity and flow; (2) In different densities, the influence of $t$ and $t_1$ on traffic is also different; (3) For the constant total crossing time and time interval for the next crossing, the increase of crossing frequency expands the density range corresponding to the saturated flow, especially in crowded areas, the increase of single crossing time can decrease the actual capacity of road obviously; (4) The distribution of crossing position, random or uniform, shows little influence on traffic; (5) Generally, under the same conditions, a decentralized crossing at several positions is superior to a centralized crossing at a single position with a long time.

Finally, the method and some results can be extended to other human factors. We hope that our results here can be useful to the signal timing dial and road construction.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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