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The influence of aggressive drivers on the properties of a stochastic traffic model

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Abstract. In this paper, we study numerically the influence of aggressive driving on the properties of the stochastic Nagel-Schreckenberg model, such as the traffic flow and the probability of car accidents. Hence, we find that these properties depend enormously on both the density ρ and the fraction f of aggressive drivers. In addition, by studying the spatio-temporal organization of the vehicles, we show that at very low density, the traffic state transits from "ordinary" free traffic to "queueing" phase when we increase the fraction f. At relatively high density, the transition from congested traffic to queueing phase may also occur.

PACS. 89.40.-a Transportation – 02.60.Cb Numerical simulation; solution of equations – 45.70.Vn Granular models of complex systems; traffic flow – 89.75.Fb Structures and organization in complex systems

1 Introduction

Recently, the phenomenon of aggressive driving has attracted public interest because it is considered as one of the major causes of crashes. In general, aggressive drivers tend to exceed safe speed limits, cut off other drivers, force their way ahead and follow too closely their predecessors. These two last kinds of driving are generally the result of accelerating very quickly and seldom slowing down. It is important to note also that aggressive drivers are not reporting exceeding the maximal speed limit, but rather exceeding the limit which they perceive to be safe on a given road. Until now, there has been little physics research on aggressive driving behavior. The purpose of this paper is then to give further insight into aggressive driving and its influence on the properties of a stochastic traffic flow model. We shall use a basic cellular automaton (CA) model that describes single-lane traffic flow; that is the Nagel-Schreckenberg (NS) model [1]. Under the NS model, different traffic features have been investigated (see [2,3] for reviews): the emergent traffic jams [4], the spatio-temporal organization of vehicles [5,6], the occurrence of car accidents [11,16], etc.

In earlier studies of the disorder asymmetric exclusion process "ASEP" (by Krug and Ferrari [7] and Evans [8]) and as well as the NS model with particle-wise disorder [9], it was shown that these models can exhibit the formation of platoons of fast particles behind the slow ones. In contrast to the models with one type of particle, the quenched randomness in the random braking in the NS model (or quenched particle-hopping rates in ASEP) can lead to the formation of platoons at low-density rather than at a high density of vehicles. In such disorder models, the conditions which can lead to the formation of platoons are (a) slow particles are sufficiently rare and (b) if the density of vehicles is sufficiently low (for more details see [2]). In this paper, we shall study the effect of varying the fraction of aggressive drivers on the traffic flow, on the probability of car accidents as well as on the traffic states of the system.

The paper is organized as follows. In Section 2, we define the model. In Section 3, the results of computer simulations are presented. We study the influence of aggressive drivers on the traffic flow. We investigate also the probability of car accidents in order to achieve how can aggressive drivers be dangerous on the roads. A detailed description of the spatio-temporal organization of the vehicles for several densities and different fractions of aggressive drivers is also presented. In Section 4, we present some discussions of our results. Finally, we conclude with a summary in Section 5.

2 Definition of the model

The NS model is a probabilistic CA of traffic flow on a one-lane roadway. It consists of N cars moving on a one-dimensional lattice of L cells with periodic boundary conditions (the number of vehicles is conserved). Each cell is either empty, or occupied by just one vehicle with velocity $v = 1, 2, ..., v_{max}$. We denote by $x(k, t)$ and $v(k, t)$ the

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position and the velocity of the kth car at time t respectively. The number of empty cells in front of the kth car is denoted by $g(k, t) = x(k+1, t) - x(k, t) - 1$ and called hereafter as the gap. Space and time are discrete. At each discrete time-step $t \rightarrow t+1$ the system update is performed in parallel for all cars according to the following four subrules:

R_1: Acceleration: $v(k, t+\frac{1}{3}) \leftarrow \min(v(k,t)+a, v_{\max})$. R_2: Slowing down (due to other cars): $v(k, t+\frac{2}{3}) \leftarrow \min\left(v(k, t+\frac{1}{3}), g(k,t)\right)$. R_3: Randomization: $v(k, t+1) \leftarrow \max\left(v(k, t+\frac{2}{3}) - 1, 0\right)$ with probability p. R_4: Motion: the car is moved forward according to its new velocity, $x(k, t+1) \leftarrow x(k, t) + v(k, t+1)$.

The NS model is fairly simple (in the standard NS model $a = 1$), which nevertheless has been shown to be able to reproduce real-life traffic phenomena for highways such as the spontaneous formation of jams.

As in reference [9], we shall characterize a careful driver by lower acceleration capability ($a_1 = 1$) and a higher value of the deceleration probability p_1; these drivers tend to brake more often and accelerate slowly. In addition, aggressive drivers who accelerate quickly correspond not only to a smaller value of p_2 [9], but also to a higher acceleration capability ($a_2 > 1$).

Recently, CA models have been extended to study the occurrence of car accidents [11–16]. Boccara et al. [11] were the first authors to propose conditions for car accidents to occur in the deterministic NS model. The first condition is that the number of empty cells in front of the car (gap) is smaller than the speed limit; the second condition is that the car ahead is moving; and the last condition is that the moving car ahead is suddenly stopped at the next time step. Using these conditions, the exact results of the probability of a car accident are obtained in special cases [12,13]. General numerical results for the probability of car accidents are reported in the nondeterministic NS model [14]. In the Fukui-Ishibashi model [10], the probability for an accident to occur is found to be proportional to the product of the fraction of stopped cars and the traffic flow [15].

Very recently, new conditions for the occurrence of car accidents based on the delayed reaction time of the careless driver were established [16]. The characteristic of this careless driver is that when the car ahead is moving, he expects it to move again at the next time step, and therefore his braking manoeuvre is done only after a delayed reaction time τ. The dangerous situation (DS) between two neighbourhood cars k and $k+1$ will exist at time $t+1$, if the following events occur. (i): the distance to cover by the kth car during the time τ is superior to its gap. (ii): the $(k+1)$th car is moving at time t. (iii): the $(k+1)$th car suddenly stops at the next time step. These three conditions could be reduced to simple expressions as:

$$\text{i) } \tau v(k, t) > g(k, t), \ \text{ii) } v(k+1, t) > 0, \ \text{iii) } v(k+1, t+1) = 0. \quad (1)$$

We notice that an aggressive as well as a careful drivers can cause accident (with probability p') if the three previous conditions occur.

The car accidents caused by an abrupt deceleration can also be derived. Suppose that at time t the car ahead with speed $v(k+1, t)$ does an abrupt deceleration. At time $t+1$ its velocity will be reduced to $v(k+1, t+1)$. If the distance covered during the delayed reaction time τ of the car following is enough to reach the next time position of the car ahead, then a DS occurs on the road. Hence, the conditions for the occurrence of DS with respect to abrupt deceleration of the car ahead are as follows.

$$\text{i) } \tau v(k, t) > g(k, t) + v(k+1, t+1), \ \text{ii) } v(k+1, t) - v(k+1, t+1) \geq v_d. \quad (2)$$

If the above two conditions are satisfied then a car accident will occur at time $t+1$ with probability p'. The parameter v_d is the deceleration limit beyond which a risk of the occurrence of DS exists. We should point out that the DS conditions of equation (2) should reduce to the conditions in equation (1) if $v(k+1, t+1) = 0$ and $v_d = 1$.

3 Simulations and results

We simulate one-lane of traffic using the NS model with a one-dimensional lattice of length $L = 10^4$ sites with closed boundary conditions. The density ρ is defined as $\rho = N/L$, where N is the number of cars. The model parameters are given by the maximal velocity of the cars $v_{\max} = 5$, the braking probability of careful drivers $p_1 = 0.5$, the braking probability of aggressive drivers $p_2 = 0.1$. The acceleration of careful drivers is given by $a_1 = 1$ whereas that of aggressive drivers is chosen as $a_2 = 2$. The parameter f will designate the fraction of aggressive drivers among the vehicles. Finally, we shall assume that the delayed reaction time of the careless drivers is given by $\tau = 1s$ and we choose for the deceleration limit the value $v_d = 2$.

3.1 Traffic flow and probability of car accidents

3.1.1 Traffic flow

Among the interesting physical properties in traffic systems is the flow J which measures the number of vehicles crossing a detector site per unit time. From Figure 1, we show the dependence of the traffic flow J on the density of vehicles ρ, for different values of the fraction f of aggressive drivers. For each fraction f of aggressive drivers, the fundamental diagram is composed of two branches. The increasing branch is the characteristic of the laminar traffic where the vehicles are in a free flow regime. The second branch which is indicated by a decreasing traffic flow describes the congested traffic. These two different regimes are separated by a "critical density" $\rho_c(f)$ which is an important characteristic of the fundamental diagrams. This can evaluate the transit capacity of the vehicular traffic. We point out that we have put the words, critical density, in quotation marks because there is no consensus concerning the existence of phase transition in the case of

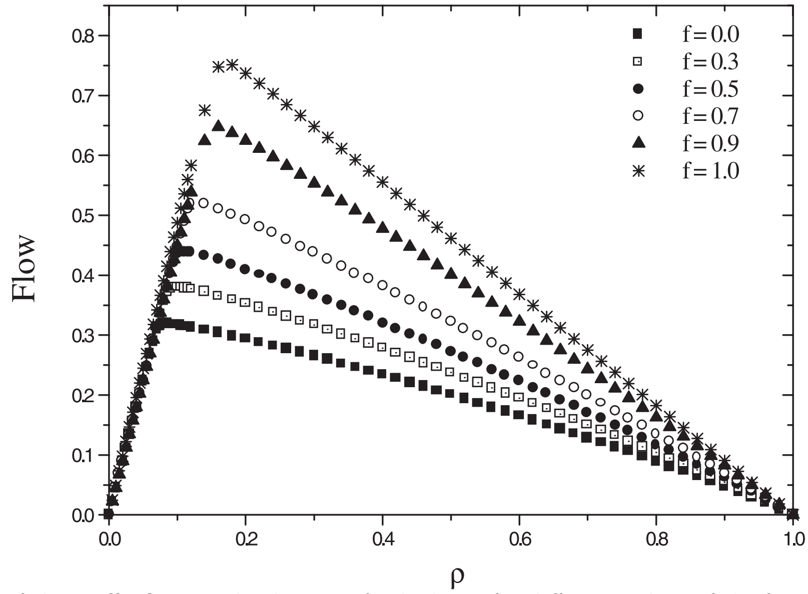


Fig. 1. The dependence of the traffic flow on the density of vehicles ρ, for different values of the fraction f of aggressive drivers.

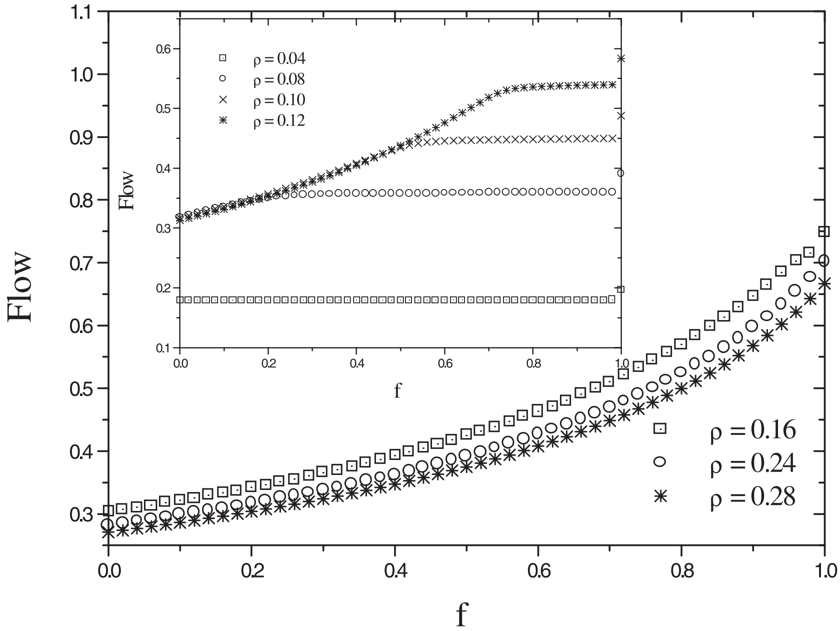


Fig. 2. The dependence of the traffic flow on the fraction f of aggressive drivers, for different vehicle densities ρ.

the nondeterministic NS model [17-20]. However, in the deterministic case of the NS model, $\rho_c = 1/(v_{max} + 1)$ is a critical density which corresponds to the transition from a free-flow regime to a congested regime where start and stop waves dominate the dynamics of the system. This transition is usually viewed as a second-order phase transition [21].

The increasing of $\rho_c(f)$ with the fraction of aggressive drivers indicates that the free flow regime is more and more broadened as the fraction of aggressive drivers is increased. Let us first study the two limits of the density, $\rho \to 0$ and $\rho \to 1$. At very low density, we observe in the fundamental diagram, that all the slopes are identical for $f < 1$. In fact, in the laminar phase, the velocity of the vehicles is given by $v_{max} - p_1$, i.e., $J_1 = \rho(v_{max} - p_1)$, $\forall f < 1$. The behavior of the system is determined by the slow vehicles (the careful drivers). One can observe also from Figure 1 that the fundamental diagram has a different slope when $f = 1$ than those for $f < 1$. Indeed, in the case $f = 1$ no slow vehicles exist in the circuit and the flow is given by $J_2 = \rho(v_{max} - p_2)$ which is superior than J_1, $\forall f < 1$. In the other limit where $\rho \to 1$, the asymptotic velocity of vehicles is given by $(1-f)(1-p_1) + f(1-p_2)$. This should explain the fact that the slopes in the fundamental diagram increases with the fraction f.

To investigate more clearly the influence of aggressive drivers on the traffic flow we plotted in Figure 2, the dependence of J on the fraction f for several fixed

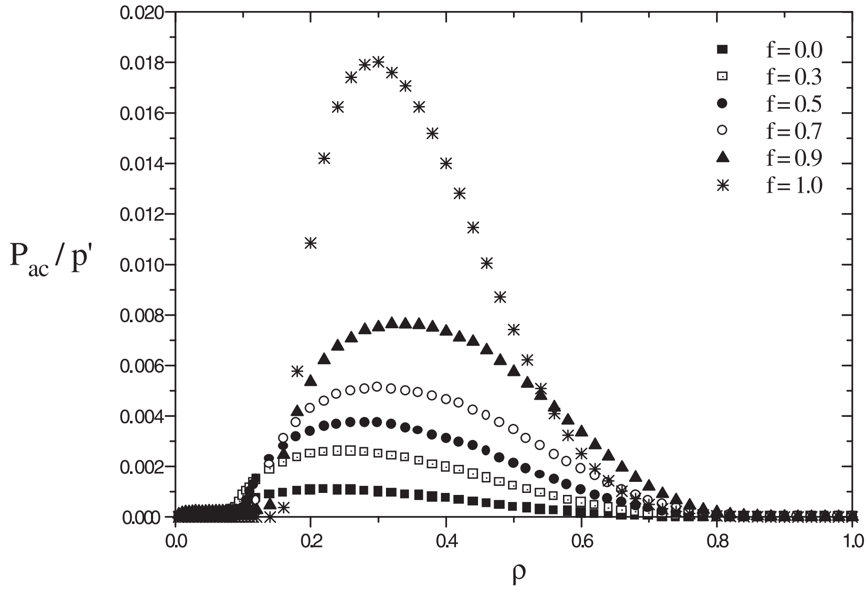


Fig. 3. The probability for an accident to occur P_{ac} (scaled by p') caused by an abrupt deceleration as a function of density ρ, for different values of the fraction f of aggressive drivers.

vehicle densities ρ. We can distinguish three different regions where different behaviors of the properties of the system can occur: region 1 where $\rho < \rho_c(0)$, region 2 where $\rho_c(0) < \rho < \rho_c(1)$ and region 3 where $\rho > \rho_c(1)$. The numerical values of the "critical densities" in the pure cases are $\rho_c(0) \approx 0.077$ and $\rho_c(1) \approx 0.165$.

For fixed very low density (region 1) and for the pure case $f = 0$, the traffic state is laminar and the velocity of vehicles is given by $v_{max} - p_1$. The traffic flow J for the disorder case $0 < f < 1$ remains unchanged; i.e. $J = \rho(v_{max} - p_1)$. For relatively high density (region 2) and $f = 0$, a jamming state takes place where clusters of stopped cars (jams) appear in the system. With increasing f, the traffic flow J increases until some limit f_0 beyond which J becomes constant ($J = \rho(v_{max} - p_1)$, see the inset of Fig. 2). Thus, one can expect that a transition from jamming state to laminar phase can occur at $f = f_0$. The limit f_0 increases with the density until it becomes equal to 1 for exactly $\rho = \rho_c(1)$. For example, we found $f_0 \approx 0.24$ for $\rho = 0.08$ and $f_0 \approx 0.58$ for $\rho = 0.10$. We remark that, in the pure case $f = 1$ the flow increases abruptly. As we have explained before, the flow in the pure case $f = 1$ is superior to that of the disorder case. In fact, the behavior of the system is determined by the slow cars even if only one slow car is present in the circuit. For high density (region 3), the system is congested at all values of the fraction f. Thus, the monotonous increase of the flow with f means that jams have a tendency to dissolve with the presence of the aggressive drivers; but never die out.

3.1.2 Probability of car accidents

The next step is to examine the consequences of the aggressive driving in terms of the probability of crashes. In Figure 3, we plotted the probability *per vehicle* and *per time step* for an accident to occur P_{ac} caused by an abrupt deceleration. As P_{ac} is proportional to the probability p', we shall study the quantity P_{ac}/p' and leave the probability p' unspecified. For each fraction f of aggressive drivers the dependence of P_{ac} on the vehicle density is described as follows. At low densities, the car accidents will not occur until the density reaches the "critical density" $\rho_c(f)$. This is because in the free flow region ($\rho < \rho_c(f)$) the mean gap between cars is superior to the maximal speed $v_{\max}$ and thus no cars decelerated abruptly. For a density ρ above $\rho_c(f)$, P_{ac} increases with the density, reaches a maximum, and then decreases with further density. In the very high density region, P_{ac} decreases rapidly and vanishes beyond a density limit $\rho_h(f)$. In the disorder case, the effect of aggressive drivers on the risk of accident is noticeable at high densities. That is, an increase in aggressive driving will result in an increase of risk of accidents.

In Figure 4, we plotted the probability of car accidents, caused by an abrupt deceleration of the vehicles, as a function of the fraction f of aggressive drivers for several fixed vehicle densities ρ. At very low density (region 1), no accident can occur until the fraction f exceeds a threshold value f_1. For example, we found $f_1 \approx 0.58$ for $\rho = 0.04$. At relatively high density (region 2), an interesting behavior of the variation of the probability of a car accident is found. An increase of the fraction f of aggressive drivers leads to an noticeable increasing of the probability of car accident. This increase ends with a local maximum of P_{ac} at certain value f_2 which increases with the density. For example, we found $f_2 \approx 0.04$ for $\rho = 0.08$ and $f_2 \approx 0.24$ for $\rho = 0.10$. With further increase of aggressive drivers, the probability P_{ac} decreases until certain value f_1 where a minimal possible probability of car accident can exist. The values of f_1 are found to increase with the density and we have for example, $f_1 \approx 0.60$ for $\rho = 0.08$ and

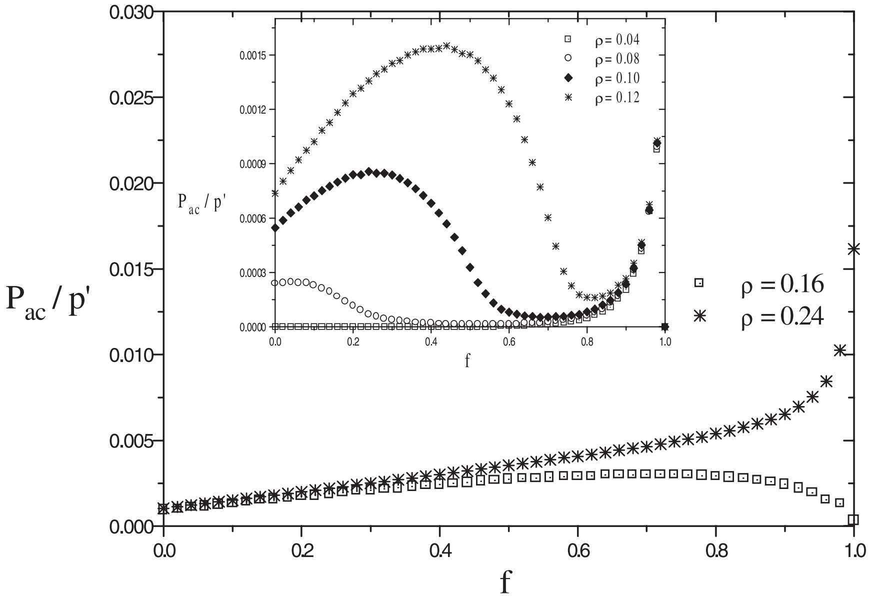


Fig. 4. The probability of car accidents, caused by abrupt deceleration of the vehicles, as a function of the fraction f of aggressive drivers for different values of the vehicle density ρ.

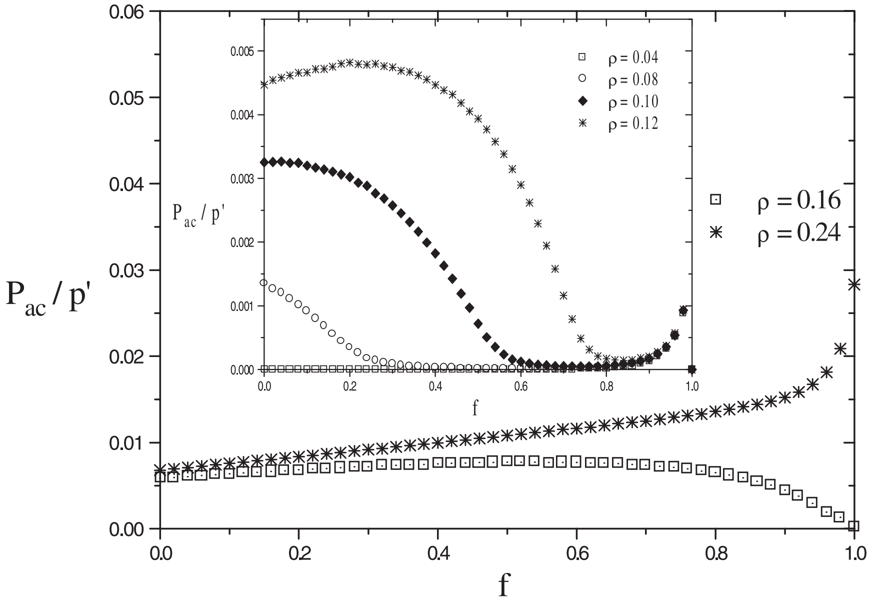


Fig. 5. The probability of car accidents, caused by stopped vehicles, as a function of the fraction f of aggressive drivers for different values of the vehicle density ρ.

$f_1 \approx 0.70$ for $\rho = 0.10$. Furthermore, just above f_1, a fast increase of the risk of accidents occurs when increasing the fraction f. As for the traffic flow, a discontinuity of the variation of P_{ac} is found in the vicinity of $f = 1$. In fact, P_{ac} is largely superior to zero for $f \lessapprox 1$ whereas it vanishes at exactly $f = 1$. For the high density region 3, P_{ac} increases monotonously with f.

Finally, we show in Figure 5, the variation with density of the probability of car accidents caused by stopped vehicles (Eq. (1)). This is quite similar to that corresponding to an abrupt deceleration (Eq. (2)). The main difference is that an introduction of few aggressive drivers may decrease the risk of accident caused by stopped vehicles, at very low densities. This is not the case when we consider only the accident caused by abrupt decelerations when a few aggressive drivers may increase the probability of accident.

3.2 Spatio-temporal organization of vehicles

Recent empirical investigations reveal that the density dependence of traffic flow alone, cannot give the whole information on the traffic system [22]. To get information on

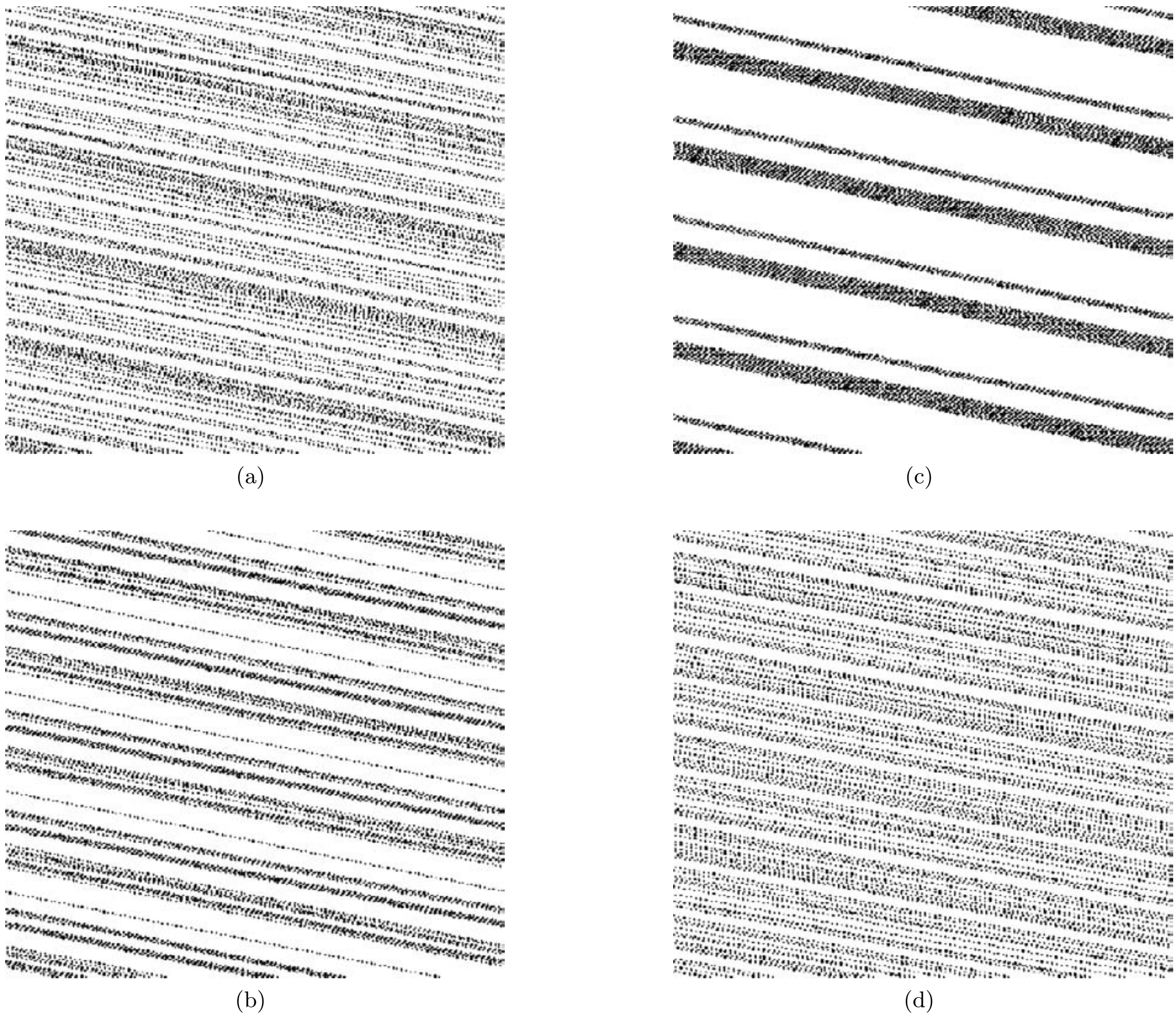


Fig. 6. Space-time diagram of the model with size $L = 500$ for $\rho = 0.04$. (a) $f = 0$, (b) $f = 0.5$, (c) $f = 0.9$ and (d) $f = 1.0$. The horizontal direction is space and the vertical (down) is (increasing) time.

the microscopic structure of traffic streams, one can determine the spatio-temporal organization of the vehicles in the highway [5,6]. This microscopic investigation can be obtained by plotting the space-time diagram and measurement of the distance and time headways. The distance headway (DH) is defined as the distance from a selected point on a car to the same point on the following car. The time headway (TH) is defined as the time interval between the departures (or the arrivals) of two successive cars recorded by a detector placed at fixed position on the highway. We shall confined this study to three different densities $\rho = 0.04$, $\rho = 0.10$ and $\rho = 0.24$ which correspond respectively to regions 1, 2 and 3.

3.2.1 Space-time diagrams

For a very low density ($\rho = 0.04$), the space-time of Figure 6a corresponding to the pure case $f = 0$ shows a laminar traffic, in which cars move freely. For a higher fraction f of aggressive drivers, the system displays the queueing of vehicles (Figs. 6b–c). This self-organization into a queueing phase was first observed by Ktitarev et al. [9] where a power-law decay distribution of gaps is found for some critical density. Let us note that the queue is increasingly long when we increase the fraction of aggressive drivers. Nevertheless, for $f = 1$, i.e. all the vehicles are aggressive, the space-time of Figure 6d indicates that no queueing phase is present and the traffic is simply laminar. The reason for this is the absence of slow vehicles, since a queueing behavior is always produced by platoons of fast vehicles (aggressive) behind the slow vehicle (careful).

For a higher density ($\rho = 0.10$), the space-time of Figure 7a corresponding to $f = 0$ shows a jamming state where there coexist free flow regions and jams. With an increasing fraction f, the traffic state changes from jamming to free flow traffic (Fig. 7b). Moreover, a queueing

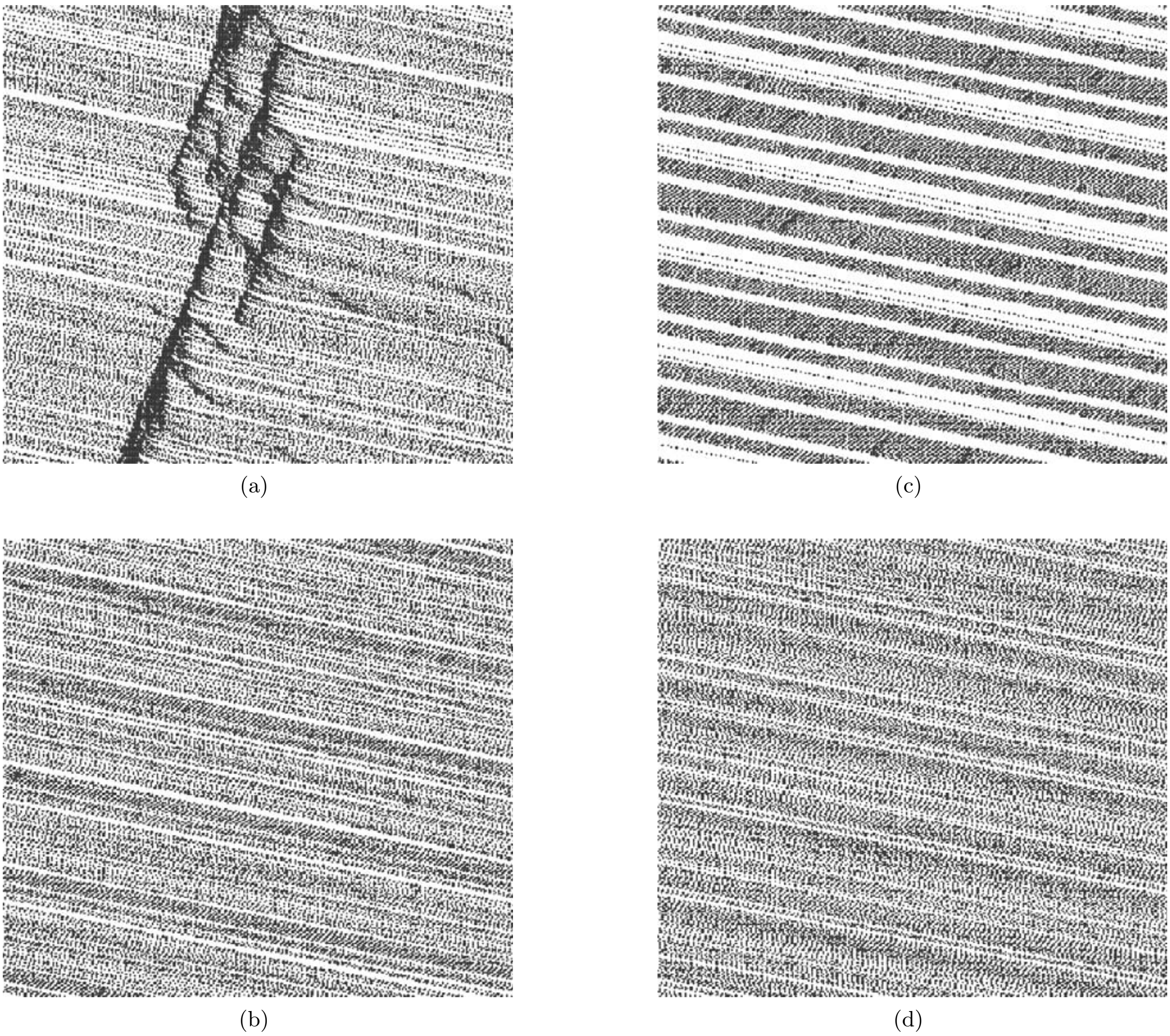


Fig. 7. Space-time diagram of the model with size $L = 500$ for $\rho = 0.10$. (a) $f = 0$, (b) $f = 0.5$, (c) $f = 0.9$ and (d) $f = 1.0$.

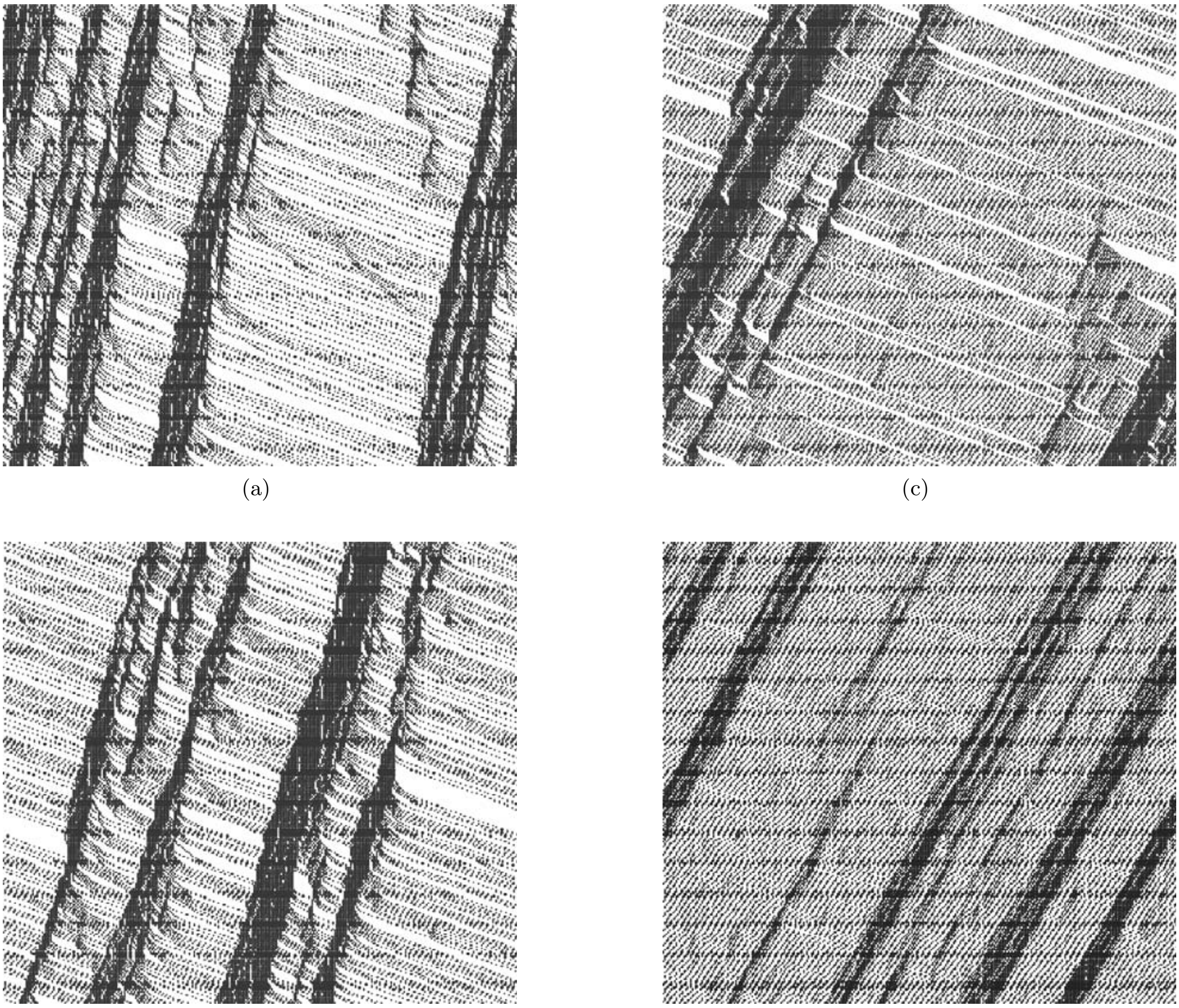
state may also appear if one increases enough the number of aggressive drivers (Fig. 7c). As before, when there are no careful drivers ($f = 1$), the state becomes free flow traffic (Fig. 7d).

For high density ($\rho = 0.24$), start-stop waves dominate the system at all values of the fraction of aggressive drivers (Figs. 8a–d). However, we can observe that the density of the cluster jams decreases as the fraction f increases.

3.2.2 Distance headway distributions

Next, we shall examine the distance headway distributions of the vehicles for different fractions of aggressive drivers. For a very low density ($\rho = 0.04$) and $f = 0$, smaller DH are strongly suppressed and the DH distribution displays a maximum which is considered as the most probable DH in the free regime. This maximum is located at $d \approx 10$; thus indicating that the drivers tend to drive with larger DH in the free flow regime. As f exceeds the vanishing value, the DH distribution exhibits a peak at $d_1 \approx (v_{\max} + 1)$ (Fig. 9a). This peak becomes more and more pronounced with an increasing fraction f. For $f \lessapprox 1$, this peak approaches the Dirac function $\delta(\tau - d_1)$. Therefore, the appearance of higher peaks in the DH distribution for large f adequately proves the existence of the queueing phase. Moreover, the increase of the height of the peaks with f indicates that the size of the platoons of aggressive drivers increases, as it was shown from Figures 6b and 6c. Note that the DH distribution of the pure case $f = 1$ resembles that of the other pure case $f = 0$ but not the disorder case $0 < f < 1$. Yet, platoons might not form at all in the case where $f = 0$ or $f = 1$ since no different kind of vehicles exist.

For a higher density ($\rho = 0.10$), the distance headway distribution depends enormously on the fraction of



(a) (c) (b) (d)

Fig. 8. Space-time diagram of the model with size $L = 500$ for $\rho = 0.24$. (a) $f = 0$, (b) $f = 0.5$, (c) $f = 0.9$ and (d) $f = 1.0$.

aggressive drivers (Fig. 9b). Hence, when $f = 0$, we observe clearly that the distribution presents two peaks. The first peak is located at $d = 1$ which represents vehicles in jams and the second at large DH which represents vehicles in free flow regime. Thus, there is a coexistence of jams and free flow. As we increase the fraction of the aggressive drivers, the height of the first peak decreases more and more until it disappears whereas that of the other peak increases more and more until becomes more pronounced. This behavior confirms well that a transition from a jamming to a queueing state may occur if one increases enough the fraction of aggressive drivers. Finally, for $f = 1$, the DH distribution displays the characteristic of free flow regime because the density of vehicles ($\rho = 0.10$) is lower than $\rho_c(1)$.

For high density ($\rho = 0.24$), only the first peak remains and high Distance-headways are suppressed when the fraction f is zero; showing therefore that a congested traffic takes place where a start-stop regime dominates the system (Fig. 9c). Moreover, the second peak of higher DH reappears as the fraction of aggressive drivers becomes important. Indeed, the height of the first peak decreases whereas that of the second peak increases when f increases; leading therefore to an increase in the traffic flow.

3.2.3 Time headway distributions

For the very low density ($\rho = 0.04$), we plotted in Figure 10a the TH distribution of the vehicles for different fractions of aggressive drivers. Hence, for $f = 0$ the TH distributions exhibit a broader peak structure at TH, $\tau = 2s$. The broadness of the peak indicates that a large range of DH can be taken by cars driving at $v \approx v_{max}$. This is the characteristic of the free flow regime with a higher randomization p. When the fraction f exceeds some

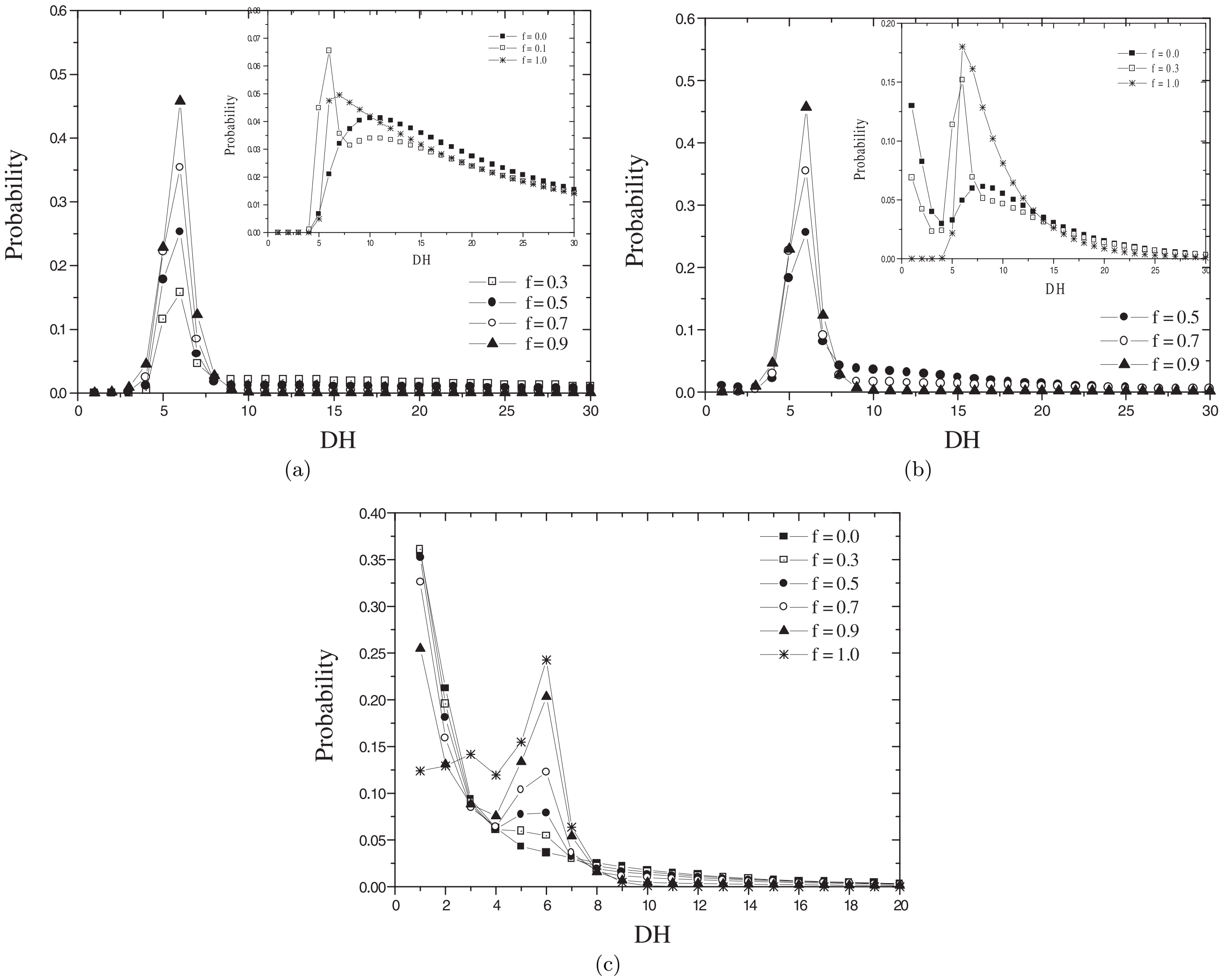


Fig. 9. Distance headway distributions of the vehicles for different fractions of aggressive drivers. (a) $\rho = 0.04$, (b) $\rho = 0.10$ and (c) $\rho = 0.24$.

threshold value f_t, the peaks in the TH distributions will be located at $\tau = 1s$. These short time-headways correspond to platoons of some vehicles travelling with a rather high speed. Moreover, as for the DH, the height of the peaks increases with f, which justifies again the increasing size of the platoons. Finally, the TH distribution of the case where $f = 1$ exhibits a peak at $\tau = 2s$; indicating that no queueing behavior exists.

In congested traffic and for high values of f, the short time-headways still remain, showing the presence of platoons but the asymptotic behavior is rather increasingly wide; reflecting the dynamics of vehicles inside the jams. Moreover, we can observe from Figures 10b and 10c, that the threshold limit f_t decreases with the increasing density of vehicles. The reason is the limitation of the highway capacity of finite length caused by high densities of vehicles.

4 Discussion

All the above results concerning the traffic flow and the probability of car accidents could be well understood after studying the spatio-temporal organization of the vehicles. In contrast to the disorder case $0 < f < 1$, the stationary states of the pure cases $f = 0$ and $f = 1$ don't present the formation of platoons since a different kind of vehicles does not exist. Because of the randomization step R_3, the dynamics of both the pure models $f = 0$ and $f = 1$ are not substantially different. In contrast to the Fukui-Ishibashi model [10], one finds spontaneous jam formation in the two pure models (see [23] where a high acceleration variant NS model with $a = v_{max}$ is proposed).

The behavior of the whole system can be distinguished according to three different regions of the density. Thus, we find that at very low density (region 1), the

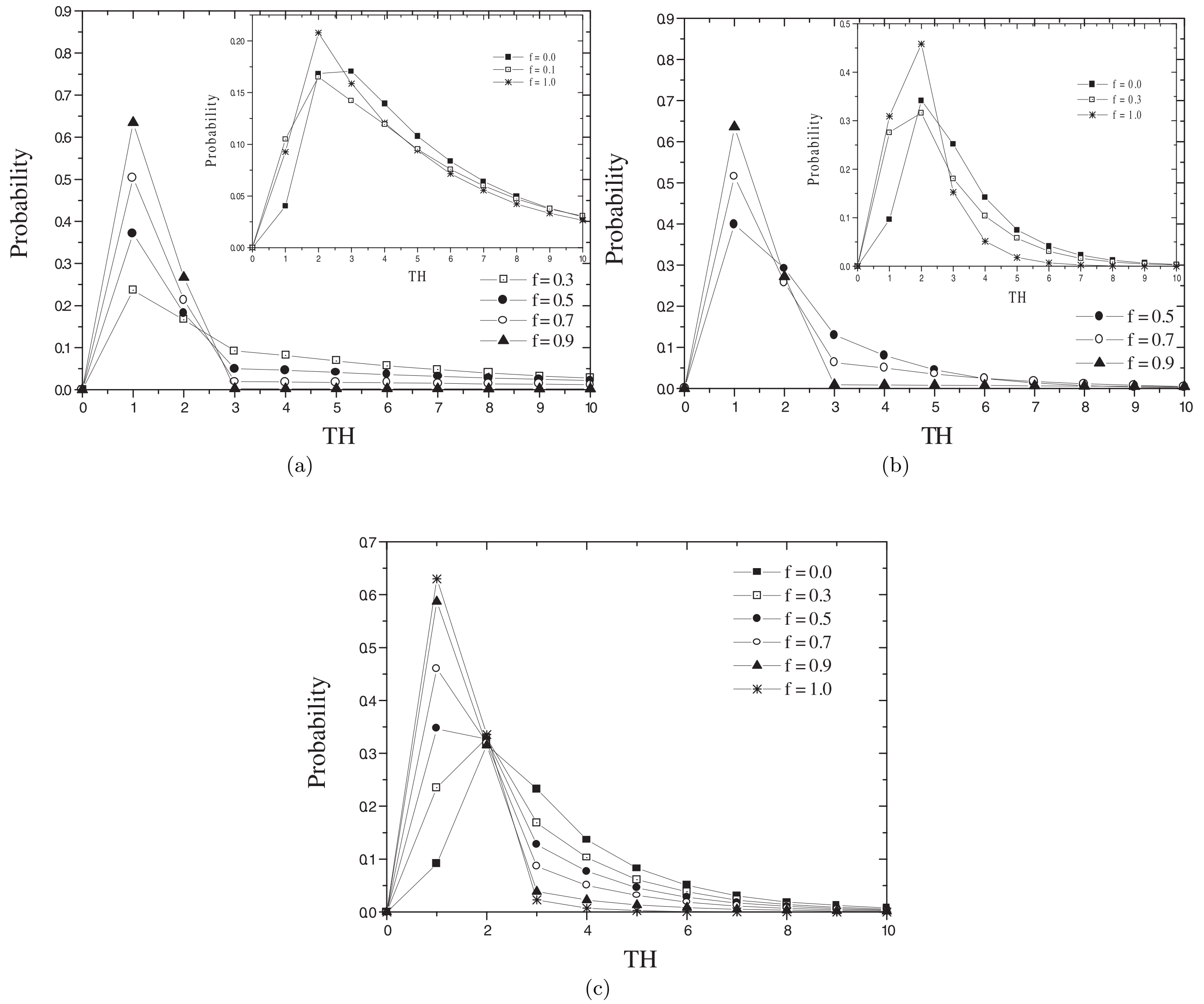


Fig. 10. Time headway distributions of the vehicles for different fractions of aggressive drivers. (a) $\rho = 0.04$, (b) $\rho = 0.10$ and (c) $\rho = 0.24$.

transition from "ordinary" free flow to the "queueing" phase occurs when we increase the fraction of aggressive drivers. This "queueing" phase is characterized by the formation of platoons of aggressive drivers behind the careful ones. The aggressive drivers are driving with maximal speeds, short time headways and keeping the distance headways $d \approx (v_{\max} + 1)$. However, these reorganizations of vehicles in platoons have no effect on the traffic flow. The behavior of the system is determined by the slow cars. It is important to note also, that the increased acceleration capability attributed to aggressive drivers does not cause any formation of platoons but gives only quantitative changes to the properties of the traffic model such as the enhancement of the flow. The platoon reorganization of the vehicles can lead to an increase of the risk of accidents especially when f is large. The head of the platoon (careful driver) slows down frequently because of his large randomization. Thus, it is highly likely that the successor vehicle in the platoon (aggressive driver), which has a weak randomization and high acceleration capability, hits his predecessor. This can lead to a chain of overreactions and crashes for all the vehicles of the platoon.

At a higher density (region 2), the transition from the jamming state to the queueing phase occurs when the fraction f is increased. This transition is usually accompanied with an increase of the flow. Indeed, the presence of aggressive drivers in the circuit tends to dissolve the jams. These jams dissolve completely when the fraction f reaches the value f_0. Beyond f_0, the flow is constant and the traffic state is the queueing phase. Thus, the limit f_0 should be the fraction of aggressive drivers where a transition from jamming to free flow states takes place. The variation of the probability of car accidents, P_{ac}, can be discussed in terms of the transition of the traffic states. Let us start with the case $f = 0$. The variation of P_{ac} with the density can be described as follows. Suppose that the state of the traffic system is congested. During the transition from congested to free flow, P_{ac} increases, reaches a maximum at certain density, ρ_0 ($\rho_0 > \rho_c(0)$), and then decreases. Recall that, at fixed density, the increasing of f leads to the transition from jamming to free flow traffic. Hence, for a fixed density ρ, one can expect the variation of P_{ac} with f (provided that $f < f_1$) to be as follows. P_{ac} decreased with f if ρ is lower than ρ_0; but increased, reached a maximum and then decreased if ρ is greater than ρ_0. Significantly increasing f ($f > f_1$), causes the queues of platoons become long; leading therefore to an enhancement of P_{ac}.

At high density (region 3), the traffic state is usually congested for all values of f. However, with increasing f, the jams have a tendency to dissolve which causes an increase of both the flow and the probability of car accidents. In general, the presence of the aggressive drivers on a highway produces some fluidity in the traffic which becomes more and more important as the fraction f increases.

5 Conclusion

We have investigated numerically the influence of aggressive driving on the properties of the traffic flow model described by the cellular automata NS rules. Although the properties of the disorder case and those of pure cases seem to be qualitatively similar, some detailed investigations reveal that traffic states change with respect to the number of aggressive drivers present in the circuit. When we increase the fraction of aggressive drivers, the traffic state transits from “ordinary” free traffic to a “queueing” phase provided that the density of vehicles is very low. During this transition the flow remains constant but the probability of car accidents may increase for large f, due to the presence of platoons. For a higher density, the transition from congested traffic to a queueing phase may also occur. This transition is usually accompanied by an increase in the flow. For high density, the traffic state is congested for all values of f, but the traffic flow as well as the probability of car accidents increase monotonically.

From realistic traffic, it is very known that aggressive driving increases not only the traffic flow but also the number of crashes. This agrees with our findings. However, the present study shows also that, at low densities, the risk of crashes could decrease when the fraction f increases. Strictly speaking, we cannot expect that in real traffic a fraction of aggressive drivers can reduce the probability of car accident. We think that the reason for the above unrealistic result arises from the fact that we did not introduce into the model all the aspects connected to aggressive driving such as exceeding safe speed limits, cutting off other drivers, etc.

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