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THE EFFECT OF ARBITRARY STOPPING OF PUBLIC VEHICLES ON FLOW OF TRAFFIC IN ONE-LINE STREETS

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Abstract. Cellular automaton method was used to simulate the flow of cars in typical streets in Indonesia. In this streets, arbitrary stopping of vehicles at anytime along the streets might happen and violating the traffic regulation by the drivers frequently occurs. This study was restricted to a one-line street passed by two types of vehicles: private car and public vehicles, and a car/vehicle cannot advance the preceding ones (car following model). Arbitrary stopping of public vehicles leads to occurrence of vehicle clustering along the line. The number of main clusters equals to the number of the public vehicles. The total distance traveled by all vehicles during iteration approximates a periodical function, with a period is equal to the stopping duration of the public vehicle. The power spectrum of this movement scales as $f^{-\alpha}$, with $\alpha = 2$ and seems to be universal. The distance traveled in unit volume of fuel consumption was also investigated and showed that this distance decreases monotonically when the ratio of public vehicle to the total number of vehicles increases.

Keywords: Cellular automata; traffic flow; public vehicle; one-line street; fuel consumption

1.0 INTRODUCTION

In big cities of most developing countries, traffic flow has become a critical problem to be solved. The increase in number of vehicles which surpasses the rate expansion of the length of streets and violating the traffic regulations by the drivers results in bunching of cars at various parts of the streets. This implies disadvantages in many aspects of our daily life like ineffectiveness in energy consumption, air and sound pollutions, etc.

Interestingly, traffic process also contains rich of physical phenomena and has attracted considerable attention of physicists [1 – 9]. Several simulation methods have been proposed to understand the physics of traffic. Some considered cars in a high way as interacting particles, like a fluid flow in a channel [1]. Both kinetic [1 – 2] and continuous approaches [2 – 4] have been introduced to solve this problem. Nagel and Schreckenberg [5] introduced a stochastic cellular automaton (CA) model to simulate freeway traffic. They showed that a transition from laminar traffic flow to start-stop waves occurs with increasing car density. Musha and Higuchi have shown that traffic flow in a highway shows a $1/f$ power spectrum by measuring directly the

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traffic flow in a real highway [6]. Density wave in traffic flow from the point of view of hydrodynamic models has also been introduced [7 – 8]. Nagatani investigated traffic flow in freeway using various CA models [9]. One dimension asymmetric simple-exclusion model with parallel dynamics was extended to take into account the car velocity.

Different models were also introduced recently, for example, probabilistic models using master equation was discussed by Mahnke and Pieret [10]. Optimal velocity model [11] successfully described the dynamic formation of traffic congestion. The transition from free flow to congested flow is understood as a kind of phase transition. In this model, the driver looks only at the preceding vehicle. Improvement to this model when the driver also looks at the vehicle that follows was also studied [12]. Nagatani proposed a model that driver looks at the next preceding vehicle as well as the preceding vehicle [13]. Lenz, Wagner, and Sollacher discussed a model in which a driver looks at many vehicles ahead of him [14].

However, the cases investigated by many authors were mostly restricted to freeway traffics. Studies on traffic processes in common streets like city streets are rarely reported. In particular, there is no investigation on the traffic process in big cities of several developing countries. For example, in most Indonesian cities, the street lines are passed by private cars and public vehicles and usually the public vehicles might stop arbitrarily along the street when there are passengers dropping from or entering the vehicle. In one-lane streets, this arbitrary stopping causes the stopping of following vehicles to imply the formation of vehicle clusters. At high vehicle densities, this act generates a clustering phenomenon to result in ineffectiveness of the traffic flow.

2.0 OBJECTIVE

The aim of this work is to simulate the flow of vehicles in one-line street which behavior is typical of Indonesian city streets using a cellular automaton method and investigate the effect of arbitrary stopping of public vehicles on flow of traffic in one-line streets. A car-following model where a driver looks only at the preceding vehicle was adopted.

3.0 METHOD

We restricted our study on one-line streets, along which a car cannot advance the preceding ones, i.e. car following model. The line is divided into N cells of equal length. Each cell is either occupied by a car or empty (part of street which are not occupied by any cars). The periodic boundary condition was used, i.e., the (N+i)-th cell is the same as the i-th cell. The same boundary condition has been used by other authors [5].

Initially, cars are placed randomly in the cells. The occupied cell is either a private car or a public vehicle, which is selected randomly. The final configuration of vehicles is reached by an iteration rule. The iteration rule is defined as follows. The private car will move ahead as long as the front cell is empty. However, a public vehicle must decide whether it has to move ahead or make a brief stop, even if the front cell is empty. The probability of stopping or moving ahead is selected randomly. We define a parameter namely critical probability, p_c, to select one of the two conditions of public vehicle movement, i.e., making a brief stop or moving ahead. If the probability is less than p_c, the public vehicle make a brief stop, and move ahead if the probability is larger than p_c, as long as the front cell is empty. We also define a stopping period of public vehicle, τ, corresponds to average time for dropping or getting passengers, and in this model this parameter is expressed in number of iteration steps. Having completed the brief stop, the public vehicle must decide again, by selecting a new probability randomly, whether it has to add another brief stop or move ahead. In each iteration step, new probabilities are generated for all moving public vehicles to decide which one will continue to move ahead and which one will make a brief stop.

We shall investigate two rules of movements. The first is a one-cell movement, i.e., a vehicle only shifts one cell as long as there are empty cells exist in the next successive cell, independent of the number of cells (spacing). The second rule assumes that each vehicle travels with a velocity that is dependent on the spacing ahead. Many authors have proposed that the vehicle velocity tends to reach the optimal velocity,

$$u(x_n) = A\left[\tanh(x_n - 2) + \tanh(2)\right] \tag{1}$$

with x_n the spacing ahead of the n-th vehicle, and A a constant [15 – 16]. However, since it is impossible for a vehicle to satisfy precisely the optimal velocity, the actual velocity should deviate from the optimal velocity. Bando formula for the vehicle acceleration was frequently used to describe the movement of vehicles, i.e., $dv_n / dt = \beta[u(x_n) - v_n]$, [15] with $u(x_n)$ the optimal velocity of vehicle when there is x_n spaces ahead, v_n the instant velocity of the n-th vehicle, and β a constant. The Bando formula is similar to feedback formulas that frequently discussed in control systems. Machines or other feed back equipments can spontaneously follow this rule. But the drivers in common vehicles are difficult to adjust their accelerations precisely to follow this relation. Deviation from this relation might be different for different drivers. We propose that it might be acceptable to represent the instant velocity of the vehicle as a small random deviation from the optimal velocity. Indeed this behavior is implicitly accommodated by Bando formula, even though the deviation is not random because it has a control equation. In this second rule of movement, the instant velocity of the vehicle is assumed to have the following form

$$v_n = u(x_n) + \Delta v_n \tag{2}$$

with Δv_n is a random deviation of the n-th velocity of the vehicle from the optimal one. Furthermore, we assumed that the drivers are facing more difficulties to adjust their velocities to approach the optimal velocity when they are traveling at higher velocities. With this assumption, the deviation from the optimal velocity should be proportional to v_n itself. To account for the randomness of the Δv_n we propose the following relation

$$\Delta v_n = \gamma\left(a_r - \frac{1}{2}\right)v_n \tag{3}$$

with a_r is a random number, $0 \le a_r \le 1$, and γ is a proportional constant. By assuming the deviation of velocity from the optimal one, $u(x_n)$, the parameter γ must be much smaller than unity. Substituting Equation (3) into Equation (2) results in the following equation

$$v_n = \frac{u(x_n)}{1-\gamma\left(a_r - \frac{1}{2}\right)} \tag{4}$$

The distance traveled by a vehicle during one step of iteration (a period of Δt) is then

$$\Delta x_n = (A\Delta t)\frac{\tanh(x_n - 2) + \tanh(2)}{1-\gamma\left(a_r - \frac{1}{2}\right)} \tag{5}$$

In the simulation of flow of vehicle in one-line street, the factor $A\Delta t$ in Equation (5) was selected so that the vehicle still has a movement even though there is only one unoccupied cell ahead. Since $\tanh(x_n - 2) + \tanh(2) = 0.202$ for $x_n = 1$, to have one movement or $\Delta x_n = 1$ even only one unoccupied cell exists in front, we used $A\Delta t = 5$. In addition, if we obtain Δx_n to be larger than the number of empty cell ahead of the vehicle after calculating Equation (5), the distance traveled by the vehicle is set to be equal to this spacing.

Observing the real traffic conditions in Indonesian cities, on average, the duration of stopping of a public vehicle is about 30 s. Assuming the average velocity of the moving vehicles is 60 km/h, during this stopping period the moving vehicle travels a distance of about 500 m. Assuming that the length of all vehicles is 5 m, we could take the length of a cell to be 5 m. Therefore, during the stopping time, the traffic vehicle makes 100 cells movement. Based on this assumption, in this simulation the stopping time τ was set as 100 iteration cycles (i.e., $\tau = 100\Delta t$) and the number of cells was fixed at 10^4, otherwise stated. The critical probability, p_c, for selecting either a brief stop or moving ahead of the public vehicle was $p_c = 0.2$.

4.0 RESULT AND DISCUSSION

This section presents discussion of some simulation results.

4.1 Vehicle Clustering

To show that arbitrary stopping of the public vehicles plays a significant effect on the traffic flow, in Figure 1(a) we present the data of accumulation content of cells as a function of cell position after 10^4 iterations for one-cell movement. The content is 1 for occupied cells and 0 for unoccupied cells. We used a number of 100 vehicles, and the number of public vehicles is varied. The presence of vehicle is indicated by the occurrence of the upper steps in the curves. It is shown that if the public vehicle is absent, random distribution of vehicles still occurs even after 10^4 iteration steps, similar to that at initial iteration step. However, if the public vehicles present, clustering of vehicles is observed, indicated by large upper steps in the curves. Horizontal parts of the vehicle represent the spacing between vehicles. The final number of the

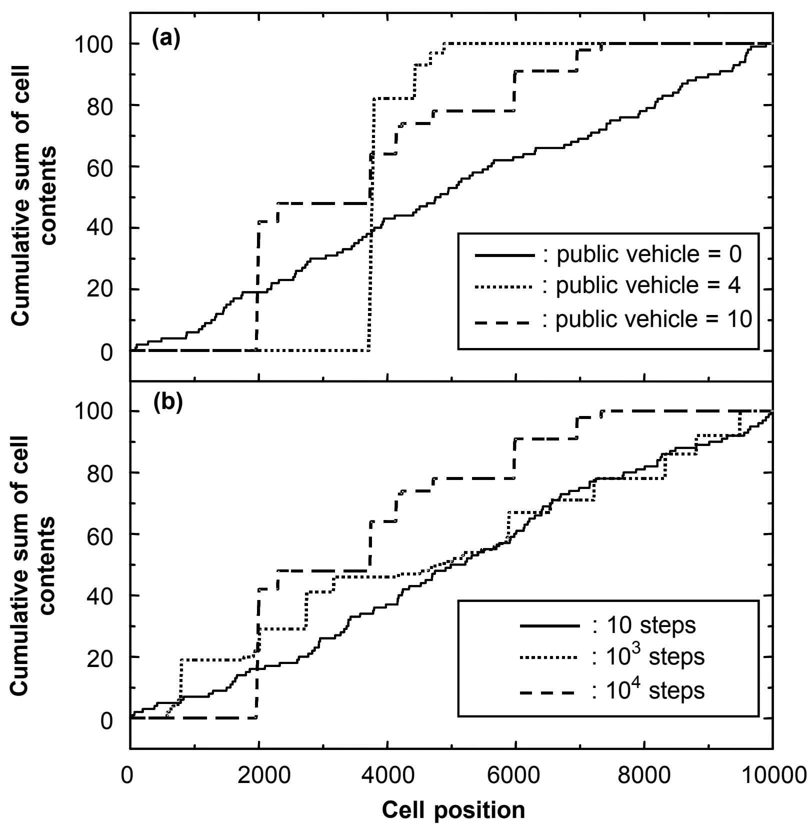

Figure 1 Cumulative sum of cell contents as a function of cell position for one-cell movement. Clustering of vehicles is indicated by upper steps in the curves, while the horizontal parts represent the spacing. (a) Data were obtained for different number of the public vehicles. The total number of vehicles was fixed at 100, the iteration step at 10^4, the stopping time at 100 steps, and p_c = 0.2 (b) Data were obtained at different iteration times. The total number of vehicles was fixed at 100, the number of public vehicles at 10, the stopping time at 100 steps, and p_c = 0.2

main clusters is the same as the number of the public vehicles. Indeed, the public vehicle always locates the front of the clusters.

The time evolution of clusters is shown in Figure 1(b). At 10 iteration steps, the vehicle position is still random and no indication of clustering. After 10^3 steps, the clustering of the vehicles is observed, and almost completely clustering is formed at 10^4 iteration steps. No change in the number of the main clusters at longer iteration times, although the cluster sizes might change.

Similar phenomenon was also observed when using Equations (4) and (5). The results are shown in Figure 2. The calculations were performed at different numbers of the public vehicles. Large cluster sizes were observed at small number of the public vehicles. It is acceptable since the public vehicles tend to occupy the front of the clusters.

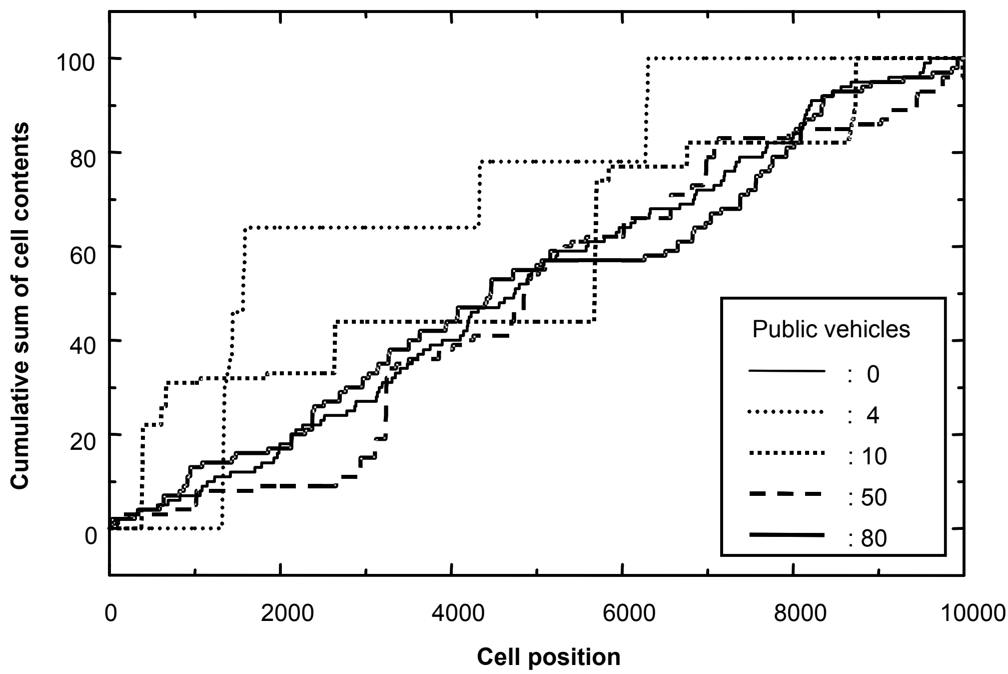

Figure 2 Cumulative sum of cell contents as a function of cell position simulated using Equations (4) and (5). Data were obtained for different number of the public vehicles. The total number of vehicles was fixed at 100, the iteration step at 10^4, the stopping time at 100 steps, and p_c = 0.2, and γ = 0.1

4.2 Time Dependent Movement

From now on we only consider movement of vehicles according to Equations (4) and (5). Figure 3 shows the effect of iteration time on the instant total movements of

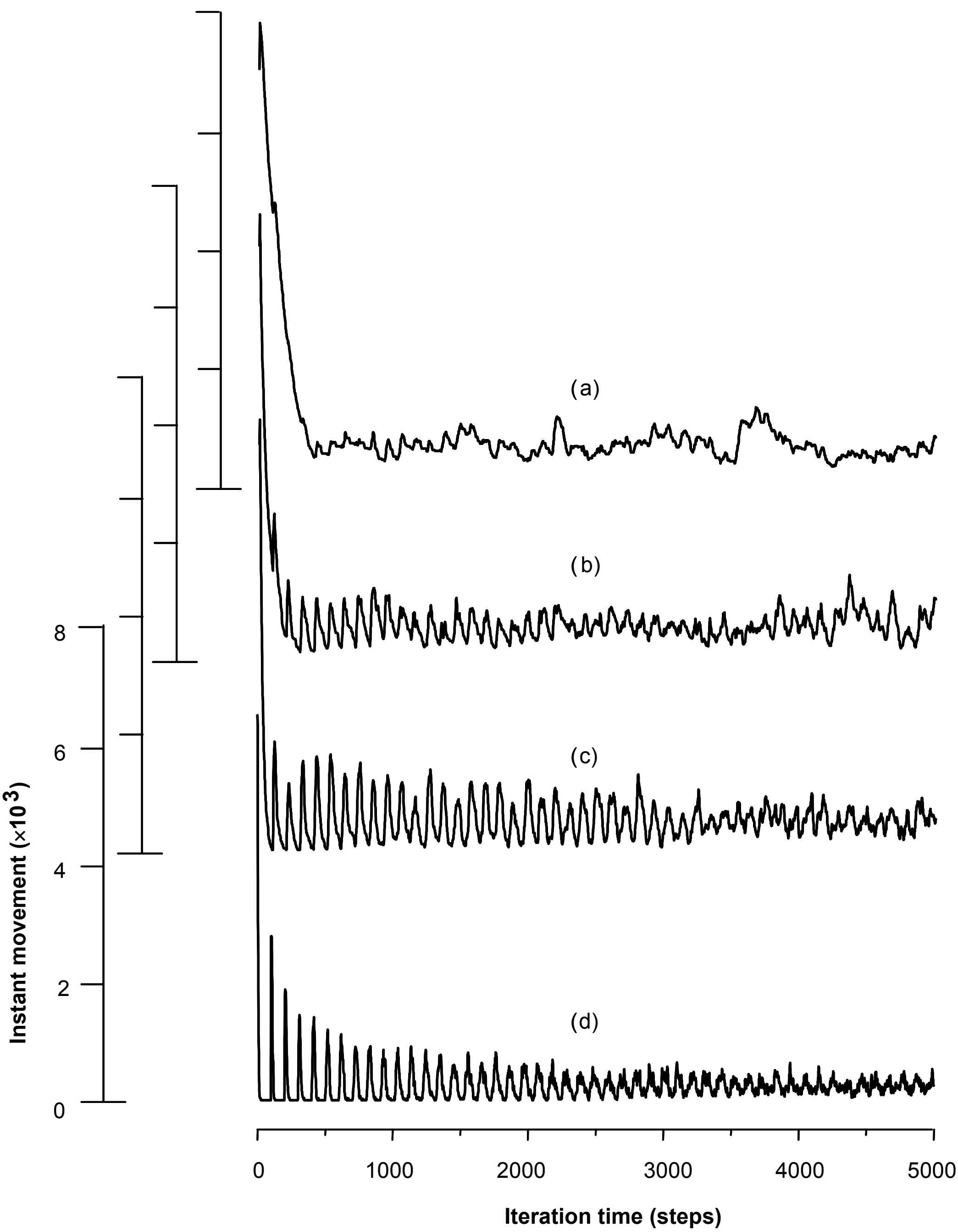

Figure 3 Effect of iteration time on the instant total movement of all vehicles at different number of public vehicles [(a) = 10, (b) = 50, (c) = 100, and (d) = 500]. The total number of vehicles was fixed at 2000, the iteration step at 10^4, the stopping time at 100 steps, $p_c = 0.2$, and $\gamma = 0.1$

all vehicles on different numbers of the public vehicles. The instant total movement is defined as

$$\Delta X(t) = \sum_{n=1}^{10^4} \Delta x_n(t) \tag{6}$$

The curve looks like 'quasi periodical pulse' with a period τ, the amplitude of which decreases with time. Well-defined periodical patterns easily occur when the

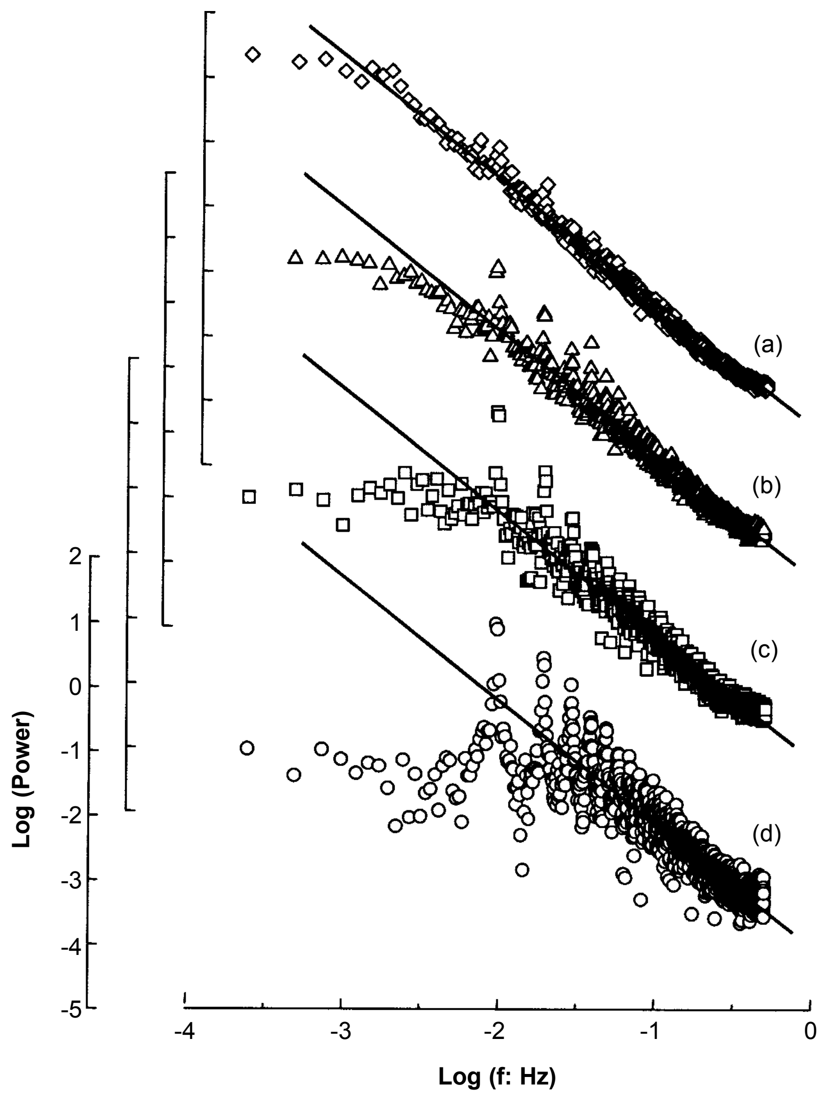

Figure 4 Power spectra of data in Figure 3 obtained using fast fourier transformation [(a) public vehicles = 10, (b) public vehicles = 50, (c) public vehicles = 100, and (d) public vehicles = 500]. The total number of vehicles was fixed at 2000, the iteration step at 10^4, the stopping time at 100 steps, $p_c = 0.2$, and $\gamma = 0.1$. Straight lines are fitted for those curves

number of the public vehicles is large, particularly at small iteration steps. This periodical pattern gradually disappears at large iteration steps. For small number of the public vehicles, random-like curve was observed almost at all iteration steps. If we inspect the spectrum of the curve using a Fourier transform, we obtain Figure 4, plotted in log-log scales. It can be seen that the spectra have a $1/f$ behavior. The power spectra varies as $f^{-\alpha}$ with $\alpha = 2$, independent of the number of the public vehicles.

Figure 5 shows the cumulative movement as function of iteration time both in logarithmic scales at different number of public vehicles. The total number of vehicles was fixed at 10^4. Without public vehicles we observed straight line for all times (not presented in the figure). In the presence of the public vehicles, we observed different behavior. At small iteration times, the cumulative movement is proportional to t^{δ}, with t = *iteration steps* $\times \Delta t$ and the exponential factor $\delta \cong 1$. At large iteration time, similar relation is also observed, with $\delta \cong 0.9$. There is a transition time in which the deviation from this relation occurs. The location of the transition time depends on the number of the public vehicles. It occurs at small time for large number of the public vehicles. However, outside this transition region, the exponential factor α is almost independent of the number of the public vehicles.

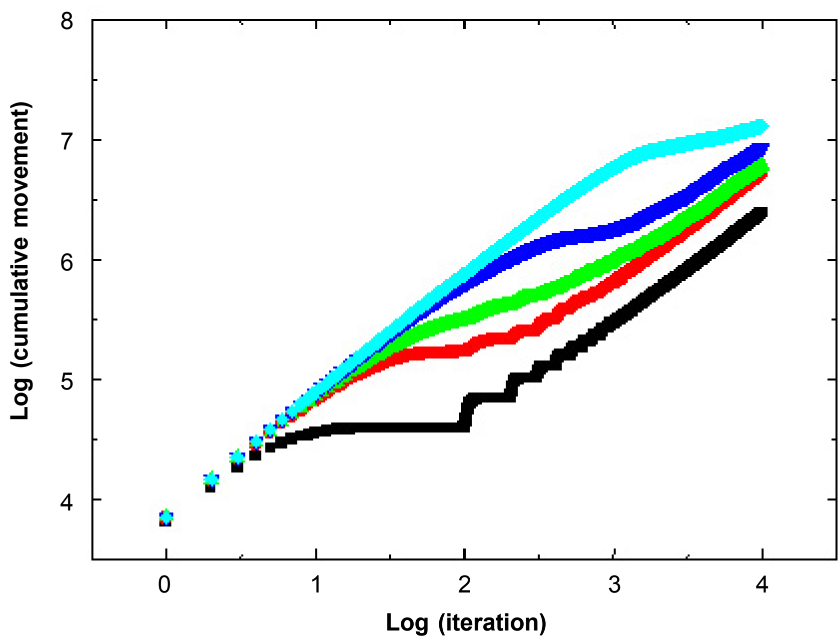

Figure 5 Cumulative movement as function of iteration time both in logarithmic scales at different number of public vehicles (top to bottom: 2, 10, 50, 100, and 500). The total number of vehicles was fixed at 10^4, the stopping time at 100 steps, $p_c = 0.2$, and $\gamma = 0.1$

4.3 Fuel Consumption

Now, we simulate the distance traveled per unit volume of fuel consumed. It is commonly known that the fuel consumption per kilometer decreases by increase in the velocity of the vehicle, and might be has a turning point above which the consumption increases by further increase in the velocity. We assume, in the speed range considered here the fuel consumption monotonically decreases with increase in the velocity. To account accurately the total fuel consumption, we need to understand the characteristic of each vehicle. Different vehicles generally have different velocity dependence of the fuel consumption on the velocity. Even similar vehicles might also have different properties if their ages are different. Our purpose in the present simulation is to compare the fuel consumption at a condition where the public vehicles are absent and when the public vehicles are present. For this aim, we assumed all vehicles are similar, and the velocity dependence of fuel consumption is also similar. The dependence of the fuel consumption per unit length traveled by vehicle on the velocity was proposed to be proportional to $B_1 - B_2 v$, with B_1 and B_2 are positive constants, and v is the velocity. Since $\Delta x_n = v_n \Delta t$, the fuel consumption for vehicle that travels a distance Δx_n is $C(\Delta x_n) = [B_1 - (B_2 \Delta t)\ \Delta x_n]\Delta x_n$. In the present simulation we ignored the unit (using arbitrary scale) and assumed $B_1 = 1$ and $B_2 \Delta t = 0.05$ so that at a single iteration step $C(\Delta x_n = 1) = 0.95$ and $C = 5$ for $x_n >> 1$, based on Equation (5) the maximum of Δx_n is 10. For stopping vehicles we assumed the fuel consumption at a single iteration step was $C(\Delta x_n = 0) = 0.3$. The total fuel consumption during a single iteration step is then

$$C(t) = \sum_{n=1}^{10^4} \left[B_1 - (B_2 \Delta t) \Delta x_n \right] \Delta x_n + 0.3 \Delta n \tag{7}$$

with Δn the number of stopping vehicles. True values of these parameters must be obtained by considering the specification of each vehicle. The average distance traveled per unit volume of fuel during the total iteration steps is then

$$\eta = \frac{\sum_t \Delta X(t)}{\sum_t C(t)} \tag{8}$$

Parameter η characterizes the effectiveness of the traffic. Large η indicates an effective traffic, i.e., in average, the vehicles travel longer distance per unit volume of fuel consumption, and on the other side, small η indicates an ineffective traffic, i.e., in average, the vehicles travel shorter distance per unit volume of fuel consumption.

Figure 6 shows the effect of number of the public vehicle on the effective of traffic at various total number of vehicles. The horizontal axis is the ratio of the public vehicle to the total number of vehicles. As expected, increasing the number of the

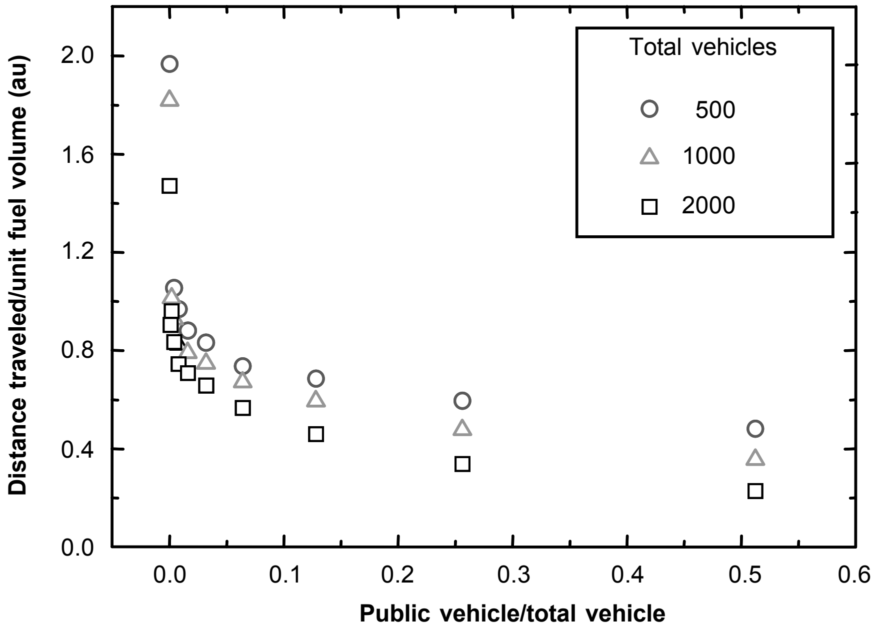

Figure 6 Distance traveled per unit fuel volume as a function of ratio of public vehicles to total number of vehicles at different total number of vehicles (circle = 500, triangle = 1000, and square = 2000). The iteration step was fixed at 10^4, the stopping time at 100 steps, $p_c = 0.2$, and $\gamma = 0.1$

public vehicle reduces the effectiveness of the traffic. Significant decreases in the effectiveness of the traffic occurs small number of the public vehicles.

This work is still a preliminary study on the traffic flow behavior in general city streets, in which arbitrary stopping of public vehicles can happen anywhere and anytime along the street. Comprehensive studies are required by considering as much as conditions taking part in controlling the flow of cars, such as the character of the drivers, character of streets, type of vehicles moving in the street, effect of pedestrian, "degree" of violating the traffic regulation, etc. Indeed, those factors might be included in the simulation after assigning proper value to those parameters.

5.0 CONCLUSION

We used a simple cellular automaton method to simulate the flow of cars/vehicles in typical streets in Indonesia in which arbitrary stopping of vehicles might happen anywhere and anytime along the street. Arbitrary stopping of public vehicles leads to occurrence of vehicle clustering along the line. The number of main clusters equals to the number of the public vehicles. The total distance traveled by all vehicles during iteration approximates a periodical function, with a period equals to the stopping duration of the public vehicle. The power spectrum of this movement scales as $f^{-\alpha}$, with $\alpha = 2$ and seems to be universal. The distance traveled in unit volume of fuel consumption is also investigated and shows that this distance decreases monotonically when the ratio of public vehicle with respect to the total number of vehicles increases.

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