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Fluctuation Effects in Fast Traffic Flow

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***Abstract*—This paper discusses a traffic flow, which considers a fluctuation in car moving, based on a stochastic cellular automaton from the viewpoint in fundamental traffic diagrams. Suppose a future traffic system such as the updates of the model, which is called a fast moving, can be performed at every cells at the same time, so that every cars can move to forward at least one cell even if all the cells are occupied by cars. We employ boundary effects and fluctuation as particle-specific properties including cars, and define six kinds of car running types based on the properties. Then, a fluctuation gives a flexibility for moving things including particles and cars, and it performs rocking effects and local adjustment. Then, we discuss how six-running types are related to a traffic flow by giving a fluctuation in future cities, and can also find the emergence of self-ordered particles.**

***Index Terms*—Traffic flow, driver modeling, multi-agents, six-running types, and fluctuation.**

I. Introduction

This paper discusses the features of the traffic flow which considers boundary effects and fluctuation, and we present the six kinds of car running types[18], [14]. Then, we discuss how six-running types are related to a traffic flow by giving a fluctuation, and show that, in fundamental diagrams, each running type is quite different from others. Finally, we show that giving the fluctuation is trying to find the emergence of self-ordered particles[16] in traffic flow.

A lot of papers have been discussed a traffic flow based on a stochastic cellular automaton which considers self-driving from the viewpoint of traffic resources. In future cities, the future traffic system is that the updates of the model can be performed at every cells at the same time, so that every cars can move to forward one cell at each time step even if all the cells are occupied by cars, where each cell is occupied at most one car. So, we can model to run the cars which are suitable to nothing time lags to move a car in future cities. We consider two unique features of psychological effects as car-specific properties in running cars: boundary effects and fluctuation, and define six kinds of car running types based on the effects. The boundary effects are to accelerate car speed if there is the other car in behind, or to reduce car speed if there is other car within the range to move at one time step. The former is called a boundary effect in behind, and the later a boundary effect in front. The fluctuation is that the average moving speed of cars is shifted to either faster or slower in averages randomly, so the fluctuation is distinct from a simple randomization. The fluctuation gives a flexibility for moving things including particles and cars, and it performs rocking effects and local adjustment.

A traffic congestion is a big problem from the viewpoints of an efficiency and energy in the world, and the huge amount of energy has been consumed since 20th century. A smart city is an attractive concept to develop cities by using information technology and Internet of Thing (IoT). You might suppose that there are noting traffic congestion in a smart city. Cities are chunks of human desires. So, a traffic accident may not happen, but a signal of desire is necessary. It might be quite difficult to prevent a traffic congestion, because a traffic resource, road, is finite and a lot of cars occupy the resources. In self-drivings in future cities, *autonomous* car moving is necessary to satisfy drivers desires. So, a car driving is sometimes sort of stressful work just as it is now. Suppose that you are now running a car in freeways. You may feel a higher stress to arrive within the scheduled time, when there is a car in front of your car or another car behind. Then, your car might accelerate/reduce the speed (a reaction to run cars, we call it a boundary effect). In another case, your car may be difficult to keep a car speed constant during running, because of uphills, downhills or others. Then, the speed of your car would be also accelerated/reduced (another running reaction, we call it a fluctuation effect). Our problem is to clarify how boundary effects and fluctuation is related to a traffic flow, where there are several running types as described later.

A variety of traffic flow models have been presented for analyzing a traffic flow and finding the solutions of the traffic congestion to escape. There are two kinds of traffic models to discuss a traffic flow: macro and micro models. A typical one of the macro model is based on Burgers equation from fluid mechanics[8]. The other micro model can be divided into two: Optimal Velocity (OV) model[1] and Cellular Automaton (CA) model [3]. OV model is presented for explaining traffic congestion based on differential equations. CA model [3] is successfully presented a fundamental model based on CA to reproduce traffic flow faithfully. But, it is sometimes difficult to explain the reason why the model is successful. This paper discusses how boundary effects and fluctuation are related to a traffic flow in fundamental diagrams, i.e. the number of car traffic vs. car density.

The works [7], [10] based on a probabilistic cellular automaton model employed the rules, which are similar to this paper, on a circle rather than our model discussed on a straight line:

acceleration, slowing-down, randomization and car motion rules, and the model is trying to reproduce fairly faithfully a traffic flow in freeways. The work [2] which employed a slow-to-stop rule indicates that the results are close to the actual traffic flow.

Our original motivation of this paper is that a traffic flow is a stochastic autonomous moving multi-agent from the viewpoint of the efficient uses of traffic resources in moving multi-agent systems[12], each car is an agent in multi-agents, and each agent is arranged on the cells exclusively. Then, the fluctuation and boundary effects play important roles to get high resource utilization. This kinds of effects never go away. Because the drivers are not satisfied unless the cars autonomously move.

There are the discussions from the viewpoint of the fluctuation in a traffic flow. The work [17] discussed the traffic flow from the viewpoint of Fractal. The work[19] presented a time series model to discuss a traffic volume. Also, there are a lot of papers to discuss a traffic flow in multi-agents[15]. The work [6] presented a multi-agent transport simulation system for solving a dynamic vehicle routing problem. There are some works to discuss the stability or utilization of resources in multi-agents. Sen et al. [11] presented a basic model for analyzing moving multi-agent behavior, and Rustogi et al. [9] developed and examined the basic features of moving multi-agents arranged on circles. Ishiduka et al. [4] presented the moving multi-agents introduced time lags and discussed the stability of the multi-agents. Shioya [12] introduced the boundary and fluctuation effects in moving multi-agents, and discussed to force the stability of the multi-agents. Their goals are to discover more stable multi-agent behavior or to get higher resource utilization. [13] discusses the traffic flow from psychological views. Then, the boundary and fluctuation effects are useful to configure multi-agent behavior to be stable or Julka et al. [5] discussed the benefits of multi-agent approaches for load balancing techniques. These discussions are available to find the solutions of traffic congestion. In fact, this paper discusses the traffic flow from multi-agent resource utilization, and utilizes the boundary and fluctuation effects to see a phase transition in an ideal traffic flow. The fluctuation effects of molecules in physics are quite small 10^{-10} around, while the fluctuation effects in a traffic flow are a bit large. The phase transitions mean that small changes get large effects so that we may be possible to get a solution of traffic congestion by a little change of traffic rules or traffic systems.

The main contribution of this paper is to see the traffic flow from two car feature aspects in the efficient uses of traffic resources: boundary and fluctuation effects. First: the boundary effects are an essential nature of a traffic flow, and are related to a transportation system. Our car update are performed by a fast car moving which is an ideal traffic flow without no time lag to move a car, i.e. the cell updates can be performed from right to left sequentially. This is suitable to run a car by self-drivings in future systems. Second: fluctuation effects are related to driving types which due to car specific features, so that the car speed is not only randomly changed but also the average car moving speed is randomly shifted to either slower or faster. We show how the boundary and fluctuation effects are related to traffic congestion to be happened in freeways under the fast car moving. They depend on their running types proposed six kinds in this paper.

This paper is organized as: the following section presents our future traffic flow model and discusses it. Our experimental results in Section III show the our experimental results. In the subsection III-A, we present the basic feature traffic flow results in our traffic mode, that is how six-running types are related to a traffic flow with respect to the variances of car speed in fundamental diagrams. In the subsection III-B, we present the emergence as self-ordered particles. In the final Section IV, we conclude this paper.

II. Proposed Traffic Flow Model in Future Cities

We describe a stochastic traffic flow cell model whose cells are arranged on a one-way traffic resource, and the traffic is one lane (Figure 1 and 2). Each cell of the traffic is occupied by a car at most, and every cars stochastically run on the traffic resource from left to right.

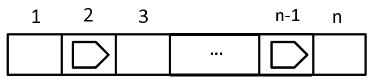

Fig. 1. Traffic resources, and cars run from left to right on a lane.

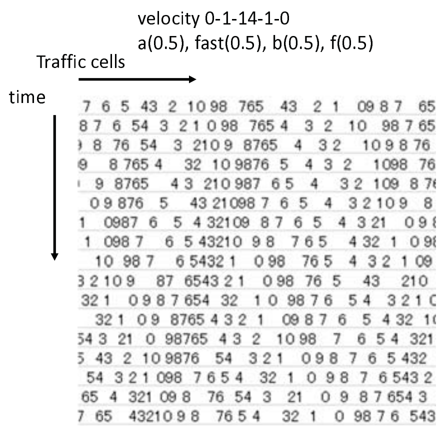

Fig. 2. The traffic resources in time domain.

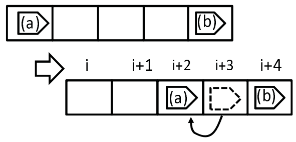

Fig. 3. Slower-in: Boundary effects in front.

The speed of each moving car is a stochastic process, and it depends on traffic rules, car performance, traffic flow and

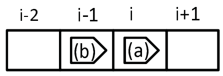

Fig. 4. Go-faster: Boundary effects behind.

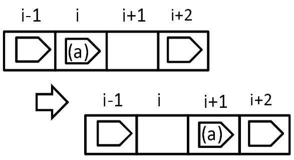

Fig. 5. Shortening one cell too close a car in front in minimum boundary effects.

car-specific characteristics. Suppose you are driving a car in freeways. We consider the *car-specific characteristics* as the following:

1) If there is a slower moving car ((b) in Figure 3) in front of your car, you ((a) in Figure 3) may slow down the speed more than necessaries in advance so that you might alleviate the stresses by slower-in and it's more safe. This is one of running types. On the other hand, if there is also another car ((b) in Figure 4) behind and there are nothing cars in ahead, the speed of your car ((a) in Figure 4) might be accelerated for avoiding from stresses behind, that is go-faster or faster-out. This is also one of running types. In this paper, the driver types that change the speed more than necessaries for avoiding collisions or alleviating higher stresses are said to be *boundary effects*. They depend on other cars stochastically.
2) As a special case of the boundary effects in above, if the cell in front of your car is unoccupied, but the second forward cell in ahead and immediately behind cell are occupied, your car either shorten one cell in front (see (a) in Figure 5) or not shorten, i.e. you either move a cell in ahead or remain there. We say that these car specific reactions are *minimal boundary effects* as described later by `a`.
3) Also, if there are small uphills or downhills in freeways (Figure 6), you would be difficult to keep the car speed constant, and the speed of your car will be accelerated/slowed down in average speed. These also arise from some reasons including human factors or others, and do not depend on other cars. We say that their running types are *fluctuation effects* that the average moving speed of cars is shifted to either faster or slower at each time randomly.

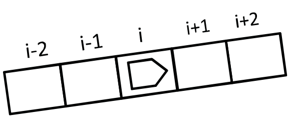

Fig. 6. An uphill in fluctuation effects.

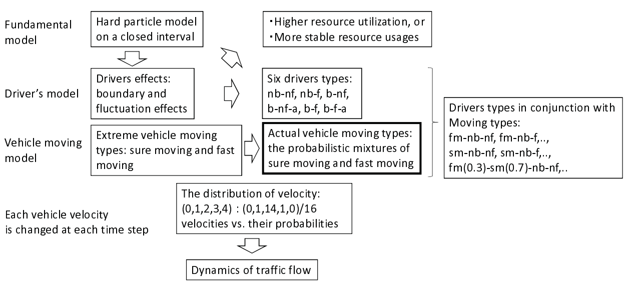

Fig. 7. Our proposed traffic flow model.

Now, how are you driving a car? We can consider two extreme car moving types in a traffic flow: "Fast moving" and "Sure moving". "Fast moving" is an ideal type of fast car moving in a traffic, so there are no time lags to move a car. Therefore, when the speed of all the cars are greater than or equal to 1, every car can move to forward at the same time by one step in CA, even if all the cells are occupied by car. That is, the updates in CA are performed from the most right cell to left cell, sequentially.

On the other hand, "Sure moving" is a type of a safe car moving at the next update step, so a car can move to forward, only if there are no cars in ahead at the previous update step. Actual car moving in freeways is the probabilistic mixture of two moving types: fast moving and sure moving. In this paper, we only consider the fast moving, and discuss the relationships between car density and traffic flow under six car running types, also described in later, of running reactions.

Our model [12] is based on a hard particle model on closes intervals, and the goal is to achieve higher resource utilization or stable multi-agent behavior. There are two magics for getting higher resource utilization in multi-agents: a fluctuation (a shake) and a boundary effect. The later depends on their positions. The two are just psychological effects in car driving. At the same time, they lead to effective use of traffic resources (Figure 7).

In the following section, our experiments show how the six kinds of running types are related to the traffic flow in fundamental diagrams.

III. Experiments

A. Experimental Features of Traffic Flow

We consider six kins of car running types based on the running reactions in Section II, show them in Table I, and assign the symbols nb-nf,.., and b-f-a to their running types.

We prepare a one-way traffic consisting cells, and the traffic is one lane. Every car moves on the traffic cells from left to right shown in Figure 1 rather than on circles. The number of the traffic cells is $2,000$ on the straight. The moving type which is considered is only fast moving, so we perform the updates of the traffic cells from right to left, reverse, at each moving step, and provide $30,000$ cars. Their cars run $30,000$

TABLE I
CAR RUNNING TYPES.

nb-nf	neither boundary nor fluctuation.
nb-f	allow fluctuation, but nothing boundary.
b-nf	allow boundary, but nothing fluctuation, no shorten, remain there, in minimum boundary.
b-nf-a	allow boundary, but nothing fluctuation, shorten one cell in minimum boundary.
b-f	allow both boundary and fluctuation, no shorten, remain there, in minimum boundary.
b-f-a	allow both boundary and fluctuation, shorten one cell in minimum boundary.

steps for each exam in our experiments. At each updating step, a car enters into the traffic only if the leftmost traffic cell is empty. Otherwise, the car has to wait to enter into the traffic until left most cell becomes empty. This means that we examine the maximum traffic flow for every driving type in fast moving on one way lane without signal lights, freeways.

Assume that each car speed v is either 0, 1, 2, 3 or 4 in the cases without running reactions, and the average value is 2 if there are no cars in ahead. Each car speed randomly changes at every moving step. We use Mersenne twister as a random number generator.

The boundary effects are implemented as every car speed v either increase 1 in average if the behind cell is occupied and two more cells in ahead are unoccupied, or decrease 1 in average if v more cells in ahead are unoccupied and the car moves to the behind of car in ahead with a slowdown in speed. Shortening one cell in the minimal boundary effect (Figure 5) is considered if there only exists an empty cell in front and the speed is greater than or equal to 1. With even probability, the fluctuation effects either increase the speed 1 or decrease the speed 1 in average.

We examine the car density and the traffic flow by varying the distributions of the speed 0, 1, 2, 3 and 4 correspond to the probabilities 0, $\frac{1}{16}$, $\frac{14}{16}$, $\frac{1}{16}$ and 0, respectively. Then, we observe the car density on the cells between 501th and 1,500th, and the traffic flow is the number of cars to pass on the 2,000th cell between 20,001th and 30,000th steps. We performed them 10 times for each running type, and obtained the traffic flow versus car density relationships, the fundamental diagrams, shown in Figure 8. Our problems are how six-running types are related to a traffic flow with respect to the variances of car speed, and we show them in the fundamental diagrams of traffic flow.

B. Fluctuation in Traffic Flow

Figure 9 shows the fundamental diagram between b-nf-a and b-f-a. The number of traffic flow is maximum value 10,000, if nothing fluctuation(0-16-0), i.e. n-nf-a. If we add the fluctuation gradually, the number of traffic is slowly down, but it increases the car density. If the fluctuation becomes to 06-04-06, that is a bottom, it finally turns to change the direction to right upper, i.e. it arrives to b-f-a: 08-00-08 (add

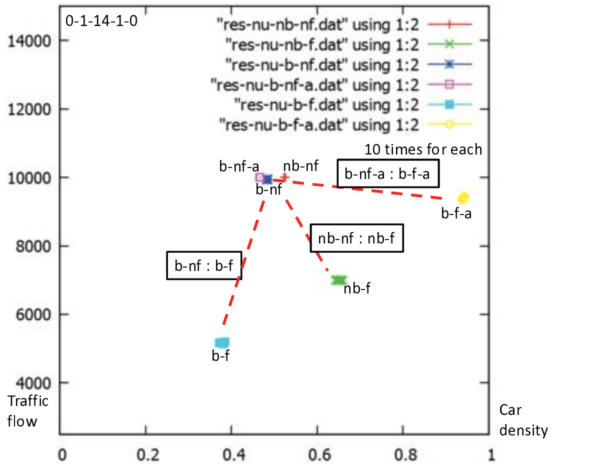

Fig. 8. Traffic flow versus car density relationships among car driving types: the probabilities for the speed 0, 1, 2, 3 and 4 correspond to 0, $\frac{1}{16}$, $\frac{14}{16}$, $\frac{1}{16}$ and 0, respectively.

the fluctuation, completely). It shows the non-linear feature between b-nf-a and b-f-a.

On the other hand, Figure 10 The fundamental diagram between nb-nf and nb-f. The number of traffic flow is maximum value 10,000, if nothing fluctuation(0-16-0), i.e. nb-nf. If we add the fluctuation gradually, the number of traffic keep the car density, and move to right. If the fluctuation becomes to 05-06-05, it moves to right most in the figure, and turns to change direction to the bottom. It finally arrives to nb-f: 08-00-08, i.e. add the fluctuation, completely. It shows the non-linear feature between nb-nf and nb-f.

Figure 11 The fundamental diagram between b-nf and b-f by adding the fluctuation gradually. The number of traffic flow and car density move to left down side at regular intervals. It shows the linear feature between b-nf and b-f.

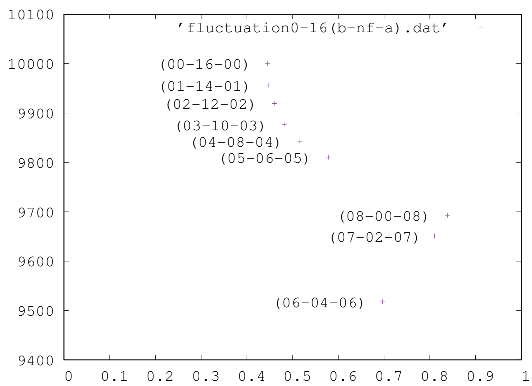

Fig. 9. The fundamental diagram between b-nf-a and b-f-a by adding the fluctuation gradually, where x and y axises are car density and the number of traffic flow, respectively.

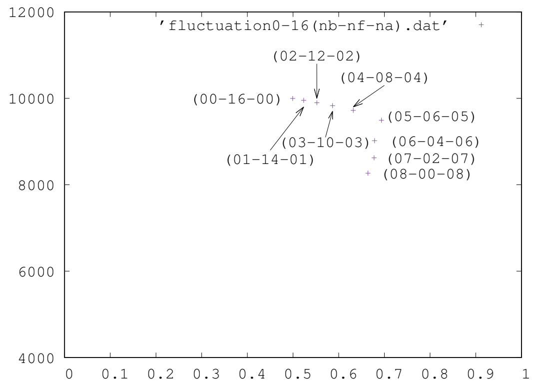

Fig. 10. The fundamental diagram between nb-nf and nb-f by adding the fluctuation gradually, where x and y axises are car density and the number of traffic flow, respectively.

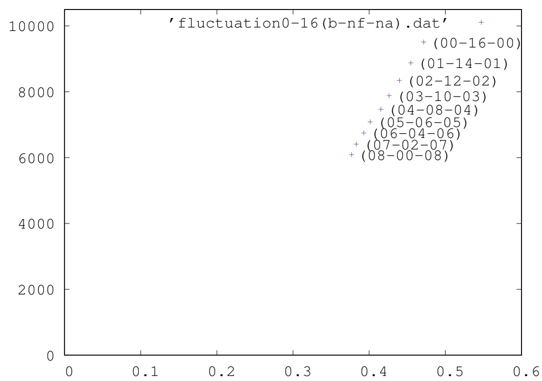

Fig. 11. The fundamental diagram between b-nf and b-f by adding the fluctuation gradually, where x and y axises are car density and the number of traffic flow, respectively.

IV. Conclusions

We have examined how running types are related to the maximum traffic flow in an ideal car fast moving. Then, we have considered six running types to run cars: nb-nf, nb-f, b-nf, n-nf-a, b-f and b-f-a, so that the traffic flow depends on the six running types. And, we discussed how six-running types are related to a traffic flow with respect to the variances of car speed in fundamental diagrams. Finally, we presented the non-linear features in our traffic model, and they showed the emergence of traffic flow as cars and particles.

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