Emergence of Congestion in Express Ways with a Entranceway

Shin-ichi Tadaki*, Macoto Kikuchi†, Yūki Sugiyama‡ and Satoshi Yukawa§

1 Introduction

Some physical models of traffic flow can reproduce fundamental features of the traffic flow in one-lane expressway systems. Most of real expressways, however, have more than two lanes. To compare the simulation results with observations, it is necessary to improve the existing traffic flow models to treat two-lane roads.

The Optimal Velocity (OV) traffic flow model[1], which is a one of car-following models, has succeeded to describe the phase transition from a freely-moving phase to a jam phase by changing the traffic density. We have proposed a new simulation model, Coupled Map traffic flow model based on Optimal Velocity functions (CMOV model), by discretizing the original OV model[2, 3].

In the CMOV model, each car controls the acceleration to tune the velocity to the optimal (safety) value V_{optimal}, which depends only on the headway Δx to the preceding car. The position x and the velocity v are updated as follows:

$$x(t+\Delta t) = x(t) + v(t)\Delta t, \quad (1)$$

$$v(t+\Delta t) = v(t) + \alpha\left(V_{\mathrm{optimal}}(\Delta x) - v(t)\right)\Delta t. \quad (2)$$

where α is a susceptibility and Δt is a fixed time step.

The OV function V_{optimal}, in general, is a sigmoidal function. Here we use the following form[1, 2]:

$$V_{\mathrm{optimal}}(\Delta x) = \frac{v_{\max}}{2}\left[\tanh\left(2\frac{\Delta x - d}{w}\right) + c_{\mathrm{bias}}\right], \quad (3)$$

*Saga University
†Osaka University
‡City College of Mie
§University of Tokyo

where parameters $v_{\max}$, d, w and c_{bias} are determined with observations (Table 1)[2, 4]. In this study all cars have the same parameter values except $v_{\max}$, which distributes uniformly in $(0.8v_{\max}, 1.2v_{\max})$.

Table 1: Parameters: They are compatible with the observation in Chuo expressway except Δt and $\Delta x_{\min}$.

parameter	value	(unit)
d	25.	m
w	23.3	m
$v_{\max}$	33.6	m/sec
α	2.	sec^{-1}
c_{bias}	0.913	
Δt	0.1	sec
$\Delta x_{\min}$	7.02	m

Our previous results show that some traffic blockade structures are required for the emergence of traffic jams. And noises can only induce weak congested flow[3]. In this study, we introduce an entranceway as a traffic blockade to a two-lane expressway.

2 Lane changing rules

The advantages of the discretization in the CMOV model is that the sequence of cars can be flexibly changed. It enables us to apply the model to realistic traffic systems such as open roads. Moreover, we can treat the rule-based behavior of cars such as lane changing. To treat two-lane systems, we introduce a set of stochastic lane changing rules. The rules are asymmetric between lanes because we consider the traffic flow in expressways.

The lane changing rules are the following (see Figs.

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1 and 2). Each car in the slow lane (the left lane in Japan) try to move to the fast lane if it can not run at the desired speed because of the short headway ($\Delta x < \Delta x_{\rm safe} \equiv d + w/2$). Each car in the fast lane try to move to the slow lane if it can run at the desired speed ($\Delta x > \Delta x_{\rm safe}$) or faster than the current speed in the slow lane ($\Delta x_p > \Delta x$). If lane changing is safe ($\Delta x_f > V^{-1}_{\rm optimal}(v_f)$ and $\Delta x \leq \Delta x_p$), the car really change the lane with the probability $p_{\rm up}$ ($p_{\rm down}$) for moving from the slow (fast) lane to the fast (slow) lane, where $p_{\rm up} \leq p_{\rm down}$. At an entranceway, we employ a set of special rules to allow cars to enter the slow lane from the entranceway (details are omitted).

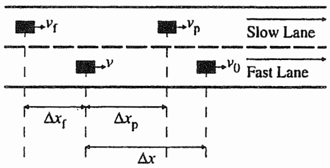

Figure 1: Lane changing rule for moving to the slow lane.

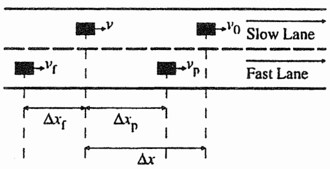

Figure 2: Lane changing rule for moving to the fast lane.

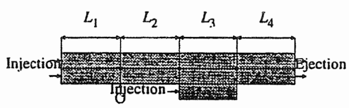

Figure 3: Setup for simulations.

3 Simulation

The simulated system has open boundaries and an entranceway (Fig. 3). Cars are stochastically injected from both the starting point of the road and the entranceway. From the starting point (the entrance) cars are injected with $v = 0$ ($v = V_{\rm optimal}(\Delta x')$) and the probability P ($P_{\rm entrance}$) if the headway to the preceding car becomes larger than the threshold $\Delta x_{\rm min}$ ($\Delta x' = d{+}w$). We observe the emergence of traffic jams at the entranceway. The traffic jam propagates upstream. We observe the flow, the average velocity and the average headway at a point O in the upper stream of the entranceway.

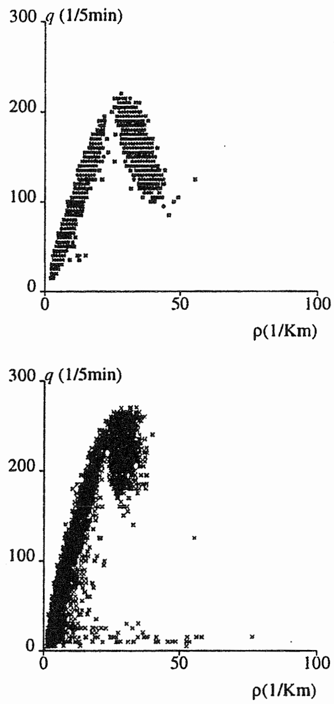

Figure 4: Fundamental diagram: The flow q in the slow lane (left) and the fast lane (right) are plotted as a function of the density ρ.

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By changing P with a fixed P_{entrance}, we observe the fundamental diagram (Fig. 4), which shows the phase transition from a freely moving phase (the left side of the peak) to a jam phase (the right side).

The lane-usage characteristic (Fig. 5(a)) is observed. In the low flow state, most of cars are running in the slow lane. As the flow increases, the flow in the fast lane exceeds that in the slow lane. If the total flow approaches the maximum capacity of the road, the flow in two lanes becomes comparable. We observe also the strong correlation of the flow between lanes (Fig. 5(b)).

The simulation results qualitatively reproduce some features of observed data in Tomei expressway..

Acknowledgments

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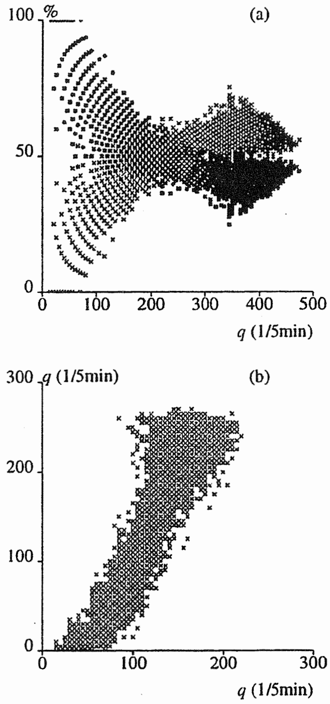

Figure 5: (a) Lane-usage characteristic: The ratio of the flow using the slow lane (○) and the fast lane (×) are plotted as a function of the total flow. (b) Correlation of the flow in two lanes. The horizontal (vertical) axis corresponds to the flow in the slow (fast) lane.