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Jam formation in traffic flow on a highway with some slowdown sections

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Abstract

We study the traffic jams appearing on a single-lane highway with a few slowdown sections. At low density, the flow (current) increases linearly with density, while it saturates at some values of intermediate density. In such case that some slowdown sections have the same speed limit, when the flow begins to saturate, a single discontinuous front (stationary shock wave) occurs before a slowdown section or some discontinuous fronts appear before some slowdown sections. For the case of different speed limits, the discontinuous front occurs before the section of strongest slowdown. The saturated flow is given by the maximal value of the current of the strongest slowdown section. The relationship between the densities is derived before and after the discontinuity. The dependence of jam lengths on density is derived numerically and analytically.

Keywords: Vehicular dynamics; Traffic jam; Discontinuity; Phase transition

1. Introduction

Traffic flow is a kind of many-body system of strongly interacting vehicles [1–5]. Vehicular traffic has been studied by several traffic models: car-following models, cellular automaton models, gas kinetic models, and hydrodynamic models [6–27]. Mobility is nowadays one of the most significant ingredients of a modern society. The traffic accident often occurs in city traffic networks [22]. Also, traffic networks often exceed the capacity. The city traffic is controlled by speed limit and traffic lights for security and priority for a road [21,23,27,28].

Traffic jams are typical signature of the complex behavior of traffic flow. Traffic jams are classified into two kinds of jams: (1) spontaneous jam (or phantom jam) which propagates backward as the stop- and go-wave and (2) stationary jam which is induced by slowdown or blockage at a section of roadway. If sensitivity of driver is lower than a critical value, the spontaneous jam occurs. The jamming transition is very similar to the conventional phase transitions and critical phenomena [1,26]. When the sensitivity is higher than the critical value, the spontaneous jam does not appear, while the stationary jam induced by slowdown occurs [1,27,28].

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Such speed limit as slowdown often induces traffic jams when a vehicular density is high. One is interested in the structure and formation of traffic jams induced by slowdown. In the previous paper [27], we have studied the traffic jam induced by slowdown at a section of roadway. We have shown the following. When a density of vehicles is low, vehicles move freely with no jams. If the density is higher than a critical value, the traffic jam is formed just before the section of slowdown. The speed of vehicles within the jam becomes lower than the speed limit of slowdown. The traffic jam ends with forming a queue of slow vehicles. A discontinuous front appears at the end (edge) of traffic jam. The relationships between the headways and velocities before and after the discontinuity have been derived.

In real traffic, some sections of slowdown exist on a highway. When a few sections of distinct slowdowns exist on a highway, where, when, and how do traffic jams occur on a highway? The traffic jams induced by some slowdown sections have little been studied by using modern traffic models.

In this paper, we apply the conventional optimal-velocity model to the traffic flow on a highway with some slowdown sections. We study the traffic states and discontinuous fronts induced by some slowdown sections. We clarify the dynamical states of traffic and the characteristic of discontinuous fronts (or traffic jams). We show where and how the traffic jams occur by increasing the density of vehicles and by varying slowdowns.

2. Model

We consider the vehicular traffic flowing on the single-lane roadway with some sections of slowdown. Vehicles move with no passing on the single-lane roadway under periodic boundary condition. We assume that vehicles are forced to slow down when they enter into a section of the slowdowns. Fig. 1(a) shows the schematic illustration of the traffic model for the single-lane highway with a single section of slowdown. Vehicles move with low speed in the section of slowdown, while they move with the normal velocity except for the section of slowdown. The length of slowdown section is L_S and the length of normal-speed section is L_N where the road length is $L=L_N+L_S$. We extend the traffic flow to that through a few slowdown sections. Fig. 1(b) shows the schematic illustration of the traffic model for the single-lane highway with two slowdown sections. The lengths of slowdown sections are L_{S1} and L_{S2}. The lengths of normal-speed sections are L_{N1} and L_{N2} where the road length is $L=L_{N1}+L_{N2}+L_{S1}+L_{S2}$. Vehicles move with low speed in the slowdown sections, while they move with the normal velocity except for the slowdown sections. We apply the optimal-velocity model to the traffic flow [1,29]. The optimal-velocity model is described by the following

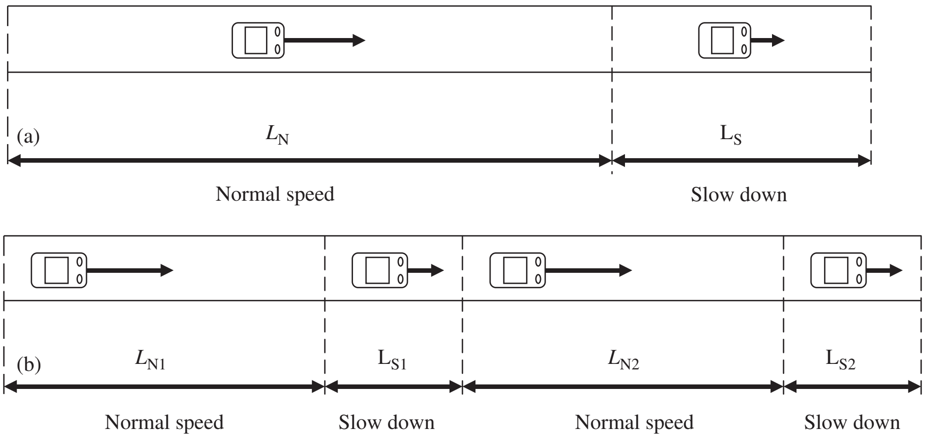

Fig. 1. (a) Schematic illustration of the traffic model for the single-lane highway with a single section of slowdown. Vehicles move with low speed in the section of slowdown, while they move with the normal velocity except for the section of slowdown. The length of slowdown section is L_S and the length of normal-speed section is L_N where the road length is $L=L_N+L_S$. (b) Traffic model for the single-lane highway with two sections of slowdown. The lengths of slowdown sections are L_{S1} and L_{S2}. The lengths of normal-speed sections are L_{N1} and L_{N2} where the road length is $L=L_{N1}+L_{N2}+L_{S1}+L_{S2}$.