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Bunching and transition of vehicles controlled by a sequence of traffic lights

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Abstract

We study the dynamical behavior of many vehicles with different desired velocities, moving through a sequence of traffic lights on a single-lane highway, where the traffic lights turn on and off periodically with the synchronized strategy. The dynamics of vehicular traffic controlled by traffic lights is described in terms of the nonlinear maps. For specific values of cycle time, the group (cluster) of vehicles exhibits the bunching without extending over the highway. It is found that two types of traffic states appear: the one is the bunching traffic and the other is the extended traffic. In the bunching traffic, all vehicles move together with the same tour time, while vehicles spread over the highway in the extended traffic. The dynamical transition between two traffic states occurs at specific values of cycle time. The phase diagram (region map) is presented.

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Keywords: Traffic; Bunching; Dynamical transition; Nonlinear map

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1. Introduction

In urban traffic, vehicular traffic is controlled by traffic lights to give priority for a road because the city traffic networks often exceed the capacity. Also, for security, high-speed vehicles are controlled by traffic lights to move together with normal speed vehicles. Mobility is nowadays one of the most significant ingredients of a modern society. Vehicular traffic is optimized by traffic control strategy. Recently, transportation problems have attracted much attention in the fields of physics [1–5]. The traffic flow has been studied from a point of view of statistical mechanics and nonlinear dynamics [6–23]. The traffic jams and dynamical transitions are typical signatures of the complex behavior of traffic flow [24,25].

The flow throughout depends highly on both cycle time and strategy of traffic light. Brockfeld et al. [26] have studied optimizing traffic lights for city traffic by using a CA traffic model . Sasaki and Nagatani [27] have investigated the traffic flow controlled by traffic lights on a single-lane roadway by using the optimal velocity model. They have derived the relationship between the road capacity and jamming transition.

The dynamical state of traffic changes by varying the cycle time and strategy. Until now, one has studied the periodic traffic controlled by a few traffic lights. A few works have been known for the vehicle traffic moving through an infinite series of traffic lights. The dynamical behavior of a single vehicle has been studied through a sequence of traffic lights. It has been shown that the vehicle displays the self-similar behavior and deterministic chaos [28,29]. However, the traffic of many vehicles has little been investigated through an infinite series of traffic lights. For security and road capacity, one must control vehicular traffic in such way that high-speed vehicles move together with normal-speed vehicles by retarding high-speed vehicles. There are open questions. When there are vehicles moving with different desired speeds on the highway, can one control the vehicular traffic by the traffic lights? Do fast vehicles move together with slow vehicles by controlling vehicles through the sequence of traffic lights?

In this paper, we study the control, bunching, and dynamical transitions of many vehicles moving through an infinite series of traffic lights, which are periodically positioned with a constant distance on a single-lane roadway and controlled by the synchronized strategy. We extend the dynamical model of a single vehicle to that of many vehicles with different desired velocities. We present a nonlinear-map model to describe the dynamics of vehicular traffic controlled by traffic lights. We investigate the dynamical behavior of vehicles by iterating the nonlinear maps. We clarify the bunching of vehicles and the dynamical transitions by varying cycle time of traffic lights.

2. Model and nonlinear map

We consider the motion of N vehicles going through an infinite series of traffic lights on the highway. Each vehicle moves at his inherent desired velocity. The