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Physica A 350 (2005) 577–587
PHYSICA A
www.elsevier.com/locate/physa

Fluctuation and transition of vehicular traffic through a sequence of traffic lights

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Received 26 October 2004
Available online 28 November 2004

Abstract

We study the dynamical behavior of N vehicles with no passing, but are 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 dynamical model of N vehicles controlled by traffic lights is described in terms of coupled maps with three parameters. The motions of vehicles display a complex behavior, interacting with other vehicles through the sequence of traffic lights. Fluctuation of the leading vehicle is amplified to the following vehicles. The amplification of fluctuation changes with cycle time. The dynamical behavior of vehicles depends highly on their position of grouping vehicles. Signal traffic at a low density changes at specific values of cycle time. The complex dynamical transitions occur by varying three parameters.

PACS: 89.40.+k; 05.45.−a; 82.40.Bj

Keywords: Traffic; Nonlinear map; Dynamical transition; Fluctuation

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doi:10.1016/j.physa.2004.11.018

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. 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 field of physics [1–5]. The traffic flow, pedestrian flow, and bus-route problem have been studied from the point of view of statistical mechanics and nonlinear dynamics [6–23]. The dynamical phase transitions have been found in transportation systems. Traffic jams and fluctuations are typical signatures of the complex behavior of traffic flow [24,25]. Physicists have clarified the physics of traffic flow, jams, and dynamical transitions.

Brockfeld et al. have studied optimizing traffic lights for city traffic by using a CA traffic model [26]. They have shown that the city traffic controlled by traffic lights can be reduced to a simpler problem of a single-lane highway. Sasaki and Nagatani have investigated the traffic flow controlled by traffic lights on a single-lane roadway by using the optimal velocity model [27]. They have clarified the characteristics of traffic in the typical strategies of signal control and derived the relationship between the road capacity and jamming transition.

The flow throughout depends highly on both cycle time and strategy of traffic light. 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. It has been concluded that a periodic traffic does not depend on the number of traffic lights [26,27]. Few works have been known for the vehicle traffic moving through an infinite series of traffic lights. Very recently, the dynamical behavior of a single vehicle has been studied through a sequence of traffic lights. It has been shown that the vehicle displays a self-similar behavior and deterministic chaos [28,29]. However, traffic of vehicles more than one has not been investigated through an infinite series of traffic lights. When there are vehicles more than one in the neighborhood of the highway, they interact with other vehicles. Then, the vehicles display behaviors different from the one observed in case of a single vehicle. Fluctuation of the leading vehicle propagates backward, accordingly, interacting with other vehicles. Then, the vehicular traffic results in complex motions. However, little is known about how vehicles move through an infinite series of traffic lights. How are grouping vehicles related with other vehicles? How do the tour times of vehicles change with cycle time?

In this paper, we study the traffic of 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 the case with vehicles more than one. We present a coupled-map model to describe the dynamics of vehicular traffic controlled by traffic lights. We investigate the dynamical behavior of vehicles by iterating the coupled maps. We clarify the fluctuation of vehicles and the dynamical transitions by varying cycle time of traffic lights.