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The traffic flow controlled by the traffic lights in the speed gradient continuum model

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Abstract

In this paper, we have studied the traffic flow controlled by the traffic lights on a circuit road using the SG model. The single light situation, the synchronized light strategy, the green wave light strategy and the random switching light strategy are investigated. The spatio-temporal patterns are presented. Our simulations show that the plot of flow against density depends mainly on the distance between the lights and the cycle time. The capacity decreases with the increase of cycle time. For small distance between the lights, the lights do not behave as a bottleneck and the plot of flow against density looks just like a fundamental diagram. For the non-equidistant traffic lights situation, the results depend on the distribution of the distance between the lights.

Keywords: Traffic flow; Traffic light; Speed gradient model

1. Introduction

Mobility is nowadays one of the most important significant ingredients of a modern society, so the investigation of traffic flow has been given considerable attention for several decades [1–18]. A variety of approaches have been applied to describe the collective properties of traffic flow. Traditionally, two types, microscopic and macroscopic models are distinguished. The former simulate the

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motion of every vehicle while the latter concentrate on the collective behavior of vehicles. For this reason, macroscopic models are more suitable for real-time simulations, short-term traffic predictions, developing and controlling on-line speed-control systems and evaluating average travel time, fuel consumption, and vehicle emissions, etc.

The development of macroscopic traffic flow models began with the seminal LWR model presented by Lighthill and Whitham [7] and Richards [8]. The LWR model is known as the kinematic wave model, and it employs the conservation equation in the following form:

$$\rho_t + (\rho u)_x = 0, \tag{1}$$

where ρ is the traffic density, u is the space mean speed, t and x represent time and space, respectively. For the speed u, the existence of an equilibrium speed–density relationship is assumed

$$u = u_e(\rho) \tag{2}$$

Using the LWR model, a variety of simple traffic flow problems can be reproduced analytically by the method of characteristics [7] and numerically by finite differences [19]. However, the LWR model has its deficiencies, the most fatal one is that the speed is solely determined by the equilibrium speed–density relationship (2), no fluctuation of the speed around the equilibrium values is allowed, thus, the model is not able to predict interesting non-equilibrium traffic flow phenomena such as "clusters" and "stop-and-go waves" etc.

In order to overcome the shortcomings in the LWR model, the high-order models are introduced by replacing equilibrium speed–density relationship (2) with a dynamic speed evolution equation. These high-order models are categorized into two classes. In the first class of models, the dynamic speed evolution equation has the form:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} = \frac{u_e(\rho) - u}{T_r} + \frac{c_0^2}{\rho}\frac{\partial \rho}{\partial x}, \tag{3}$$

where T_r is relaxation time, c_0 is propagation speed of small disturbance. The left-hand side of Eq. (3) is the acceleration of vehicles. The first term on the right-hand side of Eq. (3) is relaxation term, representing the process that driver adjusts the speed of the vehicle to equilibrium; the second term is anticipation term, representing the process that driver reacts to the traffic ahead. c_0 has different expression in different models. For example, c_0 is taken as a constant in Payne model [9] while $c_0 = \left|\rho u_e'(\rho)\right|$ in Zhang's non-equilibrium model [10].

However, there is a common problem in this class of models. For the hyperbolic equation system constituted by Eqs. (1) and (3), there are two characteristic speeds $\lambda_1 = u + c_0$ and $\lambda_2 = u - c_0$, where the characteristic speed $\lambda_1 = u + c_0$ is always greater than the macroscopic traffic speed u, which destroys the basic discipline of traffic flow—vehicles are anisotropic particles, they only respond to the stimuli