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Driving behavior and control in traffic system with two kinds of signals

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HIGHLIGHTS

- We studied the vehicular traffic controlled by two kinds of traffic signals.
- We explored the driving behavior in the traffic system with two kinds of signals.
- We showed that the traffic flow is controlled successfully by the combination of two kinds of signals.

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ABSTRACT

We study the vehicular traffic controlled by two kinds of signals which are positioned with a periodic configuration. We propose a microscopic model to explore the driving behavior in the traffic system with two kinds of signals. The control method of traffic flow by the combination of two kinds of signals is proposed. The dynamic model is described by the nonlinear map model and the CA model. The driving behavior is clarified for the traffic system controlled by two kinds of signals. The fundamental diagrams are derived for various combinations of two kinds of signals. The traffic flow through two kinds of signals is compared with that of a single kind of signals. The traffic flow displays the complex behavior different from the conventional traffic with a single kind of signals.

1. Introduction

Transportation problems have been extensively investigated by engineers so far. Physics, other sciences and technologies meet at the frontier area of interdisciplinary research. Recently, traffic problems have attracted much attention in the fields of physics [1–5]. The concepts and techniques of physics are being applied to such complex systems as transportation systems [6–20]. The effects of heterogeneity and road structure on traffic flow have been studied by Tang et al. [21–26].

Mobility is nowadays one of the most significant ingredients of a modern society. In urban traffic, vehicles are controlled by traffic signals to give priority for a road and to ensure road safety because they encounter at crossings. In real traffic, the vehicular traffic depends highly on the control of traffic signals. Until now, one has studied the periodic traffic controlled by a few traffic signals [27,28]. Very recently, a few works have been done on the traffic of vehicles moving through an infinite series of traffic signals with the same interval [29–33]. Also, Lammer and Helbing have studied the effect of self-controlled signals on vehicular flow based on fluid-dynamic and many-particle simulations [34]. Tang et al. have proposed a signal light model and analyzed the traffic behavior controlled by signals analytically [35,36].

In real traffic, the traffic lights are controlled by either synchronized or delayed strategies. In the synchronized strategy, all the signals change simultaneously and periodically where the phase shift has the same value for all signals. In the delayed

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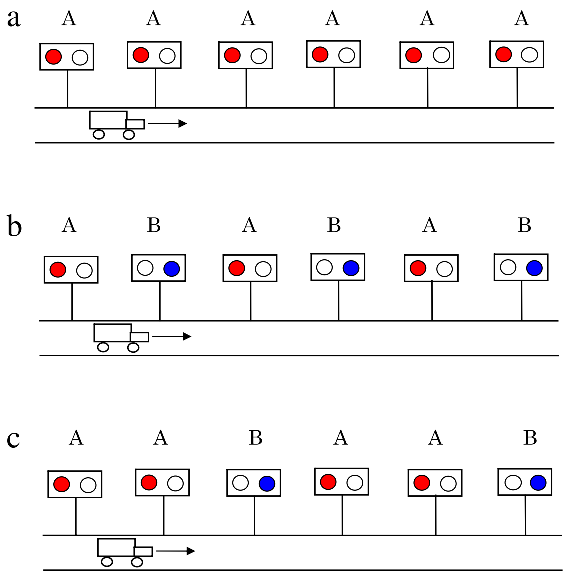

Fig. 1. (a) The conventional synchronized strategy. All the traffic signals change simultaneously from red (green) to green (red) with a fixed time period. (b) Schematic illustration of the vehicular traffic moving through the sequence of two kinds of signals (signals A and B) positioned alternately. (c) The vehicular traffic through the combination of signals A and B in which signal B is positioned every three signals. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

strategy, the signal changes with a certain time delay between the signal phases of two successive intersections. The delayed strategy is called the green-wave strategy because the red signal changes successively the green from the upstream to downstream (or from the downstream to the upstream) with a constant value of phase difference. The operator will be able to control the traffic signal by the use of the other strategy. Specifically, one can manage both cycle time and phase shift of signals. Thus, the vehicular traffic depends highly on the signal's strategy.

Until now, one has studied the vehicular traffic through a series of signals for the case in which all signals have the same cycle time. However, one will be able to control the vehicular traffic by means of a set of signals with various kinds. For example, one can consider the vehicular traffic through a sequence of two kinds of signals positioned alternately. Two kinds of signals have the cycle times different from each other. The periodic configuration of two kinds of signals has important effects on the vehicular traffic because the signal configuration changes the vehicular motion. In real traffic, it is very important to control the vehicular motion by means of the periodic configuration of two kinds of signals. However, the control of the vehicular traffic by two kinds of signals has not been investigated until now.

Generally, a metal is improved by mixing other atoms. An alloy composed of atoms A and B has the properties different from the pure metal composed of only atom A. Thus, one has improved the metal. The traffic control by the combination of two kinds of signals may be similar to the improvement of metal by alloy (mixture) composed of atoms A and B.

In this paper, we study the vehicular traffic through a series of two kinds of signals positioned periodically. We control the traffic by means of two kinds of signals. We present the nonlinear dynamic model for the vehicular motion through the sequence of two kinds of signals with the periodic configuration. We investigate the dynamical behavior of vehicular traffic. Also, we derive the fundamental diagram for the traffic flow with two kinds of signals. We clarify the control and dynamical behavior of vehicular traffic through the sequence of two kinds of signals by varying the cycle time and the combination.

2. Nonlinear-map model

First, we consider the case in which vehicular density is low. At low density, vehicles are not interacted each other. Therefore, we consider the motion of a single vehicle going through the series of two kinds of traffic signals. Later, we study the vehicular traffic at intermediate and high densities by the use of CA model.

Two kinds of traffic signals are positioned at a constant interval on a roadway. Two kinds of signals are called signals A and B. The traffic signals are numbered, from upstream to downstream, by $1, 2, 3, \ldots, n, n+1, \ldots$. The interval between signals n and $n+1$ is indicated by l. The vehicle moves with the mean speed v between a traffic signal and its next signal. Signal A changes periodically with period $t_{s,A}$. Signal B changes periodically with period $t_{s,B}$. Periods $t_{s,A}$ and $t_{s,B}$ are called as the cycle times of signals A and B respectively. The phase shift of all signals is set as zero.

At the conventional synchronized strategy shown in Fig. 1(a), all traffic signals change simultaneously from red (green) to green (red) with a fixed time period $(1-s_{p,A})t_{s,A}$ ($s_{p,A}t_{s,A}$). The period of green is $s_{p,A}t_{s,A}$ and the period of red is $(1-s_{p,A})t_{s,A}$. Fraction $s_{p,A}$ represents the split which indicates the ratio of green time to cycle time for signal A.