Physica A 465 (2017) 297–304

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Effect of stoppage time on motion of a bus through a sequence of signals

Takashi Nagatani

Department of Mechanical Engineering, Shizuoka University, Hamamatsu 432-8561, Japan

HIGHLIGHTS

- We presented the dynamic model of a bus moving through the series of traffic signals.
- We studied the effect of the stoppage time on the bus motion by using the dynamic model.
- We found that the bus motion has two kinds of dynamic states: the normal state and the offset state.

ARTICLE INFO

Article history:
Received 2 April 2016
Received in revised form 14 June 2016
Available online 22 August 2016

Keywords:
Traffic dynamics
Bus motion
Signal control
Nonlinear map
Complex system

ABSTRACT

We study the dynamic motion of a bus moving through the series of traffic signals where the bus stops at bus stops during a time. The dynamic state of the bus depends highly on both stoppage time at the bus stop and cycle time of the signal. It is found that the bus motion has two kinds of dynamic states: the one is the normal state and the other is the offset state. In the normal state, the bus stops normally at both bus stops and signals. In the offset state, the bus passes timely through the signal sometimes and the stoppage time at the bus stop is offset against the stopping time at the signal. If the bus speed has the same value as the car speed, the travel time of the bus is consistent with that of the car in the offset state. The region map (phase diagram) is shown for two kinds of dynamic states: the normal and offset states.

1. Introduction

Engineers have extensively interested in transportation problems so far. Recently, physicists have investigated the traffic systems [1–5]. They have applied the concepts and techniques of physics to the transportation systems. Physics, other sciences and technologies meet at the frontier area of interdisciplinary research. The traffic flow and pedestrian flow have been studied from a point of view of statistical mechanics and nonlinear dynamics [6–44].

In city traffic, vehicles are controlled by traffic lights to give priority for a road at crossings. The vehicular traffic depends highly on the control method of traffic lights. The operator will control the traffic light by the use of various strategies. One can manage both cycle time and phase of signals to control the vehicular traffic. The signals are controlled by either synchronized or green-wave strategies [45–49,31,50]. In the synchronized strategy, all the signals change simultaneously and periodically where the phase has the same value for all signals. In the green-wave strategy, the signal changes with a certain time delay between the signal phases of two successive intersections where the phase difference between two signals has the same value for all signals. The traffic flow at the synchronized and green-wave strategies has been studied extensively.

E-mail addresses: tmtnaga@ipc.shizuoka.ac.jp, wadokeioru@yahoo.co.jp.

http://dx.doi.org/10.1016/j.physa.2016.08.047

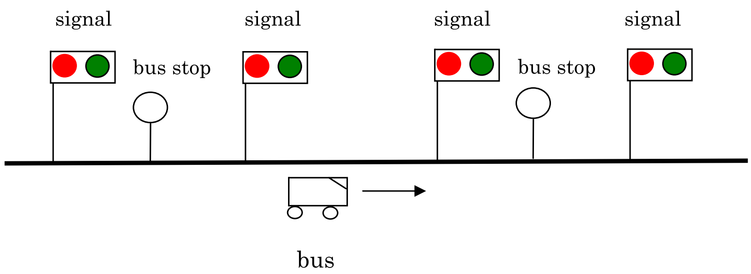

Fig. 1. Schematic illustration of the bus model through the series of signals while stopping at bus stops. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

In the public transportation system, it is important and necessary to make the bus schedule. It is well known that passengers using buses are served best when buses arrive at stations on time and there is no congestion. However, it is hard to operate buses on time. Frequently, buses are delayed or go faster due to the signal and the stoppage time at the bus stop. The bus dynamics depends highly on the stoppage time at the bus stop. The bus schedule is closely related to the dynamic motion of the bus [39]. The arrival time of the bus is not determined only by the stoppage time at the bus stop but also by the signal's control method.

When the bus stops at the bus stop during the stoppage time and then goes ahead, the next signal is red or green. If the bus is well timed, the bus goes through green signal. Otherwise, the bus stops at red signal. Thus, if the bus is timely, the stoppage time at the bus stop may be offset against the stopping time at a signal. Whether or not the bus stops at the next signal depends on both stoppage time at the bus stop and signal's cycle time. Thus, the dynamic state of the bus depends highly on both stoppage time at the bus stop and cycle time of the signal. It is not known how the stoppage time at the bus stop affects on the motion of the bus. It is necessary and important to know the effect of the stoppage time at the bus stop on the dynamics of the bus in the city traffic controlled by signals.

In this paper, we study the dynamic motion of a bus through an infinite series of signals while stopping at the bus stops. We present the nonlinear-map model for the bus motion through the series of signals. We show how the bus motion is affected by both stoppage at the bus stop and signals. We clarify the dynamical behavior of a single bus through the series of signals by varying both stoppage time and cycle time of signals.

In Section 2, we propose the nonlinear-map model for the motion of the bus through an infinite series of signals while stopping at the bus stops. In Section 3, we present the numerical result for the arrival time of the bus. We show that the bus displays two kinds of dynamic states: the normal and offset states. We present the summary in Section 4.

2. Nonlinear-map model

We consider the motion of a bus going through the infinite series of signals on the roadway with bus stops where the traffic is a low density. The bus stops at all bus stops. The signals are controlled by the synchronized strategy. All signals change simultaneously and periodically. It is known that the vehicular traffic is in the free traffic state at a low density where a vehicular motion is little affected by other vehicles. Therefore, one can assume that the bus is not correlated to other vehicles at a low density. The bus stops at red signal and go through green signal while stopping at bus stops. The bus stops at the bus stop during a time. The time is called as the stoppage time. Fig. 1 shows the schematic illustration of the bus model through the series of signals while stopping at bus stops.

The signals are numbered by $1, 2, 3, ---, n, n+1, ---$ to x direction. The signals are positioned with the same interval on the roadway where the interval between signals $n-1$ and n is indicated by l. All signals change periodically with period t_s. Period t_s is called as the cycle time. The vehicle moves with the mean speed v between a signal and its next signal. All signals change periodically from red (green) to green (red) with a fixed time period $(1-s_p)t_s$ $(s_p t_s)$. The period of green is $s_p t_s$ and the period of red is $(1-s_p)t_s$. Fraction s_p represents the split which indicates the ratio of green time to cycle time.

The bus stops are positioned with the same interval on the roadway. The bus stop between signals n and $n+1$ is numbered by n. The stoppage time at bus stop n is defined as $s_t(n)$. If there is no bus stop between signals n and $n+1$, the stoppage time $s_t(n)$ is zero.

When the bus arrives at a signal and the signal is red, the bus stops at the position of the signal. Then, when the signal changes from red to green, the bus goes ahead. We define the arrival time of the bus at signal n as $t(n)$. The arrival time at signal $n+1$ is given by

$$t(n+1) = t(n) + l/v + s_t(n) + \{r(n) - t(n)\}. \tag{1}$$

Here, l/v is the time it takes for the bus to move between signals n and $n+1$. $r(n)$ is such time that signal n just changed from red to green. Since signals vary with period t_s (cycle time), it is described by

$$r(n) = t_s\{\text{int}\,(t(n)/t_s) + 1\}. \tag{2}$$