Physica A 506 (2018) 229–236

Contents lists available at ScienceDirect

Physica A

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

# Effect of bypasses on vehicular traffic through a series of signals

Takashi Nagatani

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

## HIGHLIGHTS

- We studied the dynamic motion of a vehicle moving through the series of signals on a roadway with bypasses.
- We compared the vehicular motion on the roadway with bypasses with that without bypasses.
- We explored that the travel time decreases by using bypasses for specific values of cycle time but does not change for other values of cycle time.

## ARTICLE INFO

*Article history:*
Received 1 January 2018
Received in revised form 25 February 2018
Available online 21 April 2018

*Keywords:*
Traffic dynamics
Signal control
Bypass
Nonlinear map
Travel time

## ABSTRACT

We study the dynamic motion of a vehicle moving through the series of traffic signals on a roadway with bypasses. A vehicle moves on either main roadway or bypass. There are all signals on the main roadway and signals are controlled by both cycle time and phase difference. The dynamic model of the vehicular motion is described in terms of the nonlinear map. The vehicular motion is studied on the roadway with bypasses and without bypasses. The vehicular motion changes highly by the signal control on the roadway with bypasses. It is found that the travel time decreases highly by the use of bypasses for specific values of cycle time but does not change for other values of cycle time. Also, the dependence of the travel time on the cycle time is derived at the green-wave strategy.



## 1. Introduction

Transportation problems have been investigated extensively in interdisciplinary research fields so far. Recently, physicists have been interested in traffic problems [1–5]. Physics, other sciences and technologies meet at the frontier area of interdisciplinary research. They have applied the concepts and techniques of physics to such complex systems as transportation systems. The traffic flow and pedestrian flow have been studied from a point of view of statistical mechanics and nonlinear dynamics [6–47]. Especially, traffic congestion has been investigated numerically and analytically.

Information is a key commodity in many social systems. In vehicular traffic system, road users obtain real-time information about the traffic conditions by means of communication such as variable message signs, radio broadcasts or on-board computers. The real-time information helps the individual road users to minimize their personal travel time. Wahle et al. have proposed the dynamic model for two-route traffic flow with real-time information [48]. The traffic flow with real-time traffic information has been studied using a route choice scenario [49–53].

In city traffic network, traffic signals control vehicular traffic to give priority for a road because vehicles encounter at crossings. The vehicular traffic depends highly on the control method of traffic signals. Generally, the signals are controlled

*E-mail address:* nagatani.takashi@shizuoka.ac.jp.

https://doi.org/10.1016/j.physa.2018.04.027
0378-4371/

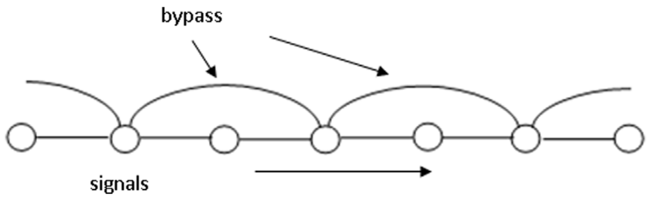


**Fig. 1.** Schematic illustration of the main roadway connected by bypasses. The traffic signals are positioned on the main roadway with the same interval. A signal is represented by open circle. The bypass is connected every two signals. The bypass bifurcates from the main roadway just after a signal and merges into the main roadway just before the next signal.

by either synchronized or green-wave strategies [54–59]. In the synchronized strategy, the phase of all signals has the same value. All signals change simultaneously and periodically. In the green-wave strategy, the phase difference between two signals has the same value for all signals. The signal changes with a certain time delay between the signal phases of two successive intersections. The traffic flow at the synchronized and green-wave strategies has been studied extensively. The vehicular traffic at the synchronized strategy is controlled only by the cycle time. While the vehicular traffic at the green-wave strategy is controlled by both cycle time and phase difference. The operator can manage both cycle time and phase of signals to control the vehicular traffic.

Roadways are connected each other. Traffic network is formed in a city. One wishes to go to destination without congestion or as fast as possible. Drivers make a route choice in order to go from a starting point (origin) to the destination. They may avoid traffic signals to move as soon as possible. Generally, there are roadways with bypasses in traffic network. Main roadways are connected with bypasses. Traffic signals are positioned on main roadways. Signals on bypasses may be less than main roadways. A driver can select a bypass to move as fast as possible. To avoid traffic signals, how short is the travel time if one selects bypasses? It is necessary and important to estimate the travel time accurately on roadways with bypasses where there are traffic signals. The travel time depends on both signal control and use of bypasses.

In this paper, we study the dynamic motion of a vehicle through an infinite series of signals on the roadway with bypasses. We present the nonlinear-map model for the vehicular motion on the roadway with bypasses and without bypasses. We show how the vehicular motion changes by the use of bypasses. We clarify the dependence of the travel time on both signal control and the use of bypasses.

In Section 2, we propose the nonlinear-map model for the vehicular motion through an infinite series of signals on the roadway with bypasses. In Section 3, we present the numerical result for the vehicular motion. We show that the vehicular motion displays a complex behavior. We present the summary in Section 4.

## 2. Model and nonlinear map

We consider the motion of vehicles moving through the series of traffic signals on the single-lane roadway with bypasses at a low density. The vehicular traffic is in the free traffic state at a low density. All vehicles move almost with the maximal speed and a vehicular motion is little affected by other vehicles. It is assumed that vehicles are not correlated each other at a low density. Here, we consider the motion of a single vehicle going through the infinite series of signals on the single-lane roadway with bypasses.

Fig. 1 shows the schematic illustration of the main roadway connected by bypasses. The traffic signals are positioned on the main roadway with the same interval. A signal is represented by open circle. The interval between two signals is defined as $l_a$. The bypass is connected every two signals. The length of the bypass is defined as $l_b$. Bypass's length $l_b$ is longer than two times the signal's interval, i.e. $l_b > 2l_a$. The bypass bifurcates from the main roadway just after a signal and merges into the main roadway just before the next signal. A driver can use the bypass to avoid the signal. Here, we assume that a driver makes a route choice stochastically. A driver selects the bypass with probability $p$. Also, we consider the case the bypass is connected every three signals. In the case, bypass's length is longer than three times the signal's interval, i.e. $l_b > 3l_a$.

The signals are numbered by $1, 2, 3, \ldots, n, n+1, \ldots$ to $x$ direction on the main roadway. The signals are positioned with the same interval on the main roadway where the interval between signals $n-1$ and $n$ is indicated by $l_a$. All signals change periodically with period $t_s$. Period $t_s$ is called as the cycle time. The phase of signals varies with signals. 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 $(1-s_p)t_s$ $(s_pt_s)$. The period of green is $s_pt_s$ 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. Each signal timing is controlled by offset time $t_{offset}$. The offset time means the difference of phases between two successive signals. In the green wave (delayed) strategy, the phase of signal $n$ is given by $t_{phase}(n) = nt_{offset}$ where the phase at signal $n$ is indicated by $t_{phase}(n)$. Then, the signal switches from red to green in green wave way.

First, we derive the nonlinear map for the case that the vehicle moves only on the main roadway with no use of bypasses. When a vehicle arrives at a signal and the signal is red, the vehicle stops at the position of the signal. Then, when the signal