Physica A xx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Physica A

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

Complex motion of a shuttle bus between two terminals with periodic inflows

Takashi Nagatani

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

HIGHLIGHTS

- We presented the dynamic model of a shuttle bus between two terminals with periodic inflows.
- We studied the dynamic motion of the bus when passengers come periodically at two terminals with different period and phase.
- We explored that the shuttle bus displays the periodic, quasi-periodic, and chaotic motions.

ARTICLE INFO

Article history:
Received 16 November 2015
Available online xxxx

Keywords:
Shuttle bus
Transportation
Circle map
Quasi-periodic motion
Chaos
Fluctuation

ABSTRACT

We investigate the dynamic behavior of a shuttle bus serving repeatedly between two terminals when passengers come periodically at two terminals A and B. The period and phase of the periodic inflow of passengers at terminal A are different from those at terminal B. The dynamic behavior of the bus is highly affected by the difference between two periods and the phase difference. The bus schedule is closely related to the dynamics. We present the extended circle map model for the dynamics of the shuttle bus. The motion of the shuttle bus depends highly on the inflow periods, the period difference, the phase difference, and the loading parameter. The shuttle bus displays the periodic, quasi-periodic, and chaotic motions. The quasi-periodic motion changes to a chaotic motion by the difference between two periods.

1. Introduction

Recently, transportation problems have attracted much attention among physicists [1–5]. Interesting dynamic phase transitions have been found in the transportation system. The dynamic transition and chaos have been studied in the traffic flow, pedestrian flow, and bus-route problems [6–41]. The dynamic transition and chaos are typical signatures of the complex behavior of transportation system.

The dynamic behavior of buses has been studied when the buses repeatedly shuttle between the starting terminal (origin) and the final terminal (destination). The shuttle bus displays the complex motion by the interaction between buses and passengers. It has been found that the deterministic chaos occurs in the shuttle-bus transportation [40,41]. The shuttle bus system exhibits severe congestion problems in the peak traffic. In managing the shuttle bus operation, it is important to transport passengers from the starting point (a terminal) to his destination (other terminal) within some period of time for the rush hour trips [40,41]. Another criterion used in shuttle bus operation is that a passenger's waiting time should not exceed some specified value. Furthermore, it is necessary and important to estimate the arrival time of buses accurately for a bus schedule.

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

http://dx.doi.org/10.1016/j.physa.2016.01.011
0378-4371/

Please cite this article in press as: T. Nagatani, Complex motion of a shuttle bus between two terminals with periodic inflows, Physica A (2016), http://dx.doi.org/10.1016/j.physa.2016.01.011

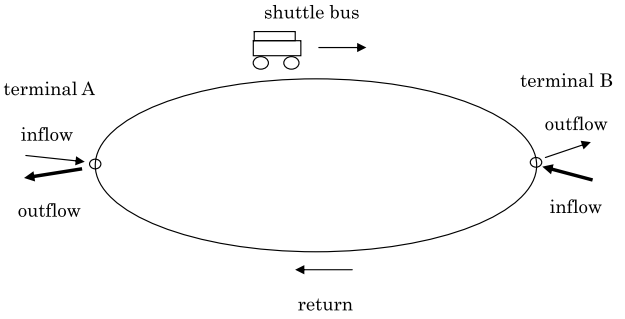

Fig. 1. Schematic illustration of the shuttle bus transport between two terminals. Passengers come into each terminal periodically. Passengers board the bus at terminal A and all passengers get off the bus at terminal B when the bus arrives at terminal B. As soon as the bus is empty, passengers at terminal B board the bus and all passengers get off the bus at terminal A when the bus arrives at terminal A.

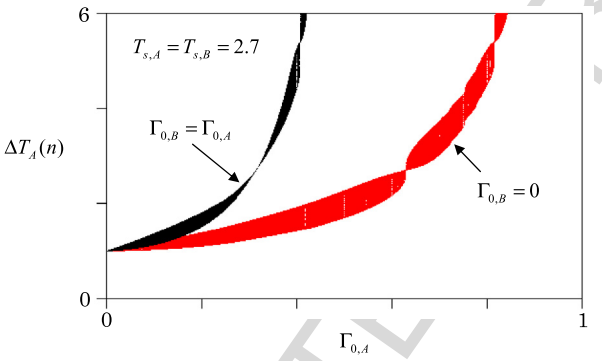

Fig. 2. Plot of tour time $\Delta T_A(n)$ versus loading parameter $\Gamma_{0,A}$ for arrival numbers from $n = 1000$ to $n = 2000$ for inflow period $T_{s,A} = T_{s,B} = 2.7$. Black dots indicate the tour time $\Gamma_{0,A} = \Gamma_{0,B}$. Red dots indicate the tour time for $\Gamma_{0,B} = 0$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

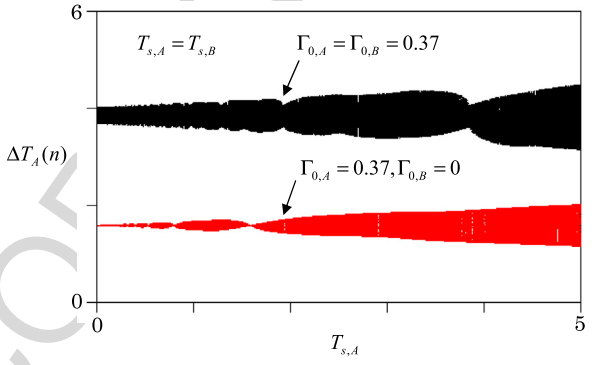

Fig. 3. Plot of tour time $\Delta T_A(n)$ versus inflow period $T_{s,A}$ for arrival numbers from $n = 1000$ to $n = 2000$ for loading parameter $\Gamma_{0,A} = \Gamma_{0,B} = 0.37$. Black dots indicate the tour time $\Gamma_{0,A} = \Gamma_{0,B}$. Red dots indicate the tour time for $\Gamma_{0,A} = 0.37$ and $\Gamma_{0,B} = 0$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

In real bus traffic, the inflow rate of passengers into the bus varies greatly with time. The bus system with a periodic inflow at the starting point has been studied. It has been shown that the bus displays a complex motion with varying the inflow rate and the period. The dynamic motion of the shuttle bus depends highly on the inflow rate and the period of incoming passengers at the starting terminal. In the model, passengers board the bus only at the starting point. Generally, in the shuttle bus system, passengers board and get off the bus at two terminals when the bus shuttles repeatedly between two terminals. It is necessary to extend the dynamic model to the shuttle bus transport serving repeatedly between two terminals with independent inflows. How does the bus motion changes by introducing a periodic inflow at another terminal? Until now, the shuttle bus system with periodic inflows at two terminals has not been investigated. In the shuttle bus transport with two inflows, the differences between period and phase will induce a complex motion of the bus by the interaction between

Please cite this article in press as: T. Nagatani, Complex motion of a shuttle bus between two terminals with periodic inflows, Physica A (2016), http://dx.doi.org/10.1016/j.physa.2016.01.011