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Chaos control and schedule of shuttle buses

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Abstract

We study the dynamical behavior of a few shuttle buses when they pass each other freely and control the speed to retrieve the loading's delay. The dynamics of the buses is expressed in terms of the nonlinear maps. The tour times of buses and the time headway between buses exhibit the complex behavior with varying trips. The buses exhibit deterministic chaos even if there are no noises. Bus speeds up to retrieve the delay induced by loading the passengers on its bus. The bus chaos is controlled by varying the degree of speedup. The chaotic motion depends on both loading and speedup's parameters. The shuttle bus schedule is connected with the complex motions of shuttle buses. The region map (phase diagram) is shown to control the complex motions of buses.

Keywords: Chaos; Bus schedule; Traffic dynamics; Nonlinear map

1. Introduction

Recently, transportation problems have attracted much attention in the fields of physics [1–5]. The traffic flow, pedestrian flow, and bus-route problem have been studied from a point of view of statistical mechanics and nonlinear dynamics [6–23]. The interesting dynamical phase transitions have been found in the transportation system. The jams and chaos are typical signatures of the complex behavior of traffic flow [24,25]. The shuttle bus system is closely connected to the traffic flow.

Frequently, one experiences an irregular arrival of shuttle buses when he waits the coming bus at a terminal. The irregularity will be induced not only by stochastic variation in passengers arriving at the terminal, but also by varying headway between a bus and the bus ahead of it. In managing the shuttle bus operation, the usual criterion is that one should be able to transport everyone from the starting point to his destination within some period and a passenger's waiting time should not exceed some specified value [26–28]. Another criterion is that buses shuttle on time between the origin and destination. Therefore, it is important and necessary to suppress the irregularity of tour times and operate the buses regularly and on time.

Until now, some models of the bus route system have been studied. In the bus route model with many buses, it has been found that the bunching transition between an inhomogeneous jammed and a homogeneous phases occurs with increasing bus density [17–22]. In the cyclic bus system not passing each other, it has been shown

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that the bus exhibits such complex behaviors as the periodic and chaotic motions [27]. Also, it has been found that the distinct chaotic motion is induced by passing each other freely in the system including a few shuttle buses [28]. The dynamical model of the shuttle buses has been extended to take into account the maximum capacity of buses. Fluctuation of the riding passengers has been connected to the chaotic motions of shuttle buses [29]. The chaos is attributable to such origin that the time headway varies abruptly when buses pass each other freely. With the increase of awaiting passengers at bus stop, a bus slows down because it takes more time for awaiting passengers to board the bus. The time headway of the bus increases more and more with trips. However, the time headway of the next coming bus decreases. In time, the bus is overtaken by the next coming bus. As the result, the bus motion becomes irregular. If the bus slows down, the bus will speed up in order to operate it on time. It will be expected that the speedup of a bus suppresses the irregularity.

In this paper, we study the chaos control by the speedup in the shuttle bus system. We present a dynamical model to describe the motions of buses taking into account the speedup. We investigate the dynamical behavior of buses induced by the interaction between buses through the passengers waiting at the starting point, when the buses shuttle between the starting point and destination repeatedly. We clarify the dynamical states of shuttle buses by varying both loading and speedup parameters. We show the phase diagram (region map) for the dynamical states.

2. Nonlinear map model

We consider the dynamical behavior of M buses shuttling between the starting point (origin) and the destination. Fig. 1 shows the schematic illustration of the shuttle bus system. The awaiting passengers at the origin board a bus just arrived, then the bus starts at the origin, moves toward the destination, all currently riding passengers leave the bus when the bus arrives at the destination, and the bus returns to the origin. When a bus reaches other buses, the bus passes those freely. A bus is stopping at the origin during the period that all the passengers waiting at the origin board the bus. Similarly, a bus is stopping at the destination during the period that all boarding passengers leave the bus. The bus slows down proportionally to the stopping periods. Also, the bus speeds up to retrieve the delay of stopping.

We derive the equations of bus motion to describe the above dynamics. Define the number of passengers boarding bus i at trip m by $B_i(m)$. The parameter γ is the time it takes one passenger to board the bus, so $\gamma B_i(m)$ is the amount of time needed to board all the passengers at the origin. The parameter η is the time it takes for one passenger to leave the bus, so $\eta B_i(m)$ is the amount of time needed to leave all the passengers at the destination. The moving time of bus i at trip m is $2L/V_i(m)$ where L is the length between the origin and the

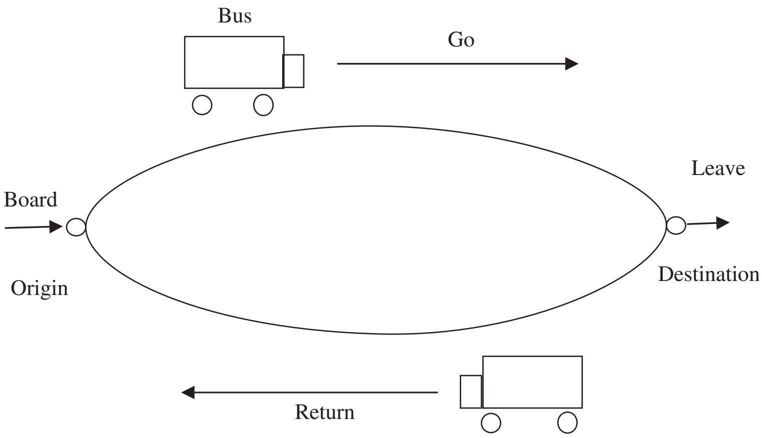

Fig. 1. Schematic illustration of the shuttle bus system. The awaiting passengers at the origin board a bus just arrived, then the bus starts at the origin, moves toward the destination, all currently riding passengers leave the bus when the bus arrives at the destination, and the bus returns to the origin. When a bus reaches other buses, the bus passes those freely. A bus is stopping at the origin during the period that all the passengers waiting at the origin board the bus. Similarly, a bus is stopping at the destination during the period that all boarding passengers leave the bus. The bus slows down proportionally to the stopping periods. The bus speeds up to retrieve the delay of stopping.