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Effect of speedup delay on shuttle bus schedule

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HIGHLIGHTS

- We presented the dynamic model of a shuttle bus with the delayed speedup control.
- We studied the dynamic motion of the speed-controlled bus by using the delayed map model.
- We explored that the bus motion changes from a stable state, through a periodic state, to a quasi-periodic state by the delayed speed control.

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ABSTRACT

We study the bus schedule in the shuttle bus transportation system controlled by speedup. The bus schedule is closely related to the dynamic motion of the bus. The motion of a shuttle bus depends on the inflow rate of passengers and the delayed speedup control. The delayed speedup control has an important effect on the dynamic motion of the bus. We present the delayed map model for the dynamics of the shuttle bus with the delayed speedup control. The bus motion changes from a stable state, through a periodic state, to a quasi-periodic state by the delayed speedup control. The return map of the tour time displays a smooth closed curve and the bus motion is quasi-periodic. The dynamic transition to the quasi-periodic motion changes greatly with the delay time. We clarify the effect of the delayed speedup control on the bus schedule.

1. Introduction

Recently, the traffic flow and pedestrian flow have been studied from a point of view of statistical physics and nonlinear dynamics [1–5]. The concepts and techniques of physics have been applied to transportation systems [6–38]. 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 in the bus transport system. The bus schedule is closely related to the dynamic motion of buses [39]. The bus dynamics depends highly on the control method. The arrival time of buses is not determined only by serving passengers but also by the speed control method of buses.

In the morning and evening peaks, the bus transport system exhibits severe congestion problems. The maximum rate of serving passengers increases with the number of buses. In managing the bus operation, the usual criterion for deciding the number of buses is that one should be able to transport everyone from the starting point to his destination within some period of time for the rush hour trips. Another criterion used in shuttle bus operation is that a passenger's waiting time should not exceed some specified value. It is very important to make an accurate estimate of the arrival time in the bus transportation.

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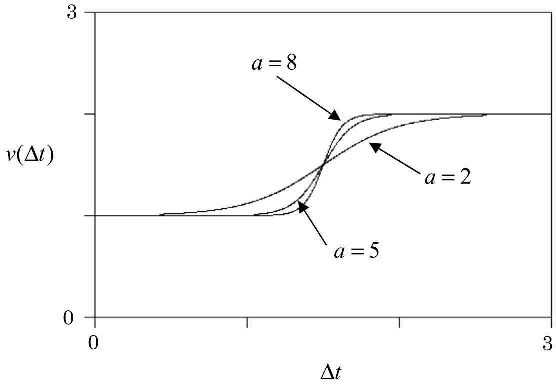

Fig. 1. Plots of speed function (1) against tour time Δt at $a = 2, 5$, and 8 where $v_0 = 1.0$, $v_{\max} = 2.0$, and $t_c = 1.5$.

Until now, some models of the bus transport system have been studied. In the bus route model with many buses, it has been found that the bunching transition between a heterogeneously jammed phase and a homogeneous phase occurs with increasing density [40–44]. In the shuttle bus system, it has been shown that the bus exhibits such complex behaviors as the periodic and chaotic motions [45–50].

The bus schedule must be determined by the motion of buses taking into account the inflow rate of passengers and the speed control method. However, there are little dynamic models to estimate the bus schedule by taking into account the speed control method. It is important and necessary to estimate the arrival time for the bus transport system with the speedup control.

It is well known that the delay of acceleration and deceleration has the important effect on the jam formation in traffic flow [1,2]. The delay effect has been studied for the vehicular traffic flow by many researchers. However, the delay effect on bus schedule is little known in the bus transportation system. It is important to study how the delay of the speedup affects the bus dynamics and schedule.

In this paper, we investigate the effect of speedup delay on the bus schedule in transportation of a shuttle bus. We present the delayed map model for the dynamic motion of a shuttle bus with the speedup delay. We make an accurate estimate of the arrival time using the delayed map model. We show that the speedup delay has the important effect on the dynamic transitions to complex motion occurring in the bus traffic. We clarify the dependence of the dynamic motion on both inflow rate and speedup delay. We discuss the relationship between the bus schedule and the dynamic motion with the speedup delay.

2. Delayed map model

We consider the dynamic model of the shuttle bus system which mimics the service of a bus shuttling repeatedly between the origin and the destination (for example, an airport and a railway station). The bus carries the passengers at the origin to the destination. This shuttle bus model has the realistic background. We model the public transport system of a shuttle bus as follows. A single bus shuttles repeatedly between the starting point (origin) and the destination. The starting point is the only position to take the bus. The passengers board the bus at the origin and then the bus starts from the origin. The bus moves toward the destination. When the bus arrives at the destination, all riding passengers leave the bus. After all passengers get off the bus, the bus leaves the destination and returns to the origin. The process is repeated.

The bus driver controls the speed of the bus according to the tour time. The driver speeds up more and more when tour time Δt approaches critical value t_c and the bus speed reaches maximum speed $v_{\max}$ after a while. We assume that the speed is controlled by the following function:

$$v(\Delta t) = v_0 + \frac{\tilde{v}}{2}\left\{1.0 + \tanh[a(\Delta t - t_c)]\right\}, \tag{1}$$

where v_0 is the cruising speed, $\tilde{v} = v_{\max} - v_0$, and $v_{\max}$ is the maximum speed. Parameter a is the slope of the speed control function at the turning point. It represents the degree of the speed change. If the driver changes the speed abruptly (gradual), parameter a has a high (low) value. When $\Delta t \to \infty$, $v(\Delta t) \to v_{\max}$. Fig. 1 shows the plots of speed function (1) against tour time Δt at $a = 2, 5$, and 8 where $v_0 = 1.0$, $v_{\max} = 2.0$, and $t_c = 1.5$. When parameter a is very high, speed function (1) approaches the step function.

We describe the dynamic model of the bus system in terms of the nonlinear map. We assume that all the passengers waiting at the origin can board the bus. New passengers arrive at the origin with inflow rate μ [persons/min]. The arrival time at the origin and trip n is defined by $t(n)$. So $\mu(t(n) - t(n-1))$ is the number of passengers that have arrived since the bus left the origin previously. The number of passengers boarding the bus at trip n is expressed by

$$B(n) = \mu\left(t(n) - t(n-1)\right). \tag{2}$$