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Delay effect on schedule in shuttle bus transportation controlled by capacity

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ABSTRACT

We study a bus schedule in a shuttle bus transportation system controlled by capacity. The motion of shuttle buses depends on the inflow rate of passengers, the number of buses, and the delayed increase of buses. The bus schedule is closely related to the dynamic motion of buses. The delayed increase of buses has an important effect on the arrival of buses. We present the delayed piecewise map model for the dynamics of shuttle buses with the delayed increase. The motion of buses changes from a stable state to an unstable state and vice versa with increasing the inflow rate. The arrival of shuttle buses oscillates with various periods in the unstable state. The dynamic transitions change highly with the delayed increase of buses. We clarify the effect of the delayed increase on the bus schedule.

1. Introduction

The concepts and techniques of physics are being applied to such complex systems as transportation systems [1–5]. The traffic flow, pedestrian flow, and bus-route problem have been studied from the point of view of statistical physics and nonlinear dynamics [6–30]. It is well known that public transport passengers are served best when buses arrive at stations on time. However, it is hard to operate buses on time. Buses are delayed or go faster in the bus transport system. The arrival time of buses depends highly on serving passengers and the number of buses. The bus schedule is closely related to the dynamic motion of buses with passengers [31].

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 a heterogeneously jammed phase and a homogeneous phase occurs with increasing density [19–22]. In the cyclic bus system not passing each other, it has been shown that the bus exhibits such complex behaviors as periodic and chaotic motions [29]. 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 [30].

The shuttle bus system exhibits severe congestion problems in peak traffic. The maximum rate of serving passengers increases with the number of buses. In managing the shuttle 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 [28–31].

In real bus traffic, the inflow rate of passengers into buses varies with time. The total capacity of all buses increases with the number of buses. It is necessary to increase the number of buses if the inflow rate of passengers increases. However, many buses are not necessary, when the inflow rate decreases. Thus, the total capacity of the bus transport system is controlled by the number of buses. If the passengers increase (decrease), an increase (decrease) of buses is done. The increase (decrease) of buses is not done instantly but a delayed increase (decrease) occurs due to the arrangement of additional buses. The bus

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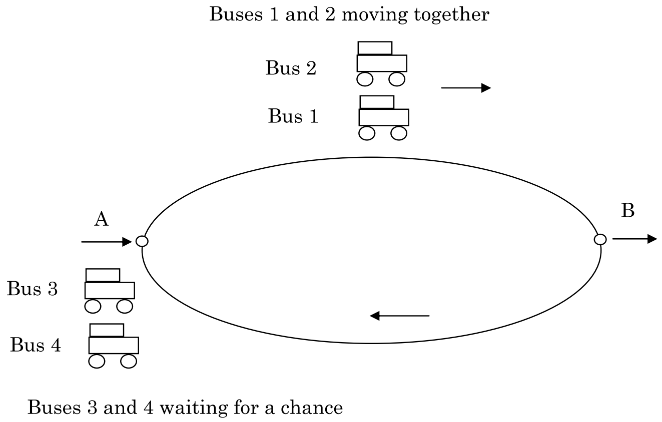

Fig. 1. Schematic illustration of shuttle buses. Point A is the starting point (origin) and point B is the destination. Passengers arrive continuously at the origin with a rate. The passengers board buses 1 and 2 at the origin and then buses 1 and 2 start at the same time from the origin. Buses 1 and 2 move together toward the destination. Buses 1 and 2 arrive at the destination at the same time. All currently riding passengers leave the bus when the buses arrive at the destination. Buses 1 and 2 return to the origin at the same time. Buses 3 and 4 wait for a chance. The operator controls the number of buses at the origin corresponding to the number of passengers.

schedule must be determined with the inflow rate of passengers, the number of buses, and the delayed increase of buses. However, there are few dynamic models to estimate the bus schedule of the shuttle buses by taking into account the delayed increase of buses. It is important and necessary to estimate the arrival time of buses for a bus transport system with a delayed increase of buses.

It is well known that the delay of acceleration and deceleration has an important effect on jam formation in traffic flow [1,2]. The delay effect has been studied for 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 for the arrangement of additional buses affects the bus dynamics and schedule.

In this paper, we investigate the bus schedule in transportation of shuttle buses where the number of buses is controlled by the capacity. We study the effect of the delayed increase (or decrease) of buses on the bus schedule. We present the delayed piecewise map model for the dynamic motion of shuttle buses with the delay. We estimate the arrival time of buses using the delayed piecewise map model. We show that the delay has an important effect on the dynamic transitions to complex motion occurring in bus traffic. We clarify the dependence of the dynamic motion on both inflow rate and delay. We discuss the relationship between the bus schedule and the dynamic motion with the delay.

2. Delayed piecewise map model

We consider the dynamic model of the shuttle bus system which mimics the service of buses shuttling repeatedly between the airport and the railway station. The buses carry the passengers getting off the airplane to the railway station. This shuttle bus model has a realistic background. We model the public transport system of buses as follows. N buses shuttle repeatedly between the starting point (origin) and the destination. The starting point is the only position to take the buses. The passengers board the buses at the origin and then the buses start at the same time from the origin. The buses move together toward the destination. The buses arrive at the destination at the same time. All currently riding passengers leave the bus when the buses arrive at the destination. The buses leave the destination and return to the origin at the same time. The operator controls the number of buses at the origin corresponding to the number of passengers.

Fig. 1 shows the schematic illustration of shuttle buses. Point A is the starting point (origin) and point B is the destination. Passengers arrive continuously at the origin with a rate. The number of buses increases one by one when the number of passengers is superior to the capacity, while the number of buses decreases one by one if the number of passengers is less than the capacity. A system of four buses is shown in Fig. 1. Buses 1 and 2 start at the same time from the origin and move together. Buses 3 and 4 stop at the origin and wait for a chance. The operator controls the number of buses at the origin corresponding to the number of passengers. If the number of passengers is higher than the capacity, bus 3 runs with buses 1 and 2. Buses 1–3 arrive at the destination at the same. Furthermore, if passengers increase, bus 4 runs with buses 1–3. When the number of passengers is less than the capacity, bus 2 stops at the origin and waits for a chance. Running buses return to the origin at the same time

The increase (decrease) of buses is determined by the number of passengers waiting at the origin. However, it takes time to arrange an additional bus. Therefore, a delay occurs when buses increase or decrease corresponding to the number of passengers waiting at the origin. The delayed increase (decrease) of buses is taken into account in the bus transportation system. The delay is defined as τ.

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 buses. New passengers arrive at the origin with inflow rate μ [persons/min]. The arrival