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Complex motion of elevators in piecewise map model combined with circle map

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ABSTRACT

We study the dynamic behavior in the elevator traffic controlled by capacity when the inflow rate of passengers into elevators varies periodically with time. The dynamics of elevators is described by the piecewise map model combined with the circle map. The motion of the elevators depends on the inflow rate, its period, and the number of elevators. The motion in the piecewise map model combined with the circle map shows a complex behavior different from the motion in the piecewise map model.

1. Introduction

The traffic systems include so many factors that it is difficult to discover the essential factors affecting on the traffic behavior. Physicists have proposed the simplified traffic models including a few factors at most to clarify the cause and effect [1–7]. The concepts and techniques of physics are being applied to the traffic systems. The physical traffic theory is an example of a highly quantitative description for a living system despite the complexity of traffic [8–17]. The traffic models have been extended to take into account the traffic interruption and forecast effect by Tang et al. [18–21].

The traffic flow with many vehicles is a self-driven many-particle system. The jamming transitions and complex behaviors occur due to the many-body effect. However, the complex behavior appears due to the nonlinearity even in the traffic system with a single vehicle or a few vehicles. For example, the complex motion of buses is induced by the nonlinear interactions between buses and passengers in the shuttle bus transportation. The bus schedule is closely related to the nonlinear dynamics [22,23]. Also, the traffic flow with bus stops has been studied by Tang et al. [24,25].

The congestions (jams) are a typical signature of the complex behavior of traffic systems. Elevator traffic also exhibits severe congestion problems during a peak period [26–29]. Poschel and Gallas have proposed a stochastic model in the evening peak traffic [30]. In the morning peak traffic, the nonlinear-map model has been presented to describe the complex motions of elevators [31,32]. In real elevator traffic, the number of running elevators varies with the passengers waiting at the lobby floor because the total capacity of elevator transport system is controlled by the number of elevators. The elevator schedule must be determined with both number of elevators and number of passengers. It is important and necessary to estimate the arrival time of elevators for the elevator schedule.

The traffic and pedestrian flows taken into account the passenger's movement have been investigated by Tang et al. [33–36]. Furthermore, Tang et al. have studied the heterogeneous traffic flow accounting for passenger's individual properties [37–39].

Generally, the elevator traffic is not a single one but there are multiple elevators. The number of elevators is controlled by arriving passengers. However, the traffic system of multiple elevators with a fluctuating inflow of passengers has not been investigated. There are few dynamic models to predict the dynamic behavior of the multiple elevators for the elevator traffic controlled by capacity with the periodic inflow of passengers. The elevator traffic system will be modeled by the combined map model in which the piecewise map is combined with the circle map. The combined map has not investigated until now. The piecewise map model combined with the circle map will also be interested from the point of view of nonlinear dynamics and chaos [40,41].

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In this Letter, we study the dynamic behavior of the elevator traffic system controlled by capacity with a periodic inflow of passengers. We investigate the effect of the periodic inflow on the elevator dynamics controlled by capacity. We describe the elevator traffic in terms of the combined map model where the piecewise linear map is combined with a circle map. We show that the elevator traffic displays the periodic, quasi-periodic, and chaotic motions. We clarify the dependence of the dynamic motion on both inflow rate and inflow period.

2. Combined map model

Elevators serve the top floor from the lobby floor during peak use time. Passengers board elevators at the lobby floor and get off elevators at the top floor. The flow of passengers is one way during the peak period. We consider the dynamic model of elevators controlled by capacity. The number of elevators increases one by one when the number of passengers is superior to the capacity, while the number of elevators decreases one by one if the number of passengers is less than the capacity. The operator controls the number of elevators at the lobby floor. If the number of passengers is higher than the present capacity, a new elevator is added and it runs together. When the number of passengers is less than the present capacity, an elevator stops at the lobby floor. Thus, the increase (decrease) of elevators is determined by the number of passengers waiting at the lobby.

We describe the dynamic model of the elevator system in terms of the nonlinear map. We assume that all the passengers waiting at the lobby floor can board the elevators. New passengers arrive at the lobby floor with inflow rate $\mu(t)$ [persons/minute] at time t. The arrival time of elevators at the lobby floor and trip n is defined by $t(n)$. So $W(n)$ is the number of passengers that have arrived since the previous elevators left the lobby floor. This is expressed by

$$W(n) = \int_{t(n-1)}^{t(n)} \mu(t)\,dt. \tag{1}$$

If one assumes that all passengers at the lobby floor board the elevators, the number $B(n)$ of passengers boarding the elevators is consistent with the number $W(n)$ of passengers waiting at the lobby floor, $B(n) = W(n)$. The capacity of a single elevator is defined as $F_{\max}$. In order to board all passengers waiting at the lobby floor, $M(n)$ elevators are necessary at trip n. If there is no delay for the increase (decrease) of elevators, the number of elevators is given by

$$M(n) = 1 + \mathrm{int}\left[\frac{B(n)}{F_{\max}}\right]. \tag{2}$$

We assume that passengers are distributed uniformly for M elevators at the lobby floor. The number of passengers boarding an elevator at trip n is given by $B(n)/M(n)$. We assume that the time it takes passengers to board the elevator is proportional to the number of the passengers. The time is given by

$$\gamma B(n)/M(n), \tag{3}$$

where γ is the time it takes one person to board an elevator. Generally, the number of passengers is more, the time boarding the elevator is longer.

Similarly, the time it takes passengers to leave the elevator is given by

$$\beta B(n)/M(n), \tag{4}$$

where β is the time it takes one person to leave an elevator.

The moving time of an elevator is $2L/V$ where L is the distance between the lobby and top floors and V is the mean speed of elevators. The tour time equals the sum of these periods. Then, the arrival time $t(n+1)$ of elevators at the lobby floor at trip $n+1$ is given by

$$t(n+1) = t(n) + (\gamma+\beta)\frac{B(n)}{M(n)} + \frac{2L}{V}. \tag{5}$$

The periodic inflow rate of passengers is expressed by

$$\mu(t) = \mu_0\left\{1 + b\cos\left(\frac{2\pi t}{t_s}\right)\right\}, \tag{6}$$

where t_s is the period of the inflow rate and b is the amplitude of fluctuating inflow rate. Because $\mu(t) \geqslant 0$, $0 \leqslant b \leqslant 1$. By substituting Eq. (6) into Eq. (1), one has

$$\begin{aligned} W(t) &= B(n) \\ &= \mu_0\{t(n) - t(n-1)\} \\ &\quad + \frac{\mu_0 b t_s}{2\pi}\left\{\sin\left(\frac{2\pi t(n)}{t_s}\right) - \sin\left(\frac{2\pi t(n-1)}{t_s}\right)\right\}. \end{aligned} \tag{7}$$

By replacing Eq. (7) into Eq. (5), we obtain the nonlinear map for the tour time as

$$\begin{aligned} \Delta t(n+1) = {} & \frac{(\gamma+\beta)\mu_0 \Delta t(n)}{M(n)} \\ & + \frac{(\gamma+\beta)\mu_0 b t_s}{2\pi M(n)}\left\{\sin\left(\frac{2\pi t(n)}{t_s}\right)\right. \\ & \left. - \sin\left(\frac{2\pi t(n-1)}{t_s}\right)\right\} + \frac{2L}{V}, \end{aligned} \tag{8}$$

where tour time $\Delta t(n)$ is defined as $\Delta t(n) = t(n) - t(n-1)$.

Eq. (8) with Eq. (2) represents a kind of nonlinear maps. Thus, we obtain the nonlinear-map model for the tour time in the elevator traffic controlled by capacity. The dynamics of elevators is described in terms of the map (8) with Eq. (2). The dynamic property of the map is controlled by inflow rate μ_0 and period t_s if parameters γ, β, and b are constant.

By dividing time by characteristic time $2L/V$, one obtains the nonlinear map of dimensionless tour time

$$\begin{aligned} \Delta T(n+1) = 1 & + \frac{\alpha\Gamma_0 \Delta T(n)}{1 + \mathrm{int}[\frac{\Gamma_0 \Delta T(n)}{F_{\max}}]} \\ & + \frac{\alpha b \Gamma_0 T_s}{2\pi(1 + \mathrm{int}[\frac{\Gamma_0 \Delta T(n)}{F_{\max}}])} \\ & \times \left\{\sin\left(\frac{2\pi T(n)}{T_s}\right) - \sin\left(\frac{2\pi T(n-1)}{T_s}\right)\right\}, \end{aligned} \tag{9}$$

where $\Delta T(n) = \Delta t(n)/(2L/V)$, $T_s = t_s/(2L/V)$, $\alpha = (\gamma+\beta)/(2L/V)$, and $\Gamma_0 = \mu_0(2L/V)$. The nonlinear map (9) is the piecewise linear map combined with a circle map [25–28]. When $b = 0$, the combined map (9) reduces to the piecewise linear map. Thus, the dynamics of elevators is described in terms of the combined map (9) for the elevator traffic controlled by capacity with periodic inflow rate. The dynamic property of the map is mainly controlled by two parameters: loading parameter Γ_0 and period T_s of the inflow rate. The combined map is unknown until now and has not been investigated. It will be important to study the dynamic properties of the combined map.