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ScienceDirect
Physica A 383 (2007) 613–623
PHYSICA A
www.elsevier.com/locate/physa

Passenger's fluctuation and chaos on ferryboats

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Received 27 April 2007
Available online 10 May 2007

Abstract

We study the fluctuation of shipping passengers on a few ferryboats which shuttle between an origin and a destination repeatedly. We present the dynamical model for the ferryboats. The model is described in terms of nonlinear maps defined from the vectors $T_i(n)$ and $W_i(n)$, $i = 1, 2, \ldots, N$ for N ferryboats where $T_i(n)$ is the arrival time of ferryboat i at the origin on trip n and $W_i(n)$ the number of passengers waiting at the origin on trip n. We clarify the fluctuations of shipping passengers and tour time for the ferry schedule. It is found that the dynamical transitions among the regular, periodic, and chaotic motions occur by varying the ferry's capacity $F_{\max}$, headway $T_{\min}$, and loading parameter $\Gamma\Pi$. Even if the second ferryboat follows the leader (first ferryboat) keeping the constant headway, the passengers shipping on the second fluctuate highly when the parameters take specific values.

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

1. Introduction

Recently, the transportation and traffic problems have attracted much attention [1–5]. The vehicular traffic has been investigated, numerically and analytically, by using various models [6–24]. The typical dynamics of traffic has been described by nonlinear differential or difference equations. Many observed self-organization phenomena in traffic flows have been successfully reproduced with physical and mathematical methods.

Traffic current and jam are determined mainly by the interaction among vehicles, while goods and passengers carried by ferryboats, trucks, and buses do not depend only on the interaction between vehicles but also on the interaction between the vehicle and passengers (or goods). The bus-route system is a typical dynamical system of interacting buses and passengers [25–28]. The dynamics of a bus route is definitely different from the traffic dynamics because buses interact with passengers at designated bus stops in addition to the interaction between buses. The single cyclic bus has been described by the nonlinear map [29]. The model has exhibited the periodic and chaotic motions of a bus. The single cyclic bus model has been extended to the shuttle-bus system with a few buses [30–33]. It has been found that the interactions among buses and passengers induce a complex behavior of buses. The complex motions of buses have induced the large fluctuation of arrival time and riding passengers.

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0378-4371/$ - see front matter
doi:10.1016/j.physa.2007.05.002

The motions of ferryboats are similar to those of shuttle buses. The ferryboats move around the terminals repeatedly. In the ferryboat system, one loads passengers or vehicles on ferryboats at the origin, the ferryboats carry a load (passengers or vehicles) toward the destination, one unloads the ferryboat at the destination, and the ferryboats return to the origin. Thus, the ferryboats shuttle between an origin and a destination repeatedly. The tour time of the ferryboats will vary from trip to trip by interacting between the ferryboats and passengers (or vehicles). In the result, the passengers shipping on the ferryboats fluctuate highly with varying tour time. It is very important and necessary to control and optimize the tour time and shipping passengers. A manager wants to know the ferryboat schedule. However, the dynamic model has little been known for ferryboat schedule. We would like to clarify the dynamical behavior of ferryboats for the schedule.

In this paper, we present the dynamical model for the ferryboat system. We study the dynamical behavior of a few ferryboats on a cyclic route. We investigate the fluctuation of shipping passengers and tour time. We clarify how the ferryboats display the complex motions. We study the dynamical phase transitions among the distinct dynamical states: the regular, periodic, and chaotic motions.

2. Model

We consider the dynamical behavior of N ferryboats shuttling between the starting terminal (origin) and destination terminal. The waiting passengers at the origin board a ferryboat just arrived, then the ferryboat starts at the origin, moves towards the destination, all currently shipping passengers leave the ferryboat when the ferryboat arrives at the destination, and the ferryboat returns to the origin. If the number of passengers waiting at the origin is higher than the maximum capacity $F_{i,\max}$ of ferryboat i just arrived, the number of passengers boarding the ferryboat is limited by the maximum capacity. The remaining passengers wait for the next ferryboat. We assume that passengers arrive steadily at the origin with a constant rate.

We assume that ferryboats do not pass the other. If the tour time is larger than the prescribed limit t_{limit}, the first ferryboat speeds up and moves with the higher speed to overcome the delay. The second ferryboat follows the first one keeping the constant time-headway $t_{\min}$. Similarly, the ith ferryboat follows the $(i-1)$th one with the same time headway $t_{\min}$ where $i = 3$–N.

We define the number of passengers boarding ferryboat i on trip n by $B_i(n)$. The parameter γ is the time it takes one passenger to board the ferryboat, so $\gamma B_i(n)$ is the amount of time needed to board all the passengers at the origin. The parameter η is the time it takes one passenger to leave the ferryboat, so $\eta B_i(n)$ is the amount of time needed to leave all the passengers at the destination. The moving time of the first ferryboat is $2L/v(n)$, where L is the distance between the origin and the destination, and $v(n)$ is the mean speed of the first ferryboat on trip n. Then the arrival time $t_1(n+1)$ of first ferryboat at the origin on trip $n+1$ is given by

$$t_1(n+1) = t_1(n) + (\gamma + \eta)B_i(n) + \frac{2L}{v(n)}. \tag{1}$$

When the tour time of the first ferryboat is higher than the prescribed limit t_{limit}, the first ferryboat speeds up to overcome the delay. So the speed function $v(n)$ is given by

$$v(n) = v_0 + \frac{v_{\max} - v_0}{2}[\tanh u(t_1(n) - t_1(n-1) - t_{\text{limit}}) + 1], \tag{2}$$

where v_0 is the regular speed and $v_{\max}$ is the maximum velocity. Parameter u represents the rate of speedup. The first ferryboat moves nearly at speed v_0 for $\Delta t_1(n) < t_{\text{limit}}$, while it moves nearly at speed $v_{\max}$ for $\Delta t_1(n) > t_{\text{limit}}$, where $\Delta t_1(n) (\equiv t_1(n) - t_1(n-1))$ is the tour time of the first ferryboat.

The arrival time of the ith ferryboat at the origin on trip $n+1$ is given by

$$t_i(n+1) = t_{i-1}(n+1) + t_{\min}, \tag{3}$$

where $i = 2$–N.

We define $W_i(n)$ as the number of passengers waiting at the origin just before ferryboat i arrives at the origin for trip n. The number of passengers waiting the first ferryboat is expressed by

$$W_1(n) = W_N(n-1) - B_N(n-1) + \mu(t_1(n) - t_N(n-1)). \tag{4}$$