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Physica A 384 (2007) 600–612
PHYSICA A
www.elsevier.com/locate/physa

An information-based traffic control in a public conveyance system: Reduced clustering and enhanced efficiency

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Received 16 April 2007
Available online 24 May 2007

Abstract

A new public conveyance model applicable to buses and trains is proposed in this paper by using stochastic cellular automaton. We have found the optimal density of vehicles, at which the average velocity becomes maximum, significantly depends on the number of stops and passengers behavior of getting on a vehicle at stops. The efficiency of the hail-and-ride system is also discussed by comparing the different behavior of passengers. Moreover, we have found that a big cluster of vehicles is divided into small clusters, by incorporating information of the number of vehicles between successive stops.

Keywords: Traffic; Traffic control; Public conveyance; Bus route model; Asymmetric simple exclusion process; Cellular automation

1. Introduction

The totally asymmetric simple exclusion process [1–3] is the simplest model of non-equilibrium systems of interacting self-driven particles. Various extensions of this model have been reported in the last few years for capturing the essential features of the collective spatio-temporal organizations in wide varieties of systems, including those in vehicular traffic [4–8]. Traffic of buses and bicycles have also been modeled following similar approaches [9,10]. A simple bus route model [10] exhibits clustering of the buses along the route and the quantitative features of the coarsening of the clusters have strong similarities with coarsening phenomena in many other physical systems. Under normal circumstances, such clustering of buses is undesirable in any real bus route as the efficiency of the transport system is adversely affected by clustering. The main aim of this paper is to introduce a traffic control system into the bus route model in such a way that helps in suppressing this tendency of clustering of the buses. This new model exhibits a competition between the two opposing tendencies of clustering and de-clustering which is interesting from the point of view of fundamental physical

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0378-4371/$ - see front matter
doi:10.1016/j.physa.2007.05.047

principles. However, the model may also find application in developing adaptive traffic control systems for public conveyance systems.

In some of earlier bus-route models, movement of the buses was monitored on coarse time intervals so that the details of the dynamics of the buses in between two successive bus stops was not described explicitly. Instead, the movement of the bus from one stop to the next was captured only through probabilities of hopping from one stop to the next; hopping takes place with the lower probability if passengers are waiting at the approaching bus stop [10]. An alternative interpretation of the model is as follows: the passengers could board the bus whenever and wherever they stopped a bus by raising their hand, this is called the *hail-and-ride* system.

Several possible extensions of the bus route model have been reported in the past [11–13]. For example, in Ref. [11], in order to elucidate the connection between the bus route model with parallel updating and the Nagel–Schreckenberg model, two alternative extensions of the latter model with space-/time-dependent hopping rates are proposed. If a bus does not stop at a bus stop, the waiting passengers have to wait further for the next bus; such scenarios were captured in one of the earlier bus route models [12], using modified car-following model. In Ref. [13], the bus capacity, as well as the number of passengers getting on and off at each stop, was introduced to make the model more realistic. Interestingly, it has been claimed that the distribution of the time gaps between the arrival of successive buses is described well by the Gaussian unitary ensemble of random matrices [14].

In this paper, by extending the model in Ref. [10], we suggest a new public conveyance model (PCM). Although we refer to each of the public vehicles in this model as a ‘‘bus’’, the model is equally applicable to train traffic on a given route. In this PCM we can set up arbitrary number of bus stops on the given route. The *hail-and-ride* system turns out to be a special case of the general PCM. Moreover, in the PCM the duration of the halt of a bus at any arbitrary bus stop depends on the number of waiting passengers. As we shall demonstrate in this paper, the delay in the departure of the buses from crowded bus stops leads to the tendency of the buses to cluster on the route. Furthermore, in the PCM, we also introduce a traffic control system that exploits the information on the number of buses in the ‘‘segments’’ between successive bus stops; this traffic control system helps in reducing the undesirable tendency of clustering by dispersing the buses more or less uniformly along the route.

In this study we introduce two different quantitative measures of the efficiency of the bus transport system, and calculate these quantities, both numerically and analytically, to determine the conditions under which the system would operate optimally.

This paper is organized as follows: in Section 2 PCM is introduced and we show several simulation results in Section 3. The average speed and the number of waiting passengers are studied by mean field analysis in Section 4, and conclusions are given in Section 5.

2. A stochastic CA model for public conveyance

In this section, we explain the PCM in detail. For the sake of simplicity, we impose periodic boundary conditions. Let us imagine that the road is partitioned into L identical cells such that each cell can accommodate at most one bus at a time. Moreover, a total of S $(0 \leqslant S \leqslant L)$ *equispaced* cells are identified in the beginning as bus stops. Note that, the special case $S = L$ corresponds to the *hail-and-ride* system. At any given time step, a passenger arrives with probability f to the system. Here, we assume that a given passenger is equally likely to arrive at any one of the bus stops with a probability $1/S$. Thus, the average number of passengers that arrive at each bus stop per unit time is given by f/S. In contrast to this model, in Refs. [15,16] the passengers were assumed to arrive with probability f at all the bus stops in every time step.

The model A corresponds to those situations where, because of sufficiently large number of broad doors, the time interval during which the doors of the bus remain open after halting at a stop, is independent of the size of waiting crowd of passengers. In contrast, the model B captures those situations where a bus has to halt for a longer period to pick up a larger crowd of waiting passengers.

The symbol H is used to denote the hopping probability of a bus entering into a cell that has been designated as a bus stop. We consider two different forms of H in the two versions of our model which are