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Cellular automaton model for railway traffic

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Abstract

Based on the deterministic NaSch model, we propose a new cellular automation (CA) model to simulate the railway traffic. Using the proposed CA model, we analyze the space–time diagram of traffic flow and the trajectory of train movement, etc. Our aim is to investigate the characteristic behavior of railway traffic flow. A number of simulation results demonstrate that the proposed model can be successfully used for the simulation of railway traffic. Some complex phenomena can be reproduced, such as the go-and-stop wave and the complex behavior of train movement.

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1. Introduction

A few decades ago, moving-block signalling system was proposed to provide more room for headway reduction [1]. In this system, its operations rely on continuous bi-directional communication links between trains and controllers. However, most successful implementations of moving-block systems are not exactly utilizing the concept in its original form [2,3]. The communication is not absolutely continuous. As signalling technology developed, moving-block system has gained considerable importance and there have been on attempts to instead fixed-block system. It offers the advantage to allow the distance between two trains to be varied according to their actual speeds. This is rather like applying the freeway rules for speed separation. In theory, the trains may get as close as a few meters, just sufficient allowance for reaction time and small errors.

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NaSch model is one of the microscopic traffic models [4]. Using very simple rules, this model can reproduce the basic phenomena encountered in real traffic. The advantage of NaSch model is that it is much simpler and more convenient for computer simulations (it is able to perform several millions updates in a second [5]). For the description of more complex situations, the basic rules of NaSch model have to be modified, such as the multi-lane traffic, bidirectional traffic and the traffic with different types of vehicles, etc. [6–9].

Computer simulation can be used to test theoretical control algorithms for improving the performance of railway signalling system. Several types of models have been developed for the train movement calculation, such as the basic model, the time-based model and the event-based model, etc. [10,11]. Using the basic model, when the length of track conductor loop is small, a continuous braking profile is a reasonable approximation. The time-based approach is easy to design and build simulation models, but it makes a high computational demand. The event-based model substantially saves computational effort, but inevitably at the expense of a certain degree of accuracy. In this work, we propose a new cellular automation (CA) traffic model for simulating the railway traffic. Our model has the following features: (1) Using very simple rules, our model can be used to simulate the railway traffic with shorter computation time. (2) It is a flexible model, and is easy to simulate different types of railway traffic by modifying the basic rules of the model. To our knowledge, this work explicitly shows this effect for cellular automata for the first time. The paper is organized as follows: we introduce the principle of the railway signalling system in Section 2, and introduce the simulation model in Section 3; the numerical and analytical results are presented in Section 4; finally, conclusion of this approach is presented.

2. Principle of the railway signalling system

2.1. Moving-block system

In a moving-block system, the traditional fixed-block track circuit is not necessary for determining the train position. Instead, the continuous two-way digital communication between each controlled train and a wayside control center are adopted. In this system, the line is usually divided into areas or regions, each area is under the control of a computer and has own radio transmission system. Each train transmits its identity, location, direction and speed to the area computer. The radio link between each train and the area computer is continuous so that the computer knows the location of all the trains in its area all the time. It transmits to each train the location of the train in front and gives it a braking curve to enable it to stop before it reaches that train. In theory, as long as each train is travelling at the same speed as the one in front and they all have the same braking capabilities, they can travel as close together as a few meters. The system adopted in London Dockland light rail (DLR) is very well-documented [2]. In this system, the safety–critical or 'vitally programmed' computers and high-integrity telemetry were used to maintain continuous communication between the control center and trains. A similar approach has been found in the LZB510 system [12], in which track conductor loops are used to improve the performance of train control.

Several types of moving-block scheme have been discussed [1]. Moving space block (MSB) is the simplest scheme, in which the minimum instantaneous distance between successive trains is

$$d_n = v_{\max}^2/(2b) + SM, \tag{1}$$

where $v_{\max}$ is the maximum speed, b denotes the deceleration of the train n and SM is the safety margin distance. In this scheme, the only information that the following train requires is the position of the leading train and its own position.

Moving time block (MTB) is another scheme, in which the headway between two trains is always constant and independent of travel speed. In this scheme, the minimum instantaneous distance between successive trains is