Chaos, Solitons and Fractals 81 (2015) 43–51

Contents lists available at ScienceDirect

Chaos, Solitons and Fractals

Nonlinear Science, and Nonequilibrium and Complex Phenomena

journal homepage: www.elsevier.com/locate/chaos

# Train flow chaos analysis based on an improved cellular automata model

Xuelei Meng[a,b,*], Wanli Xiang[a], Limin Jia[b], Jie Xu[b]

[a] School of Traffic and Transportation, Lanzhou Jiaotong University, P.O. Box 405, Anning West Road, Anning District, Lanzhou, Gansu 730070, China

[b] State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, No. 3 Shangyuancun, Haidian District, Beijing 100044, China

ARTICLE INFO

*Article history:*
Received 2 July 2015
Accepted 20 August 2015

*Keywords:*
Train flow
Chaos
Improved cellular automata model
Poincare section

ABSTRACT

To control the chaos in the railway traffic flow and offer valuable information for the dispatchers of the railway system, an improved cellular model is presented to detect and analyze the chaos in the traffic flow. We first introduce the working mechanism of moving block system, analyzing the train flow movement characteristics. Then we improve the cellular model on the evolution rules to adjust the train flow movement. We give the train operation steps from three cases: the trains running on a railway section, a train will arrive in a station and a train will departure from a station. We simulate 4 trains to run on a high speed section fixed with moving block system and record the distances between the neighbor trains and draw the Poincare section to analyze the chaos in the train operation. It is concluded that there is not only chaos but order in the train operation system with moving blocking system and they can interconvert to each other. The findings have the potential value in train dispatching system construction and offer supporting information for the daily dispatching work.



## 1. Introduction

Natural disasters and emergencies affect trains operating greatly, especially in the condition that the railway network is becoming more and more complicated. Chaos usually occurs when disturbs appear on the trains, which will lead to a disorder.

In common usage, “chaos” means “a state of disorder”. However, in chaos theory, the term is defined more precisely. Although there is no universally accepted mathematical definition of chaos, a commonly used definition says that, for a dynamical system to be classified as chaotic, it must have the following properties [15]:

- It must be sensitive to initial conditions;
- It must be topologically mixing; and
- Its periodic orbits must be dense.

Sensitivity to initial conditions implies that each point in a chaotic system is arbitrarily closely approximated by other points with significantly different future paths, or trajectories. Thus, an arbitrarily small change, or perturbation, of the current trajectory may lead to significantly different future behavior. The requirement for sensitive dependence on initial conditions implies that there is a set of initial conditions of positive measure that do not converge to a cycle of any length.

Topological mixing means that the system will evolve over time so that any given region or open set of its phase space will eventually overlap with any other given region. This mathematical concept of “mixing” corresponds to the standard intuition, and the mixing of colored dyes or fluids is a case of a chaotic system.

* Corresponding author at: School of Traffic and Transportation, Lanzhou Jiaotong University, P.O. Box 405, Anning West Road, Anning District, Lanzhou, Gansu 730070, China. Tel.: +86 15117071015.

*E-mail address:* mengxuelei@gmail.com (X. Meng).

http://dx.doi.org/10.1016/j.chaos.2015.08.015

For a chaotic system to have a dense periodic orbit means that every point in the space is approached arbitrarily closely by periodic orbits.

There are numerous kinds of traffic phenomena, such as the erratic movement of the cars, traffic jams, release of the traffic jams. The status of the traffic on the road changes among sparsity, high density, congestion, which shows that the status of the traffic turns into disorder from order, and then back to order again and again. Moreover, the chaotic characteristics are implicit in traffic phenomena. For instance, a serious congestion is caused by a single brake, which proves the "butterfly effect". So there are many chaotic phenomena in the traffic system.

There is also significant chaos in the train operating in emergencies. The disturbance lead to unpredictability of the train operating and it may cause the uncertainty of the delay propagation. Since there are many strict constraints in dispatching the trains, a tiny disturbance may lead to a serious disorder situation, even railway system breakdown. So it is a very important work to study chaotic characteristics in railway operation system, control the chaos, and propose the rescheduling method for the train operation, which is most valuable for the train dispatching work. In this paper, train flow chaos is related to the order and disorder of the trains moving activities. If disorder and order occur alternately and can interconvert into each other in case if disturbs, accordingly, there is a strange attractor, the chaos is believed to occur in the trains moving process. Order and disorder are identified by the distance between the trains and the strange attractor is checked from a Poincare section in this paper.

There are not many publications on the train flow chaos at present. Daganzo [6] studied the dynamics in the traffic flow. Prigogine et al. [22] studied the local equilibrium approach to transport processes in dense media. Bianca [2] dealt with the kinetic theory framework for the modeling of the complex dynamics of crowds constituted by a large number of individuals that interacted in a nonlinear fashion in a domain with and without obstacles, based on the multiscale mathematical model [4] which reproduces the predominant features of crowd dynamics by taking into account the distance among pedestrians. Bianca and Coscia [3] discussed the derivation and the analysis of a new mathematical model for vehicular traffic along a one-way road obtained by the coupling of a uniform and an adaptive discretization of the velocity variable in the framework of the kinetic theory. These publications showed that there were complex dynamics in traffic flow. Spyropoulou [23] discussed several issues that arise while using the cellular model for the simulation of traffic at signalized intersections and investigated the relationships between the randomization parameter of the model, the model dynamics and the estimated saturation flow. Zhang et al. [24] studied the behavior of pedestrians and the influence of pedestrians' behavior on the vehicle flow, pedestrian flows, and the vehicle waiting time with cellular automata. Li et al. [17] proposed a novel cellular automation model to simulate the railway traffic. They analyzed the space–time diagram of traffic flow and the trajectory of train movement, etc with the aim to investigate the characteristic behavior of railway traffic flow. Fu et al. [10] proposed a cellular model to simulate the tracking operation of trains in Beijing subway line 2. By means of speed-time-position graphs, they investigated some important characteristics of subway train flow and have analyzed the relationships of speed, time, and position. Maerivoet and Moor [19] gave an elaborate and understandable review of traffic cellular automata (TCA) models, which are a class of computationally efficient microscopic traffic flow models. Chowdhury et al. [5] explained the guiding principles behind all the main theoretical approaches and presented detailed discussions on the results obtained mainly from the so-called "particle-hopping" models, particularly emphasizing those which have been formulated in recent years using the language of cellular automata. Olmos and Muñoz [21] proposed a car cellular automaton model that reproduced the experimental behavior of traffic flows in Bogotá. Lárraga et al. [16] proposed a cellular automata model to simulate microscopic traffic flow, in which vehicles follow a reduced set of rules that can be applied in parallel. Simulation results show the ability of this modeling paradigm to capture the most significant features of the traffic flow phenomena. Bham and Benekohal [1] developed a high fidelity cell based traffic simulation model (CELLSIM) for simulation of high volume of traffic at the regional level, using concepts of cellular automata (CA) and car-following (CF) models. It was more detailed than CA models and has realistic acceleration and deceleration models for vehicles. Nagel and Schreckenberg [20] introduced a stochastic discrete automaton model to freeway traffic and hired Monte-Carlo simulations to show a transition from laminar traffic flow to start-stop-waves with increasing vehicle density. Fang and Shi [8] studied the traffic chaos with an improved discrete dynamic coupled map model which was derived from both the flow–density–speed fundamental diagram and Del Castillo's speed–density model. They analyzed stability of the control system and provided a procedure to design the decentralized delayed-feedback controllers for the traffic control system.

Hampton and Doostan [14] studied the compressive sampling of polynomial chaos expansions and identified an importance sampling distribution which yielded a bound with weaker dependence on the order of the approximation. Fullmer et al. [11] studied a system of two coupled PDEs, which was dynamically similar to a one-dimensional two-fluid model of two-phase flow. Farshidianfar and Saghafi [9] extended Melnikov analysis to develop a practical model of a gear system to control and eliminate the chaotic behavior. Das et al. [7] presented a novel swarm dynamics and illustrates its applications in automated multi-agent systems. They adopted a Lyapunov-function procedure to analyze stability and chaos of a novel swarm dynamics. Gardini et al. [12] investigated the dynamics of a one-dimensional piecewise smooth map, which represented the model of a chaos generator circuit. Ma and Chen [18] proposed a variation of Lyapunov exponent to detect anomalies in network traffic, based on entropy. Experimental results showed that the approach outperformed entropy-based method while reflecting the relationship between source IPs and destination IPs. Grossu et al. [13] presented a new version of Chaos Many-Body Engine (CMBE). They implemented a new parameter, namely the "Mean Free Time", and presented a toy-model for chaos analysis of relativistic nuclear collisions at 4.5 A GeV/c (the SKM 200 collaboration). These publications gave us much enlightenment when we carried out the study.