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Original articles

Revisiting the 7/23 train accident using computer reconstruction simulation for causation and prevention analysis

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Highlights

- The CA model for railway traffic is utilized for railway accident reconstruction.
- The simulation model is addressed to replicate the true train movement.
- The accident reconstruction methodology is proposed for train movement collision.
- The accident reconstruction model and methodology provides a quantitative analysis measure to render suggestions.

Abstract

Accident reconstruction by means of computer simulation facilitates the analysis of the causes of accidents and deriving suggestions for preventing an accident. A train movement simulation model based on cellular automata is developed in order to reconstruct the train collision process. An event-driven accident reconstruction procedure is proposed to describe the aberrant train movement processes. The selection of accelerations and decelerations is based on the statistically average tractive, resistive, and braking forces related to train movement speeds. The reconstruction results regarding the collision accident between multiple-unit trains D3115 and D301 on July 23, 2011 in China (the 7/23 accident for short) demonstrate that the proposed reconstruction methodology can achieve remarkable accuracy. The 7/23 accident reconstruction reveals that train D301 ran according to illogical track circuit code signals, indicating the disappearance of train D3115 running ahead, which is consistent with the official report. It is suggested that online analysis of train movement situations is conducive to quantitatively justifying train operation mechanisms and safety. A further finding is that the marginal emergency braking positions for preventing such an accident are only located beyond approximately 0.555 km. The lesson drawn from this accident reconstruction is that advanced automatic train control cannot paralyze the driver's alertness, particularly in an environment of atrocious weather, which often induces failure of the train control equipment and endangers the safety of train operations.

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1. Introduction

Traffic accident reconstruction employs known locale information in order to reconstruct accident occurrence scenarios by means of computer simulation, so that accident causations can be revealed and responsible parties identified. Vehicle movement simulation models are required to reconstruct the dynamic courses of accident occurrences. The cellular automaton (CA) model provides a powerful tool for replicating the movement dynamics among vehicles [4,15,16]. It has also been utilized to represent moisture flow, microstructure evolution, system design, and wildfire spread, among others [6,7,9–12]. This study attempts to adopt the CA model for railway traffic in order to perform reconstruction and analysis of railway accidents.

Accident reconstruction is a beneficial approach in accident analysis, which has attracted significant attention in terms of road traffic. It takes advantage of acquired partial data, such as stop positions, braking traces, vehicle damage, and personnel injuries, from the field investigation, in order to infer the entire accident occurrence courses between or among vehicles, pedestrians, and bicyclists, by means of kinematic modeling, numerical simulation, and computer graphics [24,26]. With accident reconstruction, clarification can be obtained regarding whether or not a vehicle was speeding and a party disobeyed traffic regulations.

The basic CA models for railway traffic were proposed in [14,17], while a CA model for the moving-like block system was developed and railway delay propagation was investigated in [27]. A CA model for four-aspect fixed-block systems was established and the effects of freight train proportion, station dwelling time, and platform number on train operations were discussed [5]. A CA model for speed limit was proposed for the four-aspect fixed-block system, and the effects of speed limit and train time interval on traffic flow were investigated [13]. The unified CA model was developed to be appropriate for different train operation control mechanisms in order to describe the restrictive, synergistic, and autonomous behaviors among trains, synthetically considering scheduling commands and control behaviors with various speed limits [28–30].

Computer simulation is a powerful measure for designing and analyzing railway signal and transportation systems [2,19–23]. This study attempts to employ the CA model for railway traffic in order to reconstruct realistic train movement; that is, the particularly catastrophic front-rear collision accident between high-speed multiple-unit trains D301 and D3115, on July 23, 2011 in China (the 7/23 accident). As a result of this accident, 40 people died, 172 people were injured, transportation was interrupted for 32 h and 35 min, and a direct economic loss of 19.37165 million Yuan occurred. The reconstruction results of the 7/23 accident are basically consistent with the official reports regarding the critical instants, places, and speeds. Possible accident prevention measures are discussed according to the reconstructed train collision process and behaviors of responsible parties. The remainder of this paper is organized as follows. Section 2 outlines the train movement CA model. Section 3 presents the CA model parameter selection and event-driven reconstruction procedure. Section 4 demonstrates the reconstruction results and provides an analysis of the 7/23 accident. Finally, conclusions are drawn in Section 5.

2. Train movement model

Numerous countries have developed corresponding railway traffic management and control architectures. The European rail traffic management system (ERTMS) and European train control system (ETCS) have achieved a worldwide influence, and specify three operation levels: Level 1 (L1), Level 2 (L2) and Level 3 (L3) [1,8]. Level 1 utilizes unoccupied track circuits from a train to its preceding train or operational target point in order to calculate movement authorities (MAs), which constitutes a fixed-block control system. Level 2 takes advantage of the global system for mobile communications-railway (GSM-R) in order to realize bidirectional information communication, including MAs. Level 3 develops into a moving-block control system, in an advanced form, in order to improve railway line transport capacity further, where the target point for calculating an MA is the minimum safe rear-end of the preceding train. In China, according to the development history of railway traffic and hardware equipment adopted, the China train control system (CTCS) classifies five levels, namely CTCS Level 0 to Level 4 (CTCS-L0 to L4). In