Accident Analysis and Prevention 112 (2018) 94–104

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

Collision risk analysis based train collision early warning strategy

Li Si-hui[a,b], Cai Bai-gen[a,b,*], Liu Jiang[a,b], Wang Jian[a,b]

[a] School of Electronic and Information Engineering, Beijing Jiaontong University, No.3 Shangyuancun, Haidian District, Beijing, PR China
[b] Beijing Engineering Research Center of EMC and GNSS Technology for Rail Transportation, No 3 Shangyuancun, Haidian District, 100044, Beijing, PR China

ARTICLE INFO

Keywords:
Collision risk
Train collision early warning system
Time to avoid collision

ABSTRACT

A Train Collision Early Warning System (TCEWS) has been developed for collision avoidance. However, there are few studies regarding how to evaluate the collision risk and provide an early warning concerning a preceding train on the railway. In this paper, we have found that the time for collision avoidance is constrained by the timing of events, such as wireless communication latency, driver reaction, safety protection distance and deceleration rate. Considering these timing components, the time to avoid a collision is calculated accurately. To evaluate the potential collision severity when the following train approaches, the collision risk is defined based on the time to avoid a collision. The train collision early warning signal is divided into a four-tier color-coded system based on the collision risk, with red representing the most severe collision risk, followed by orange, yellow and blue. A field test of the train collision early warning strategy on the Hankou–Yichang Railway is analysed. It is demonstrated that the strategy has sufficient capability to indicate a potential collision and warn the following train.

1. Introduction

With the rapid development of high-speed railway transportation in China, several passenger-dedicated lines and high-speed railways have been constructed and are now in operation. Currently, in view of operation control and dispatching management, while considering high safety and reliability, the Chinese Train Control System (CTCS) level 3 has been adopted as the uniform technical platform in passenger-dedicated lines and high-speed railways. The CTCS ensures operational safety and efficiency for high-speed trains.

In practical operations, an inevitable fault and failure because natural and human factors can lead to serious accidents. As shown in Table 1, in the last decade in China, there were 7 serious collisions that caused 141 deaths and 786 injuries. A rear-end collision happened in Wenzhou (Zhejiang province, China) on July 23, 2011, which is caused by an undetected train position after the failure of the track circuit. In the train control system, track circuit is used for train detection and Movement Authority (MA) is for collision avoidance. However, trackside equipment (including track circuit and Balise) based signalling system causing a significant maintenance effort and account for large part of the disturbances and failures of the signalling system. To get rid of trackside equipment and test new technologies, a global navigation satellite system (GNSS) and Global System for Mobile-Railways (GSM-R) based Train Collision Early Warning System (TCEWS) is proposed by the Ministry of Railways (Jiang et al., 2014). The TCEWS is used as a safety assurance by monitoring and tracking a train motion state and it highlights potential collision situations for drivers and is designed to provide collision warning signals.

For an existing train control system, the TCEWS can act as an independent technical supplementary method to provide a solution to problem like in Wenzhou accident. Because in the existing train control system, only the dispatcher has an overview of the traffic situation and a train driver has to be informed of hypothetical collision by the dispatcher. The TCEWS is designed to be able to function as an active protection that it provides the information of preceding train to the drivers and managers, and they are suggested to confirm the situation and slow down the speed to avoid a collision. While for the Next Generation of Train Control (NGTC) and other GNSS-based train control system, the TCEWS should be one part of Automatic Train Protection (ATP) system in NGTC.

Technologies for a collision avoidance system for trains are being investigated in many countries. Germany has already demonstrated a railway collision avoidance system (RCAS) on a test section at the German Aerospace Center (Strang et al., 2006; Lehner et al., 2008). Konkan Railway Corporation Limited has also developed an anti-collision system named the Anti-Collision Device Network (Simsky et al., 2004). The Alaska Railroad (ARRC) developed a railroad Collision Avoidance System (CAS) project (Federal Railroad Administration and Department of Transportation, 2009). Meanwhile, the Shinkansen in Japan has implemented a vehicle access warning system (Hachiga et al.,

* Corresponding author at: School of Electronic and Information Engineering ,Beijing Jiaontong University, No.3 Shangyuancun, Haidian District, Beijing, PR China.
E-mail address: bgcai@bjtu.edu.cn (B.-g. Cai).

https://doi.org/10.1016/j.aap.2017.11.039
Received 20 August 2014; Received in revised form 26 October 2015; Accepted 27 November 2017

Table 1
Serious railway collisions in China during the last decade.

Date	Railway line	Fatalities	Injuries
2005.7.31	Beijing-Haerbin	5	30
2006.4.11	Beijing-Jiulong	2	18
2008.1.23	Qingdao-Jinan	18	9
2008.4.28	Qingdao-Jinan	72	416
2009.6.29	Beijing-Guangzhou	3	63
2011.7.23	Ningbo-Wenzhou	40	200
2013.10.23	Qinghai-Tibet	1	50

1993). In China, a train collision early warning system that suits high-speed rail has been studied and explored since 2011 (Jiang et al., 2013; Jiang et al., 2014).In the CTCS, a moving block is used for collision avoidance (Zhang, 2008). A moving block is a signalling block system where the blocks are defined in real time by computers as safe zones around each train. Both the RCAS and the CAS evaluate the collision risk by the estimated braking distances. In the Shinkansen, collision avoidance is based on the relative distance and speed of the preceding train. The anti-collision device network identifies a potential collision based on the distance and track occupancy. Collision risk, however, cannot be evaluated when the following train is approaching. There are collision risk evaluation indices for vehicles in road traffic, such as the time to collision (TTC), but they are not suitable for the railway domain. In this paper, the specific effects of a high-speed railway in China are accounted for using a safety warning method that suits the TCEWS. We analyse the time to avoid a collision (TAC) by partitioning it into timing factors such as wireless communication latency, driver reaction, safety protection distance and train braking. With these timing components, we calculate the time to avoid a collision. Then, we propose a collision risk to evaluate the conflict severity on the basis of the TAC. To inform drivers on how to respond to a collision threat, we developed a four-tier color-coded early warning strategy.

2. Tcews

The TCEWS is independent from the existing signalling system (such as the CTCS in China). A GNSS is employed to monitor the dynamic state of high-speed trains and a GSM-R wireless channels are used to achieve train-ground communication. By using the train location information, a warning signal about a potential collision can be given for trains travelling on the same line and in the same direction. Adopting a non-signalling mode, the TCEWS could provide an efficient safety warning of potential collisions when the signalling system is inoperative.

The structure of the GNSS-based TCEWS is illustrated in Fig. 1. Using an integrated train positioning system, which includes a Global Positioning System (GPS), BeiDou Navigation Satellite System (BDS), odometers and Inertial Measurement Unit (IMU), the TCEWS could pinpoint the trains. The train location information, such as travelling miles, speeds and direction, would be transferred through the GSM-R. The Train Location Controller (TLC) in the ground monitoring centre receives the train location messages, conducts a comprehensive detection, logic calculation of the location judgment, and calculation of the dynamic distance between trains; then, it makes early warning decisions; and finally, sends a warning signal to the following train through the GSM-R. According to the received warning signal, the Driver Machine Interface (DMI) device would alert the driver of the operation status. The driver then could take safety measures.

Before early warning decisions, the TCEWS would judge the locations of the preceding and following trains.

Preceding train: Train travelling in front of, relatively, the neighbouring following train in the same direction (a train travelling away from its headquarters or travelling towards its headquarters) and on the same track.

Following train: Train travelling directly behind, relatively, the neighbouring front train in the same direction (a train travelling away from its headquarters or travelling towards its headquarters) and on the same track.

During the operation of a train, the on-board unit would send a location message to the TLC every 3 s. The message includes the train number, ID of the on-board unit, railway line number, latitude, longitude, speed, timestamp, mileage and direction. After receiving the location message, the TLC would conduct a logic calculation based on the direction to confirm the running sequence. Then, the distance between neighbouring trains will be calculated based on mileage, direction, etc. The combined location with speed and timestamps messages allows a potential collision danger to be detected. Meanwhile, travelling mileage and speed of the preceding train would be sent to the following train to alert the driver through the DMI device. Finally, a response to the warning signal should be sent back to the TLC by on-board unit. Note that the collision avoidance of trains in a different direction will be managed separately. Furthermore, the train collision early warning is only made when the train travelling between stations. Once a train rolled into a railroad siding in the station and stopped, this train will not be taken into account in collision avoidance.

To be in conformity with the Fail-Safe principle, the TCEWS is decomposed as the operation mode to help to identify the system performance. From the on-board unit perspective, two modes are defined for the TCEWS.

(1) Normal mode: the on-board unit is powered up, and works properly.
(2) Failure mode: the on-board unit is powered up, and in abnormal condition. Then the warning of the failure mode will be sent to the following train. The abnormal condition is:
    - The measurement of localization unit is unavailable due to GNSS signal loss or bad satellite geometry. Or when the GNSS receiver still delivers train location, but the accuracy level is beyond the performance limit, it is also a failure mode.
    - The wireless communication outage happens when the delay exceeds a threshold value.
    - TLC does not receive response to the warning signal from the on-board unit. Then the manager should pay attention to the safety and inform the dispatchers and drivers.
    - Other exceptions lead to a system malfunction.

In principle, the TCEWS only provide the information of the preceding train and warning signal for collision avoidance, but not involve in train control. The driver who received the warning signal decides the safety actions (slow down or stop to safety). Once a conflict happened between these two systems, drivers should slow down (even switch to the on-sight mode or stop) and contact to the managers. Managers should confirm the situation of preceding train until safety.

3. Collision avoidance timing components

In the TCEWS, a collision avoidance strategy relies on the contextual information gathered in real-time. For instance, in a given scenario, the TLC must compute the time to potential collision, and compares that with the timing events such as drivers' reaction time, wireless communication, GNSS-based train positioning performance and train braking. Furthermore, different alarms should be sending by severity of dangers based on the timing events. These timing events are dynamic and can differ between train motion state, environment and drivers. In order to design the behaviour of a collision-avoidance strategy in TLC based on wireless communication and the dynamic timing events, we must analyse the key factors that influence the time from when a warning is given to the time when a collision can be avoided. We call this timing zone a collision timing avoidance zone (Antony and Alice, 2010).