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# A novel train control approach to avoid rear-end collision based on geese migration principle

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ABSTRACT

For current train interval control based on Automatic Train Protection (ATP) system, when the ATP outputs erroneous commands or is unable to realize fail-safety in the case of ATP equipment failure, train rear-end collision will be likely to happen. The "7.23" train accident happened in 2011 in China is a typical example. A method of parallel control of train interval by using both Centralized Traffic Control (CTC) and ATP, or simplified as CTC&ATP based interval control, is proposed. By adding some hardware and software into the existing CTC system, the CTC can monitor train following interval and give early warning. In this method CTC based interval control works together with the existing ATP, the monitoring of train interval will be doubled. This method can improve the safety of train interval control, compensate for the lack of control when the autonomic control fails, and avoid common cause failures. The geese migration theory is used in the proposed method, in which the CTC controls the train interval as the goose line, while the ATP controls the train interval as goose interval. This paper analyzes the necessity and feasibility of the proposed CTC based train interval pre-warning and control method, and explains the basic structure of the system, data acquisition, train following interval calculation, pre-warning rules and implementation of the system. The CTC based train interval calculation model was established and the warning distances under different speed were calculated. The safety and reliability of CTC&ATP train interval control system were analyzed.



## 1. Introduction

Nowadays train rear-ending accidents are not uncommon around the world. In existing train operation control systems, the train following interval is monitored by Automatic Train Protection system (ATP). If the signaling equipment fails, and fail-safety is not realized by ATP, train following interval will no longer be monitored, and a rear-ending accident will be likely to happen. Train rear-ending accidents have happened occasionally at home and abroad, which account for a certain proportion of all train related accidents. Some train rear-ending accidents in China are listed as follows:

- On July 23, 2011, the EMU (Electricity Multiple Unit) train D301 rear-ended the EMU train D3115, in the section between Yongjia station and Wenzhou south station on the Yongwen line, resulting a death toll of 40 people with 172 injuries.
- On July 31, 2005, the passenger train K127 from Xi'an to Changchun rear-ended the freight train NO.3219, resulting the derailment of 5 carriages; and causing 6 people died and 30 people injured.
- On July 10, 1993, the passenger train NO.163 from Beijing to Chengdu rear-ended the freight train No. 2011 between Xinxiang South-field to Qiliying station on Beijing-Guangzhou line, causing 40 people died and 48 people injured.

Similar accidents occurred in other countries include:

- On November 30, 2007, a passenger train rear-ended a freight train in Chicago, causing serious injuries to at least five people and slight injuries to dozens of others.
- On July 13, 2005, a train stopped in Geteji of Southern Sindh province in Pakistan was rear-ended by another train, which pushed several carriages into a diversion that in turn crashed with another oncoming train on a nearby rail, leading to the

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derailment of more carriages. The death toll rose up to 150 with about 1000 injuries.

The accidents listed above are only some examples. The key to prevent train rear-end collision primarily depends on guaranteeing the interval distance between following trains (Hsu et al., 2008). Some research for preventing train rear-end collision has been carried out. Rajkumar et al. (2015) proposed a concept of Multiple Mobile Agents used to collect the position information of all trains, process the received information, and make the decision of controlling the operation of trains by themselves during the occurrence of collision. Geethanjali et al. (2013) proposed a train position calculation method by sharing the track number with neighboring trains using Radio Frequency Communication of the supervision system to avoid train collision. Kunnenkeri (2004) proposed a method of automatic radio warning against train collisions. The accidents mentioned above show that trains equipped with ATP system or other monitoring systems are not guaranteed to avoid rear-end collision. Therefore, it is important to figure out a method to avoid rear-ending accidents in addition to the ATP system. This paper proposes a pre-warning method of train following interval based on Centralized Traffic Control (CTC). This method works in parallel with the ATP based train interval control system. In case of ATP malfunctioning or outputting errorneous commands, the CTC can realize fail-safety to ensure train operation safety. This method is an application and extension of the parallel control theory in high speed train control and safety areas (Wang, 2010; Wang et al., 2016a, 2016b, 2015; Song et al., 2011).

## 2. The necessity of CTC based train interval control and pre-warning

The signaling system of high-speed railway consists of the Train Control System (TCS), the Computer Based Interlocking system (CBI), the CTC, and other auxiliary signaling systems, such as the Maintenance & Monitoring System of the signaling equipment (MMS), the Dynamic Monitoring System of train control equipment (DMS), the train number following and wireless checking system, the wireless transmission system of the dispatching orders. ATP is the key equipment of TCS.

The train interval is the distance between two following trains. The minimum safety interval shall take train safe operation and driver comfort into consideration, and make reference to the minimum distance between trains.

The train interval has direct influence on line passing capacity and train operation safety. The main factors that determine the minimum safety interval include: relative speed between trains, the distance for train control response and driver reaction, the braking distance of the train, the distance for protection against the errors generated from equipment and operators, the comfort and safety of driving distance, the length of the train, the restrictive speed of the switches, the length of the station throat area, the time for handling station operations, and the effective length of station tracks, etc. If the train interval is less than the minimum safety interval and the relative speed of ahead train and following train is continuously negative, the rear-end accident will likely to happen. In order to avoid train rear-end collision, the major concern is not only to ensure the safe distance between two neighboring trains, but also realize dual control for the train interval (Wang, 2011).

In the high-speed railway signaling system, the necessity of design the CTC based train interval control and pre-warning system is as follows:

(1) The signaling system of the high-speed railway is an integration of all the signaling equipment, subsystems and the auxiliary equipment. The integration of the systems is one of the key technologies of the signaling system of the high-speed railway; it plays a very important role in maintaining the safety of the signaling system. The TCS Functional Requirements Specification, TCS System Requirements Specification, and the TCS Form-Fit Functional Interface Specification are the main references for the integration of the systems (Science and Technology Division Ministry of Railways, 2009). Currently, the integration of the signaling system of the high-speed railway focuses on the interfaces among different equipment and subsystems, as well as the interoperability when the signaling equipment provided by different suppliers are integrated into one single system. These signaling equipment and subsystems are developed at different times. Logically, the integrated signaling system constructed in this way is not designed completely in accordance with system engineering theory; therefore it cannot function with the advantages of the system as a whole or operate at system level. This simplified integration is lacking in sharing and fusion of information, without adequate inter-supervision and warning among the subsystems, and without fail-safe design at the system level (Wang and Lin, 2011).

(2) In the existing signaling system, ATP is merely used to control the following interval between trains and the train speed. Sometimes the ATP cannot calculate the train interval and the safe braking distance, due to the failure of signaling equipment, or the errors in acquisition and transmission of signaling information, thus affecting the safety of the train operation. In the "7.23" train rear-ending accident, the ATP wayside signaling equipment failed to realize "fail-safe", which was damaged by lightning. At the same time, the track circuit, as a part of the ATP wayside equipment issued a green signal to the following train instead of a red signal, allowing the following train to proceed and finally rear-end the preceding train. During this process, the ATP hadn't given any pre-warning and hadn't realized train following interval control, and its control behavior hadn't been monitored by other equipment or subsystem. Therefore, it is likely to result in an accident when a train operates according to the instructions calculated and outputted by ATP solely, without any other supervision. Particularly under emergency situations, there are some uncertain and dangerous elements in the instructions calculated and outputted by the ATP. Therefore, it is necessary to take additional means to supervise the ATP (Wang, 2004).

(3) There are limitations to the ability of train dispatchers to carry out auxiliary supervision. The dispatchers should utilize the CTC to supervise train operation and the status of signaling equipment by getting information from the large screen or monitors, including train following, train position and, signal status, train route, section blocking status, etc. Facing these abundant information about trains and signaling equipment, the dispatchers are not able to respond promptly. And visual fatigue will be caused by watching the monitors for a long time. All of these factors make it impossible to supervise the train operation by manpower alone (Huang and Ji, 2010).

## 3. The principle and structure of CTC&ATP based interval control system

The train interval control based on ATP&CTC interval pre-warning and control method is newly proposed, which is realized based on the existing CTC system. The wild geese migration theory is used in the proposed method (see Fig. 1).