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Elementary Analysis of Rail Transit Interlocking Technology

Zhixin Du[1], Tong Wang[1], Jitong Xia[1] and Lin Wang[1, *]

[1]School of Electronics and Information Engineering, Dalian Jiaotong, University, Dalian, China

Abstract

As cities continue to grow, traffic congestion problems are getting worse and cities need to be more closely connected to each other. In order to keep pace with urban development and solve transportation problems, rail transportation technology was born. CBTC, the automatic train operation control system, has been more widely used, and the interlocking system is one of the core technologies to ensure the safety of automatic train operation. As one of the core aspects of rail train control system, the research and development of CBTC computer interlocking is particularly important.

Keywords

Rail Transit; CBTC; Interlocking.

1. Introduction

In recent years, the rapid growth of the urban population has caused great pressure on transport, especially in the peak season such as holidays, traffic pressure is quite large. Urban rail trains have a large passenger volume and a fast running speed. They can complete the transportation of passengers safely and on time, which can effectively improve the phenomenon of traffic congestion and optimize the urban structure at the same time. Since Beijing built the first urban rail line in the 1960s, after more than 50 years of development, China's urban rail has entered a period of vigorous development. Before December 31, 2020, a total of 7978.19 kilometers of urban rail transit lines have been opened in Mainland China, including 6302.79 km of subway, 217.60 km of light rail, 98.50 km of monorail, 805.70 km of urban express rail, 485.70 km of modern tram, 57.70 km of magnetic levitation traffic, and 10.20 km of APM. As of April 1, 2021, there are 70 urban rail transits (in order of the opening time of the first rail transit) that have been opened in China. Therefore, urban rail transit has an important position in my country's transportation field.

In order to meet the requirements of large traffic volume and low time consumption, urban rail transit has continuously reduced the driving tracking interval and increasing the driving density. The driving interval has generally reached 2 minutes or even shorter. The traditional mode in which the dispatcher manually monitors the operation by managing the route, specifying the train operation level, and controlling the train stop time, is far from being able to meet the driving requirements. Therefore, the control technology of urban rail transit is particularly important, especially in the field of signal control, requiring more precise, efficient and stable technology to meet new demands.

In the urban rail signal system, the interlocking system is a very important part. The traditional interlocking technology of our country has been applied to the main railway and local railways for more than 20 years, and the application scope is very wide. However, in the field of urban rail signaling, domestic technology started late and progressed slowly. The existing technology cannot fully meet the operational requirements of urban rail signaling system for high efficiency, safety, high automation, and multiple functions. The domestic subway construction is mainly based on the introduction and re-absorption of foreign advanced technology [1] This method of introduction and reuse is high in construction costs, and later maintenance is inconvenient. These factors restrict the development of urban rail transit in China. Therefore,

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in-depth research and design of interlocking subsystems for my country's urban rail needs can not only realize the localization and autonomy of my country's urban rail interlocking system [2], but also promote the development of my country's urban rail industry [3, 4]

We mainly analyze the structure, function and development of rail transit interlocking system at home and abroad in this paper, and then studies the composition, characteristics and working principle of the ATC system (CBTC system) based on wireless communication, and summarizes the problems existing in rail transit interlocking technology. Carry out an outlook, and finally give a conclusion.

2. Interlock System for Rail Transit

2.1. Structure of the Rail Transit Interlocking System

Interlocking in engineering technology means both the relationship, but also mutual constraints (interlocking) of the two movements or the coordination of two manipulation action. On the railroad, interlocking means in order to ensure the safety of traffic, through technical methods, so that the road, turnout and signal machine in accordance with certain procedures, certain conditions to establish a relationship between the interconnection, but also the constraints of the relationship is the interlocking. To complete the interlocking relationship and the installation of technical equipment is called interlocking equipment.

Manipulation, transmission and locking/unlocking are the three basic functional elements of the station interlocking system. Transmission is to link the basic units of the approach such as signals, turnouts and track sections; locking is to control and lock/unlock the linked relationships according to the specified conditions; transmission and locking are the core of the process. The word "interlocking" can be said to express the core elements of such systems eloquently, and can also be understood simply and figuratively as the "linking" of specific constraints to "lock" them. The word "interlocking" can be understood literally and simply as "linking" specific constraints and "locking" them. Figure 1 shows the schematic structure of the interlocking system

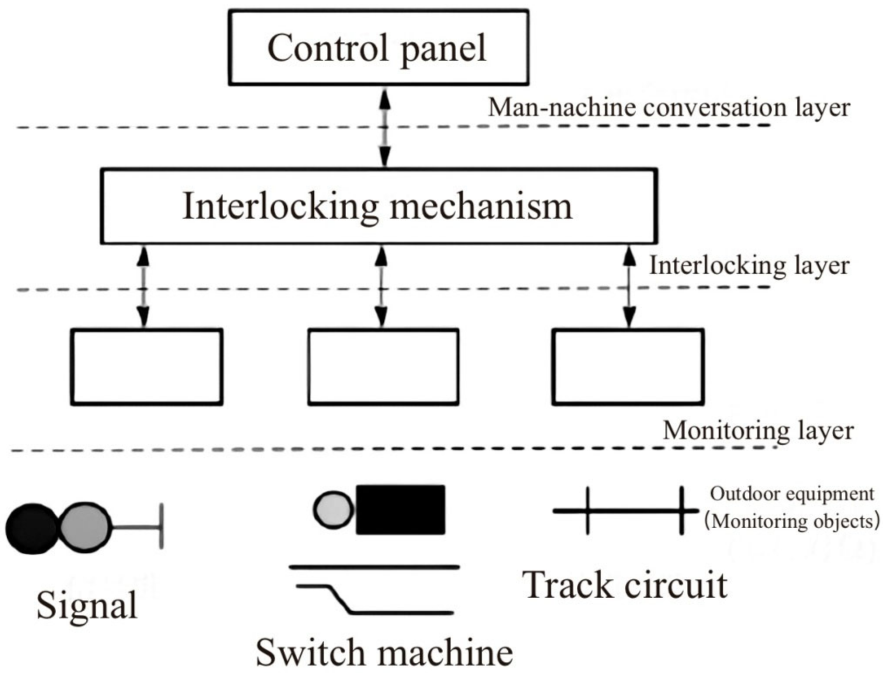

Figure 1. Structure of the interlocking system

The logic of control and locking/unlocking is based on defined conditions; transmission and locking are central. The word "interlocking" can be said to express the core elements of such systems eloquently, and can also be understood simply and figuratively as the "linking" of specific constraints to "lock" them. The word "interlocking" can be understood literally and simply as "linking" specific constraints and "locking" them. Figure 1 shows the schematic structure of the interlocking system

(1) Human-machine session layer: The operator inputs operation information to the interlocking mechanism through the human-machine session layer, and receives the equipment status information and traveling operation information from the interlocking mechanism at the same time.

(2) Interlocking layer: The interlocking layer realizes interlocking logic processing and is the core of the interlocking system. The interlocking mechanism performs interlocking logic operations on the operation information input from the human-machine session layer and the signal equipment status information such as signal machine, rutting machine and track circuit feedback from the monitoring layer to change the information stored inside the interlocking system and generate the corresponding control orders.

(3) Monitoring layer: The main functions of the monitoring layer include accepting the control command from the interlocking mechanism and changing the signal machine display through the signal control circuit; accepting the turnout control command from the interlocking mechanism and driving the turnout conversion; feeding back the signal machine status, turnout status and track circuit status information to the interlocking mechanism.

At present, the interlocking equipment is mainly centralized interlocking equipment, divided into two categories: relay centralized interlocking and computer interlocking. Interlocking equipment for urban rail transit used relay centralized interlocking in the early days, while computer interlocking is mostly used now. Computer interlocking has domestic and imported from abroad.

The centralized interlocking controls and supervises the turnouts, approaches and signaling machines of the whole station by electrical means, and realizes the interlocking between them. Centralized interlocking includes relay-type electrical centralized interlocking and computerized interlocking. If a circuit composed of relays is used to control and realize interlocking equipment, it is called relay-type electrical centralized interlocking, or relay-type centralized interlocking. The computer interlocking is the use of the existing industrial control computer, the development of a special hardware and software system to achieve the interlocking relationship between the signal, the approach and the turnout. It is essentially an interlocking logic operation system that satisfies the fault-safety signal principle. The role of the computer in the system is to read in the operation commands and various input representation information from the site, and then carry out logical operations according to the internal state of the computer and other conditions, and output control information to the actuator after judgment, realizing the transformation of such a complex transfer function as multivariable digital input and multivariable digital output. Figure 2 shows the schematic diagram of the logic operation of the computerized interlocking system.

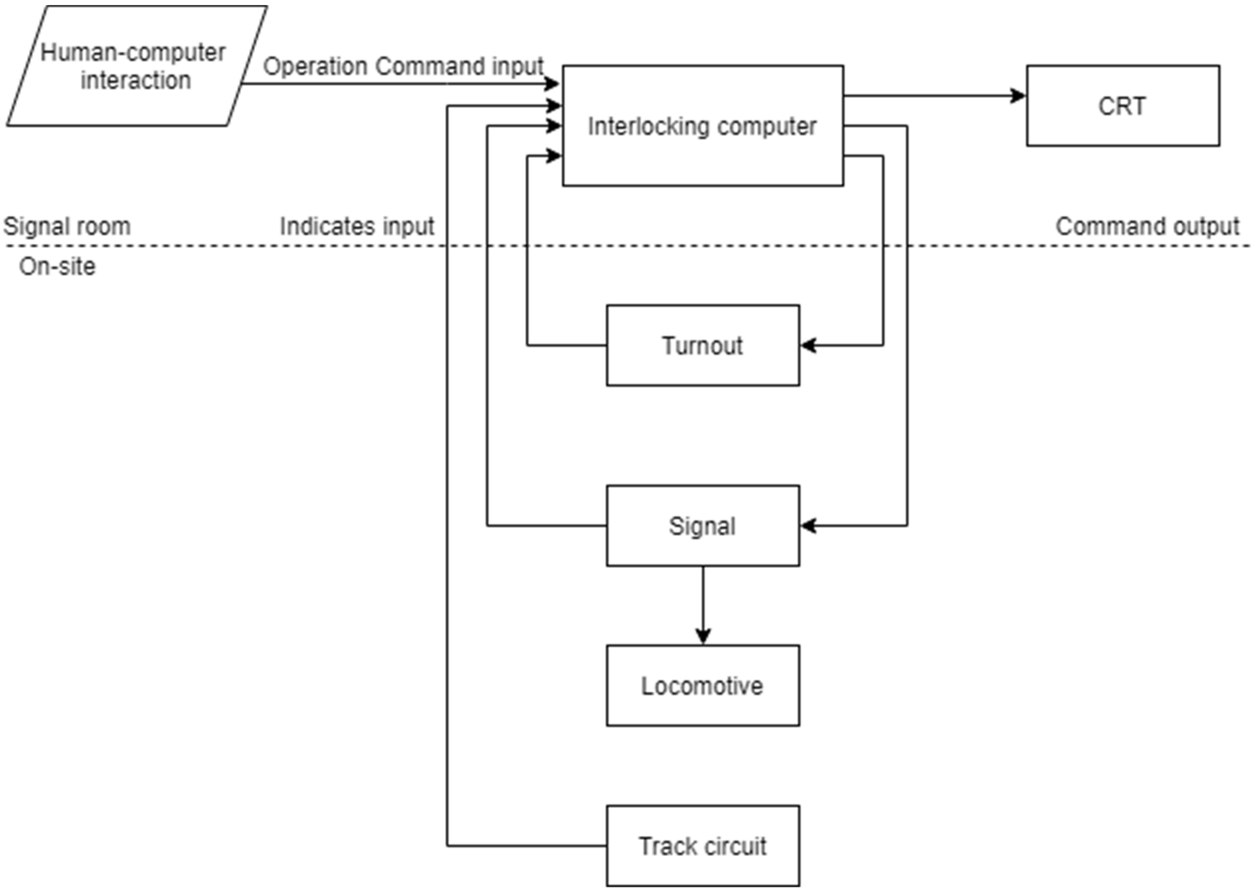

Figure 2. Schematic diagram of the logic operation of the computer interlocking system

Computer interlocking system is one of the safety core subsystems of CBTC signaling system for urban rail transit, which can meet the needs of various station sizes and transportation operations in the field of urban rail transit, and use computer as the main technical means to realize the constrained control of field equipment, ensure the safety of traffic, improve transportation efficiency and improve labor conditions. More details about CBTC signaling system will be introduced in Chapter 3.

2.2. Role of Rail Transit Interlocking Systems

In urban rail transit, the interlocking system is used for interlocking of mainline stations and rolling stock/car parks, controlling the opening and closing of signaling machines, controlling the switching and locking of rutters, receiving commands from ATS, providing information to ATP, and serving as a degradation mode of CBTC. Under CBTC conditions, although the role of the interlocking system has changed somewhat, it still has the following important roles.

(1) Checking segment idleness

The interlocking system determines the idleness or occupancy of a track section by means of a track circuit or an axle counter.

(2) Establishment of approach

The interlocking system checks that the relevant interlocking conditions are met, locks the relevant turnouts and hostile approaches, and sends the "signal open" message to the ATP zone controller (ZC).

(3) Approach unlocking

After the train has driven through the approach, check the relevant conditions to unlock the approach.

(4) Signal display

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Signal display is given when operating in backup mode in the event of an on-board signal equipment failure.

(5) Protecting the approach

Complete side-swash protection and protect the continuation approach if there is a continuation approach.

(6) Determining the running direction

Set the running direction for each track section.

(7) Exchange of information

Information is provided for ATS and ATP. Track-side information such as screen doors, flood doors, and station emergency switches are not acquired directly by the ZC, but are sent to the ZC after being processed by the interlocking system.[5]

2.3. Development of Interlocking Technology for Rail Transportation

The first worldwide urban rail transit was introduced in 1862 in England. Subsequently, countries started large-scale urban rail transit construction. After so many years of research, interlocking technology has slowly matured in these countries [6]. Currently, the representative interlocking systems are as follows:

(1) EBILOCK system from Sweden

This system was developed by Adtranz, in which the 750 series uses relays to complete the control of turnouts, signal machines, etc.; the 850 and 950 series both use contactless methods to achieve fully electronic control [7].

(2) Westrace system from the UK.

This system is a cooperative research and development of several companies in the UK. The hardware connection uses a combination of some functional modules. In terms of security, the system uses a three-take-two voting model.

(3) SMIS system and SICAS system in Germany.

These two systems are developed by Siemens in Germany, among which SIMIS system adopts the structure of "two hard and one soft" to ensure safety and is suitable for stations with large control and complex interlocking conditions [8]. Currently, it is mainly used in urban rail transit [9].

(4) Japanese K5 type system.

This system was developed by Kyo-San and does not limit the size of the station. It uses a dedicated computer to ensure "fail-safe", and each computer is equipped with dual CPUs to achieve a dual hot standby redundancy mode [9].

(5) VPI system and Microlock system in the US.

Both systems operate in a stand-alone state, with "security logic" in the host computer to ensure the safety of the system [10].

The interlocking system produced by Siemens in Germany is the most widely recognized and used in the world. Among the subways built in China, Guangzhou Metro Line 1 and Line 2; Shenzhen Metro Line 1 and Line 4 of the first phase of the project; Nanjing Metro Line 1 and Shanghai Xinmin Light Rail all use Siemens signal systems [11].

Domestic research on urban rail transit interlocking system started late, and most of the signal control systems of many domestic lines introduced foreign equipment. In recent years, domestic breakthroughs have been made in the field of urban rail transit signal control, and the transformation from scientific research to mass production has been realized. The representative interlocking systems are as follows [12]:

(1) TYJL-2, TYJL-TR9 and TYJL-ADX type interlocking systems.

The three interlocking systems were developed by the Railway Science and Research Institute. Among them, TYJL-2 type system is in hot standby mode and TYJL-TR9 is in three-take two mode. The system developed by the Chinese Academy of Railway Sciences has undergone laboratory commissioning and field trial operation commissioning, and all have achieved success.

(2) DS6-20, DS6-II and DS6-K5B interlocking systems.

These three interlocking systems were developed by the All-Road Communication Signal Design Institute, of which DS6-20 is a three-take two mode, DS6-II type system is a hot standby mode, and DS6-K5B is a two-by-two take two mode. The system independently developed by Allroad Communication Signal Design and Research Institute has been successfully put into operation in Beijing Metro Line 2 Phase II Project and other lines, and can maintain stable and efficient working condition.

(3) JD-IA and E132-JD type interlocking systems.

Both systems were developed by Beijing Jiaotong University, where the JD-IA type system is in hot standby mode and E132-JD is in two-by-two take two mode.

(4) VPI and iLOCK systems.

These two systems were developed by Casco Signal Corporation. CASCO Signal Company has completed the design and production of the complete system after continuous research and experiment. The systems have been successfully put into operation in Shanghai Metro Line 1 and other lines.

3. ATC System Based on Wireless Communication (CBTC System)

3.1. CBTC System Composition

CBTC system, i.e., ATC system based on wireless communication. The outstanding advantages of this system are that it can realize the two-way communication between the vehicle and the ground, and transmit the large amount of information, fast transmission speed, easy to realize the mobile automatic blocking [13], can significantly improve the interval passing capacity, flexible organization of two-way operation and one-way continuous departure, easy to adapt to different speed, different capacity, different types of traction of train operation control, etc. The way of wireless communication is mainly divided into wireless AP transmission mode, induction loop mode, leakage cable transmission mode and wave conduit transmission mode, among which the first two methods are more used.

CBTC system usually includes automatic train supervision system ATS, database storage unit DSU, area controller ZC, computer interlocking CI, on-board controller VOBC and data communication system DCS, and also includes backbone network, network switch, wireless access point and on-board mobile wireless equipment.

3.2. Principle of Moving Block for CBTC System

CBTC transmits information by wireless communication, and the line is divided into zones, each zone consisting of a certain number of line units, each controlled by a local controller and a communication system. The local controller maintains continuous two-way communication with the trains and interlocking subsystems in the area.

The real-time position of the train is determined by onboard positioning equipment as well as by ground-assisted positioning equipment. The regional controller tracks the train based on the position reports from the train, and the ATP/ATO computer calculates the maximum braking distance at the current speed of the train based on the operating speed and position information of the actual train itself and the preceding train, as well as the track line information from the data storage unit, to obtain the safety distance between trains. The mobile block uses the

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calculated safety distance to implement interlocking by using continuous two-way communication between the vehicle and the ground, and the regional controller issues movement authorization to the trains in the region. The trains are guaranteed to operate at the minimum safe interval distance.

The mobile blocking partition between this is mobile and enables two trains to travel safely on the basis of a smaller distance. CBTC, as a subsystem to ensure the safe operation of trains, must be guaranteed for the accurate operation of its entire system, so the regional controller ZC corresponding to the interlocking zone takes a 3-take 2 test redundancy configuration in order to ensure that the correct information is sent to the train. At the same time, as an on-board ATP/ATO device, the on-board controller (VOBC) also adopts the same 3-take-2 test redundancy configuration. [13]

3.3. Features of CBTC System

(1) High-capacity continuous two-way vehicle-ground communication can be realized.

(2) Both ground equipment and on-board equipment use safety computers to process train status and control commands in real time to realize continuous interval control, approach control, speed protection, automatic driving, etc.

(3) High-precision train positioning.

(4) Flexible and high-precision train operation control, which can realize high-efficiency mobile occlusion.

(5) High equipment integration, which reduces ground equipment, simplifies system structure, and improves reliability and maintainability, reducing whole life cycle costs.

(6) CBTC information can be superimposed on the existing signal system, which facilitates the transformation of existing lines and can realize the interconnection of urban rail transportation. [13]

3.4. Computer Interlock in CBTC

In the CBTC signal system, the computer interlocking system collects real-time station status information, receives data from other signal systems and operation commands from train operators, performs interlocking logic operations, controls field equipment, and sends data to other signal systems. The interlocking logic operation function of the computer interlocking system mainly includes: signal machine control, turnout control, section control, approach control, protection approach control, shield door control and supervision, emergency stop button supervision, anti-flooding door control and supervision, field link control, main signal control message control and other functions. In addition, the computer interlocking system also provides functions such as station equipment status representation and system information query [14, 15].

The interlocking system in CBTC signaling system should not only provide interlocking logic guarantee, but also support new requirements applicable to urban rail transit such as mobile blocking, main signal control, ATP control, and mixed running of different modes of trains. Although the traditional mainline railroad interlocking technology in China has been successfully applied for more than 20 years, the system cannot meet the new operational requirements such as multi-vehicle tracking operation and mixed running of different modes of vehicles proposed by urban rail transit signal operation.

4. Problems and Prospects of Rail Transit Interlocking Technology

4.1. Existing Problems and Solutions

As we all know, the signal system currently used in China is based on automatic train control under wireless communication, and all data transmission is managed by ZC ground area controller, which divides several large interlocking areas in the whole line, and each large interlocking area controls the trackside equipment (rutters, signals, turnouts) in the area through ZC ground area controller. If the ZC ground zone control goes down or fails, all trains in the interlocking area cannot receive MA (Mobile Authorization). At present, the mainstream design of CBTC system is still ground equipment as the core, and trains realize mobile blockage through the information interaction mode of "vehicle-ground-vehicle", although this design is logical and meticulous, but there are some shortcomings. In particular, the structural load, ground equipment and trackside equipment, there is a complex information interaction between the equipment, which also leads to increased construction costs and operating costs.

In response to the above problems, it is assumed that the control function of trackside equipment can be transferred to the on-board equipment, thus reducing the corresponding ground equipment, which can reduce the construction cycle and operation and maintenance cost of ground equipment, and also improve the operation efficiency. That is, the direct vehicle-vehicle communication mode based on the CBTC communication level can be realized.

The theory of "vehicle-vehicle communication mode" was first proposed by Alstom, and the construction of Line 1 in Lille, France, was successfully piloted in 2016 and completed in 2017. After using the "vehicle-vehicle communication mode" scheme, a large number of ground equipment such as CI (interlocking) and other control equipment were streamlined, and the equipment for direct communication between the ATS system and the on-board controller was retained, thus reducing the number of ground equipment by 20%, making the operation more flexible and reducing the safety interval to 66 seconds.

The difference between the "vehicle-vehicle communication mode" based on the CBTC communication level and the existing mainstream CBTC system is that: the traditional ground interlocking machine is eliminated and the corresponding functions are integrated into the on-board control VOBC; the central ATS system sends the approach information directly to the on-board controller VOBC, simplifying the communication link; the on-board controller VOBC can send the information according to the approach information. This adjustment in hardware architecture reduces the complexity of data interface and data interaction, reduces the network load of the signaling system, shortens the delay time, and thus improves the overall system efficiency. As shown in Figure 1, the comparison reveals that the vehicle-vehicle communication mode has a clear interface and simple structure compared to the traditional CBTC mode, which is easy to maintain and manage.

There are roughly three ways of vehicle-vehicle communication management: (1) The central ATS equipment completely obtains the train data of the whole line and assists the train to determine its associated front train, and the train only maintains communication with the front train. (2) The central ATS equipment obtains the train data of the whole line, and the on-board equipment determines the associated front car, and the train only maintains communication connection with the front car. (3) The on-board equipment of the train gets the position of the front train through vehicle-vehicle communication, determines off and associated front train by itself, and keeps communication with the whole line of trains. The information processing burden of the on-board equipment in mode 1 is much smaller than that of the latter two stations, and the requirement of vehicle-vehicle wireless communication is very low, but the central equipment needs to have strong information processing capability and bear greater safety responsibility, and this mode is almost equivalent to the calculation function of the travel permit of the regional control center of the CBTC system, which is against the original design intention of "heavy vehicle, light ground This is against the original design intention of "emphasizing on board, but not on ground". In mode two, the center equipment does not need to have the logic calculation function, and only acts as an "intermediary" for the storage and forwarding of train-built information, which reduces the complexity of vehicle-ground communication to a greater extent. Way three of the vehicle-ground communication is simple,

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communication content single, minimize the vehicle-ground information interaction, but the wireless communication capability between the vehicle and the vehicle is too demanding, when the line is too many trains, easy to broadcast storms and other problems.

4.2. Future Prospects

With the advent of the 5G era, it marks a new era of information technology in China across the board. Urban rail transit signaling system seizes this opportunity and simplifies the signaling system as much as possible while riding on the 5G network express. However, the network communication rate and information interaction time in vehicle-vehicle communication mode have become a major technical difficulty in vehicle-vehicle communication. With the ushering in of 5G era in China, this problem will be solved. I believe that in the next 3-5 years, vehicle-vehicle communication technology will be popularized in all urban rail lines. [15]

5. Conclusion

In a word, with the development of rail transit in China, the technical level of rail transit interlocking system is also improving. Only with the core technology, can we promote the good development of this field, China's rail transit interlocking system should constantly learn from the advanced countries, learn from experience, promote the promotion of innovation. Under the current wave of 5G, we try to combine the technology of 5G with the technology of interlock in rail transit, and lead the development of rail transit through the technology revolution of 5G to realize the technology surmounting.

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