Reliability and safety verification of the new collision avoidance strategy for Chinese train control system

Junting Lin[1*], Xiaoming Wang[1], Jianwu Dang[1]

[1] *School of Automation & Electrical Engineering, Lanzhou Jiaotong University, Anning West Road, Lanzhou, China*

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Abstract

Although equipped with comprehensive and complex technologies on the railway to avoid collisions between trains, such as train control system extensively deployed in the infrastructure, there are still enormous amount of collision between trains. The safety of railway operation mainly depends on the correct operation of the interlocking and train control system, because only the control centre has an overall overview of the traffic situation, and a train driver could only be warned of a possible collision if the operation centre decides it. Experiences from the aviation, the maritime navigation and road transportation have shown that the probability of collisions could be significantly reduced with infrastructure-less collision avoidance system. In this paper, an enhanced safety strategy, namely, Collision Avoidance System overlay Train Control System (CASOTCS) for Chinese railway was provided, which was based on direct vehicle-to-vehicle communication and independent of the regular control mechanism. CASOTCS can receive and evaluate the information broadcasted by other neighbouring trains all the time, which will trigger collision alert and provide a solution for the collision when a potential collision is detected. The unit architecture and its key issues of CASOTCS were also discussed. After the analysis of reliability and safety of both the traditional train control system and the enhanced CASOTCS, the reliability block diagram and isomorphic Markov model were established in the paper. Through the calculation of the indexes of the reliability and safety about the two kinds of control systems, a significant conclusion has been made, that is, the reliability and safety of the train control system plus collision avoidance system are much higher than that of the traditional one and CASOTCS has the ability to increase the reliability, safety and efficiency in the future.

Keywords: Collision Avoidance, Chinese Train Control System, Safety Verification, Reliability, Markov

1 Introduction

Actual statistics of the European Railway Agency (ERA) [1] and German Aerospace Centre (DLR) show that there are serious train-collision accidents all over the world, despite millions of money have been invested in infrastructure equipment. In order to increase safety in railway system, many countries are installing Train Control Systems (TCS), mainly centralized management ones, where trains are monitored by control centre.

Additionally, TCS used in rail transportation is heavily infrastructure-based, it is therefore clear that there is a need for a completely new safety system or overlay system that improves safety while reducing infrastructure and maintenance costs[2].

Experiences from the state of the art of collision avoidance system for different transport means, i.e. Traffic Alert and Collision Avoidance System (TCAS) [3], Automatic Dependent Surveillance Broadcast (ADS-B) [4], Automatic Identification System (AIS) [5] and Car-to-Car (C2C) [6] have shown us that the probability of collisions can be significantly reduced collision avoidance system, which do hardly require infrastructure components To meet the requirements of the systems for high safety and high reliability, various redundancy and restructuring cells are widely applied in electronic product design to improve the reliability and safety of the systems, as well as online fault diagnosis technology. In terms of safety, reliability and cost, dual hot spare dynamic redundancy structure is a kind of ideal design scheme, and has already been widely applied in modern railway signal systems. Analysis of reliability and safety of redundant systems have been researched extensively. As in [7], He applies fault tree to investigate the safety of the switch control unit of all-electronic computer interlocking system. Zhang [8] analyzes and compares the reliability and safety of several common-used redundant structures. Hence, the paper aims at dynamic redundant communication systems between trains, which has already been widely applied in Chinese high-speed railway, and established reliability block diagram of centralized TCS and CASOTCS. Synthetically considering the influence of many factors such as coverage of diagnostic systems, online maintainability and many failure modes, we finally established the Markov model and analyzed the safety indexes. The result shows collision avoidance system has the ability to increase safety and efficiency.

The rest of this paper is organized as follows: Section 2 we describe the state of art in Chinese train control system. Section 3 introduces the collision avoidance systems in maritime, air, and road transport, and

* ***Corresponding author*** e-mail: linjt@mail.lzjtu.cn

discusses the unit structure of Collision Avoidance System overlay Train Control System (CASOTCS) and its key issues. Section 4 verifies the reliability and safety of CASOTCS. Finally, conclusion is given in section 5.

2 State of the art in CTCS

Conventional trains in China were manually controlled and operated by drivers based on trackside interlocking and blocking, in conjunction with various train signaling and surveillance devices [9]. As the high-speed railway systems being rapidly developed in China recently, the old Track Based Train Control (TBTC) has gradually been replaced by the modern Communication Based Train Control (CBTC).

The Chinese Train Control System (CTCS) is a train control system implemented since 2002, which is specified for compliance with the high-speed and the conventional interoperability and directives. CTCS by nature is an automatic train protection (ATP) system, based on cab-signaling and signal aspects as well as continuous tracking to the data transmission on the train system. The movement authority (MA) and the corresponding line information are transmitted to the control unit of the train and then being displayed in the cab for the driver as commands or references. A train with complete CTCS equipment and functionality can operate on any CTCS line without much technical restriction.

Based on the signaling system of Chinese railway network, Chinese Train Control System (CTCS) has been divided into five levels, namely CTCS level-0, 1, 1, 2, 3 and 4, referring to European Train Control System (ETCS) [10]. The definition of the levels depends on how the line is equipped and the way the information is transmitted to the train. Interoperability is necessary for the train control system to achieve joint operation among Dedicated Passenger Lines (DPL, another name for high-speed railway in China) and rebuilt lines, where CTCS levels-2, 3 and 4 are back-compatible with lower levels.

CTCS level 0. It consists of the existing track circuits, universal cab signaling (the digital, microprocessors-based cab signaling that be compatible with the six kinds of track circuits on Chinese Railway Network, designed by the research team of Beijing Jiaotong University ten years ago) and train operation supervision system. With level 0, wayside signals are the main signals and cab signals are the auxiliary signals. It is the most basic mode for CTCS. It is no necessary to upgrade the wayside systems for CTCS level 0. The only way to realize the level 0 is to equip with the on-board system. CTCS level 0 is only for the trains with the speed less than 120km/h.

CTCS level 1. It consists of the existing track circuits, transponders (or Balises) and ATP system. It is for the train with the speed between 120km/h and 160km/h. For this level, the block signals could be removed and train operation is based on the on-board system, ATP, which is called as the main signals. Transponders (Balises) must be installed on the line. The requirements for track circuit in blocks and at stations are higher than that in the level 0. The control mode for ATP could be the distance to go or speed steps.

CTCS level 2. It consists of digital track circuits (or analog track circuits with multi-information), transponders (Balises) and ATP system. It is used for the trains with the speed higher than 160 km/h. There is no wayside signaling in block for the level 2 anymore. The control mode for ATP is the distance to go. The digital track circuit can transmit more information than analog track circuit. ATP system can get all the necessary information for train control. With this level, fixed block mode is still applied. The system indicates the special feature of Chinese railway signaling.

CTCS level 3. It consists of track circuits, transponders (Balises) and ATP with GSM-R. In the level 3, the function of the track circuit is only for train occupation and train integrity checking. Track circuits no longer transmit information concerning train operation. All the data concerning train operation information is transmitted by GSM-R. GSM-R is the core of the level. At this level, the philosophy of fixed block system is still applied. It was firstly used on the Wuhan-Guangzhou High-speed Railway services, where trains have speeds up to 350 km/h on DPL, which was started operation in December 2009. It has two subsystems: ground subsystem and onboard subsystem. The ground subsystem includes Balises, track circuits, a wireless communication network (GSM-R), and a Radio Block Centers (RBCs). The onboard subsystem, on the other hand, includes onboard devices and an onboard wireless module.

CTCS level 4. It is the highest level for CTCS. Moving block system function can be realized by the level 4. The information transmission between trains and wayside devices is made by GSM-R. GPS or transponders (Balises) are used for train position. Train integrity checking is carried out by on-board system. Track circuits are only used at stations. The amount of wayside system is reduced to the minimum in order to reduce the maintenance cost of the system. Train dispatching can be made to be very flexible for the different density of train operation on the same line.

From the above categories, we can see that the safety of railway operation is mainly ensured by the centralized infrastructures, such as interlocking and block system, which set and lock the train route. The trains are equipped with the onboard part of the train control system, which triggers automatically a braking if the train passes a signal at danger.

The safety of railway operation depends on the correct operation of the train control system where the trains are monitored by devices located along the rail. These devices send the collected information to an operation center named Train Control Center (TCC) or Radio Block Center (RBC) that can pass specific instructions to the train, as shown in Figure.1. Human errors and the communication failure between train and control center lead to most of the accidents. Additionally, only the operation center has an overall overview of the traffic situation, and a train driver could only be warned of a hypothetical collision if the operation center decides it.

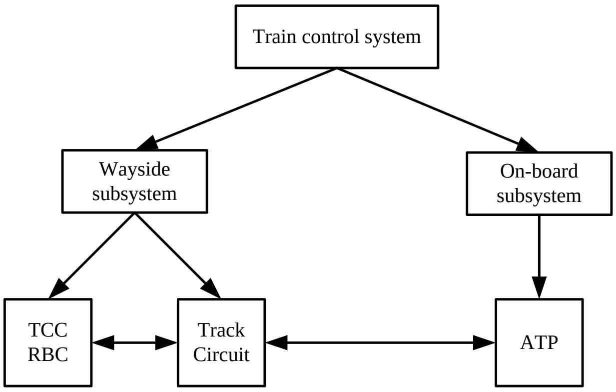

FIGURE 1 Control strategy of CTCS

3 State of the research in CAS and applicability to CTCS

3.1 CAS AND ITS APPLICABILITY

Collision avoidance systems related with aviation, maritime, and road transport systems have gone through a rapid evolution and improvement with significant growths.

Aviation: TCAS relies on the Secondary Surveillance Radar (SSR). By means of this radar, a TCAS equipped aircraft interrogates other aircraft in its vicinity and listens for the transponder replies [11]. Computer analysis of these replies determines which aircraft represent potential collision threats. Consequently Traffic Advisories (TA), in TCAS I, and resolution advisories (RA), in TCAS II and III, can be provided. ADS-B conform the evolution of TCAS. Based on the Global Positioning System (GPS), an aircraft can automatically broadcast its identification address. GPS derived latitude and longitude, altitude and the 3D velocity.

Maritime navigation: The maritime surveillance application of AIS consists of a continuous interchange of driving data from ships like GNSS position, speed and direction, as well as relevant information like identification numbers, length and beam, ships draught, route plan etc..

Road Transport: The Car 2 Car Communication Consortium aims to establish an open European industry standard for the ad-hoc communication between vehicles and vehicles to infrastructure, which is currently in the development phase. Together with the position determined by a GNSS receiver this information is broadcast to the vehicles in the vicinity which may detect the presence of traffic jam by exploiting the received information.

Applicability to Chinese Railway: While maritime, air, and road transport have a vehicle integrated collision avoidance system available or in the development phase, we find no satisfactory solution of this type of technology in railway transportation. Therefore, it is necessary to develop a system that will allow the train conductors to have an up-to-date accurate knowledge of the traffic situation in the vicinity and act in consequence. The system is intended to not rely on components in the infrastructure, this way substantially reducing its rollout and maintenance costs, as well as inherently providing a migration strategy. The basic idea is to communicate relevant own context information to all other nearby trains.

Experiences from the TCAS and ADS-B, as well as AIS and C2C, have shown that the probability of collisions can be significantly reduced with collision avoidance systems. In this section, we introduce our CASOTCS approach consisting only of Train-to-Train communication components, i.e. without the necessity of extensions of the railway trackside infrastructure, as depicted in Figure 2. Each train determines its position, direction and speed using Global Navigation Satellite System (GNSS) and broadcasts this information, complemented with other important information in the region of its current location. This information can be received and evaluated by other trains, which may – if a potential collision is detected – lead to traffic alerts and resolution advisories up to direct interventions (usually applying the brakes).

3.2 KEY ISSUES OF CASOTCS

In the designed CASOTCS, each trains has to calculate its own position and movement vector and broadcast this information as well as additional data like vehicle dimensions to all other trains in the area. Thus, the driver's cabin could be equipped with a MMI showing the position of the other vehicles in the region. CAS vital computer analyzes all received context information, the own position and movement vector and an electronic track map detects possible collisions, displaying an alert signal, and advising the driver of the most convenient strategy to follow in order to avoid the danger. The system can take into account different danger sources, like advancing trains or road vehicles or obstacles, and classify them according to a specific scale.

In principle, the CASOTCS is very similar to TCAS/ADS-B used as a "safety overlay system" in aeronautical transport, which is as well controlled by a number of operation centers. The advantages of such infrastructure-less collision avoidance overlay system are:

- Collision avoidance system works independently of the regular traffic control mechanism.
- No changes are required on the existing train control system infrastructure.
- Direct train-to-train communication as the supplement of GSM-R to enhance safety.
- Continuous "roll-out" is possible.

- Lower costs compared to infrastructure based system.
- Potential to increase efficiency, e.g. shorter distances between trains.

The railway specific boundary conditions require new design considerations [12]. The major components of an infrastructure-less collision avoidance system for CTCS are position detection, direct train-to-train communication and collision surveillance resolution.

3.2.1 Speed detection and positioning system

The precise detection of the position plays a key role for collision avoidance system and train control system. The positioning system proposed in CASOTCS determines the position of the train independently from the trackside equipment. Because of inadequate fulfillment for safety-critical application, GNSS-based positioning system has to be combined with at least one additional positioning technique such as digital map, odometer or inertial system.

3.2.2 Direct train-to-train communication

Simulations have been done in shown that using an air brake system to stop a train at initial speed of 300 km/h, it will take 4.1 km for the train to arrive at a complete stop. In order to design a suitable direct train-to-train communication system, a six phase work approach was conducted: preliminary analysis and selection of an adequate frequency band, characterization of the propagation channel, MAC layer design, physical layer design and verification of the system [13, 14]. The following challenges arise designing the system: no infrastructure can be used, transmission is broadcast and the system will run in high speed line.

3.2.3 Collision surveillance resolution

Each collision avoidance system unit produces messages with a fixed length that are broadcasted with a variable rate based on its own speed and the vicinity traffic situation. The Train Number (TN) or the Locomotive Number (LN), the current speed, the braking distance, and the forward and the backward length of the train with respect to the localization unit are included in the messages to allow other vehicles to identify potential collision (head-on, rear-end or flank collision). To avoid collision, a Collision Alert (CA) signal as the first step shall warn the driver in case of a detected close approach to another CAS unit on a collision course, and the driver is prepared to perform a braking operation in the second step. Reliability of collision detection in time is the most important property in CAS, and it is the estimated braking distances that can distinguish collision scenarios from regular operation.

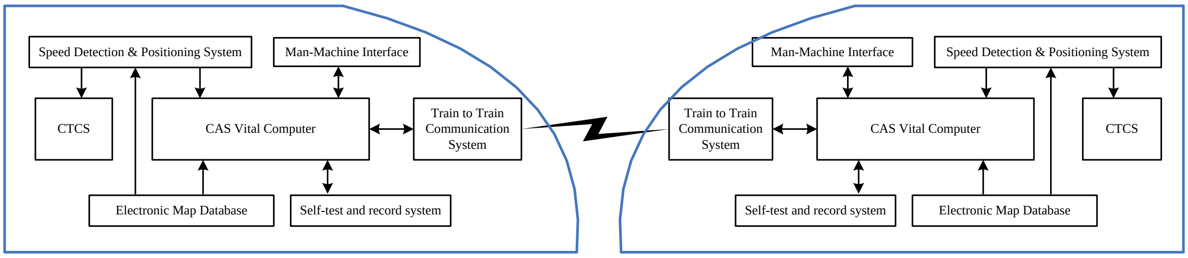

FIGURE 2 Unit architecture CASOTCS

4 Reliability and safety verification of CASOTCS

Reliability is defined as the probability that a system (component) can complete the regulated function under specified conditions and in range of the prescribed time. To express this relationship mathematically we define the continuous random variable T to be the time to failure of the system (component) [15]. Then reliability can be expressed as

$$R(t) = \begin{cases} P(T > t) & t \geq 0 \\ 0 & t < 0 \end{cases}, \quad (1)$$

where $R(t) \geq 0$, $R(0) = 1$ and $\lim_{t\to\infty} R(t) = 0$. In analyzing a complex system, an alternative approach is to determine an appropriate reliability or reliability model for each component of the system, and by applying the rules of probability according to the configuration of the components within the system, compute a system's reliability.

Corresponding to the reliability, the unreliability can be defined as

$$F(t) = P(0 \leq T \leq 0) = 1 - R(t) \quad (2)$$

Thus, mean time to failure (MTTF) can be presented by

$$MTTF = E(T) = -\int_0^{+\infty} td\left[R(t)\right] = \int_0^{+\infty} R(t)dt \, . \quad (3)$$

Safety refers to the ability that the system could not generate the dangerous side outputs when the fault occurs. Reliability, availability, and *MTTF* are only for the normal work of the system concerned. As the system enters into the failure state from the normal one, we can say that it breaks down and terminates the job, and cannot continue to perform the regulated function. At the moment, there are two significant states to need to be considered, that is, the safety failure state and the dangerous failure state. The former is corresponding to a safe failure probability (PFS) and the latter is corresponding to a dangerous failure probability (PFD).

Thus, the unreliability may be written as

$$F(t) = PFS(t) + PFD(t). \tag{4}$$

In terms of the repairable systems, the availability is

$$A(t) = 1 - [PFS(t) + PFD(t)]. \tag{5}$$

The safety availability is different with the availability, and defined as

$$S(t) = 1 - PFD(t). \tag{6}$$

Through online condition monitoring and fault diagnosis, we can reduce maintenance time and control the implementation of some tolerant structure. The diagnostic coverage rate can be applied to express the power of the diagnostic system, which reflects the probability that if a failure occurs it can be detected. In the numerical value, it equals the sum of the detected failure rates is divided by total failure rate. Hence, it is necessary to consider the influence of failure detection system when analyzing a system safety [16].

Without consideration common cause, the failure rate of the channel is partitioned as the two parts, that is, the safety failure rate λ^S, and the failure rate λ^D, and then

$$\lambda = \lambda^S + \lambda^D. \tag{7}$$

Consider the role of online diagnostic systems, the failure rate λ^S is divided as the two parts, that is to say, the detected safety failure rate λ^{SD} ,and the undetected safety failure rate λ^{SU}, and then

$$\lambda^S = \lambda^{SD} + \lambda^{SU}. \tag{8}$$

For λ^D, likewise, we let λ^{DD} expresses the detected dangerous failure rate, and λ^{DU} be the undetected dangerous failure rate. We have

$$\lambda^D = \lambda^{DD} + \lambda^{DU}. \tag{9}$$

Components within a system may be related to one another in two primary ways: in either a serial or a parallel configuration. In series, all components must function for the system to function, while in a parallel, at least one component must function for the system to function.

To simplify the notation, the argument of $R(t)$ will be dropped [17] In this case, it is understood that all reliabilities are to be evaluated for the same point in time t. Generalizing to n mutually independent components, serial system reliability is expressed as

$$Rss = \prod_{i=1}^{n} R_i, \tag{10}$$

where R_i represent the reliability of the unit i. System reliability for n parallel and independent components is given by

$$R_{SN} = 1 - \prod_{i=1}^{n} (1 - R_i). \tag{11}$$

Systems typically contain components in both serial and parallel relationships. To compute the system reliability, the network may be broken into serial or parallel subsystems.

There are dynamic redundant structures applied in modern train control system, which are here respectively defined as the fundamental mode is shown in Figure 3. The enhanced mode including train-to-train communication channel is shown in Figure 4.

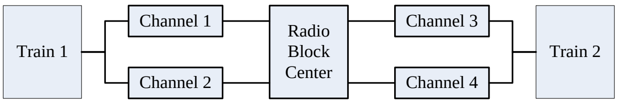

FIGURE 3 Fundamental mode of train to train communication channel

$$\begin{aligned} R_{S1} &= [1-(1-R_{Ch1})(1-R_{Ch2})] \times \\ & R_{RBC} \times [1-(1-R_{Ch3})(1-R_{Ch4})], \end{aligned} \tag{12}$$

where R_{Ch1}, R_{Ch2}, R_{Ch3} and R_{Ch4} represent the reliability of Channel1, 2, 3 and 4 respectively, and R_{RBC} is the reliability of RBC.

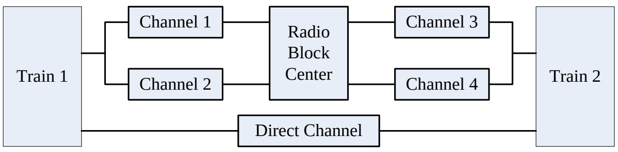

FIGURE 4 Enhanced mode of communication channel in CASOTCS

Let the direct channel reliability be R_{DC}, we have

$$R_{S2} = 1 - (1 - R_{S1})(1 - R_{DC}). \tag{13}$$

According to equation (12) and equation (13), the diverse reliability and their difference are calculated as shown in Table 1 and Figure 5. Clearly, system reliability relies on the reliability of units. The higher is the unit reliability, the higher is the system reliability. Enhanced mode is more reliable than the fundamental mode, but differences between them are minimized.

The security of single channel with single version software only relies on channel own security, which is difficult to meet the safety requirements. Dual channel with double version software cannot only detect the most software faults, but also can find the hardware faults, and the requirements on the hardware are not so high. If the self-diagnosis program detects and prompts the emergence of a failure, then the failure can be immediately repaired, and otherwise it may not still known. To be able to find the failures early, the regular repairing and detecting on the equipment's is necessary. Regular maintenance is implemented by the professional and technical personnel, who manually examine each part of the equipment to see whether they operate normally. Assume that the manual inspection can find all the problems, then two specific maintenance rates occur. One is on-line maintenance rate, which occurs as the diagnosis programs detect and prompt the emergence of a failure, and the other is regular maintenance rate, which occurs during periodic detection and maintenance, and includes the testing time and repairing time. Compared with on-line maintenance rate, the regular maintenance rate is lower.

TABLE 1 Reliability calculation

R	R_{S1}	R_{S2}	R_{diff}
0.9000	0.88209000	0.98820900	0.10611900
0.9100	0.89531771	0.99057859	0.09526089
0.9200	0.90826168	0.99266093	0.08439925
0.9300	0.92090833	0.99446358	0.07355525
0.9400	0.93324418	0.99599465	0.06275047
0.9500	0.94525594	0.99726280	0.05200686
0.9600	0.95693046	0.99827722	0.04134676
0.9700	0.96825479	0.99904764	0.03079286
0.9800	0.97921616	0.99958432	0.02036817
0.9900	0.98980201	0.99989802	0.01009601
0.9950	0.99495025	0.99997475	0.00502450
0.9955	0.99545968	0.99997957	0.00451989
0.9960	0.99596813	0.99998387	0.00401574
0.9965	0.99647559	0.99998766	0.00351208
0.9970	0.99698205	0.99999095	0.00300889
0.9975	0.99748753	0.99999372	0.00250619

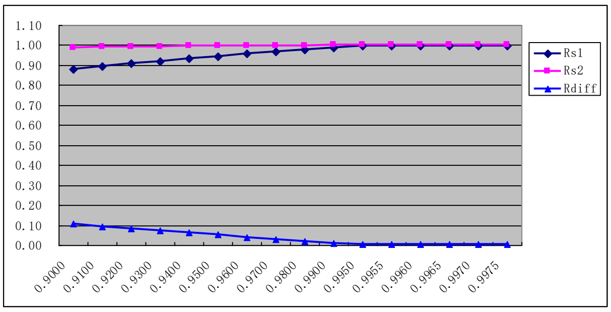

FIGURE 5 Reliability of fundamental and enhanced mode

The working principle of the enhanced mode is basically consistent with the fundamental mode, but it adds train-to-train direct channel to perform redundant communication channel to ensure the system safety. This kind of structure, as shown in Figure 6, adopts single machine performing double- channel software, and each channel possesses the diverse software, which makes the system realize 2-vote-2 from the hardware to the software. This ensures the system safety, further. This kind of the structure cannot only find most of the software errors in the process of operation, but also can detect the hardware failures. Therefore, its security is very high.

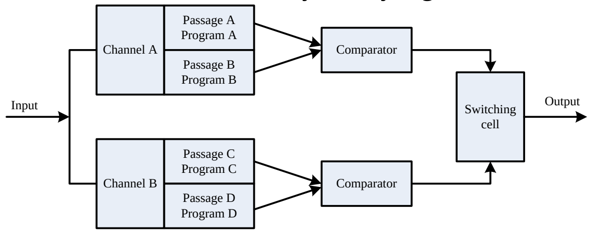

FIGURE 6 Reliability structure of the enhance mode

According to the former analysis, the Markov models of three kinds of dynamic redundant structures are isomorphic. Though observing carefully the states, we find two states meet the condition of mergers. Hence, we may establish a merged state transfer model for them as shown in Figure 7.

In Figure 7, the state zero expresses the two channels are perfect and work normally, and the state one expresses one channel is in failure and can be detected, and the state two represents one channel generates the failure (dangerous or safety) that self-diagnostic program cannot find but comparison program may detect out, and the state three presents the system safety failure, and the state four expresses the system dangerous failure but can be detected, and the state five presents the system dangerous failure undetected. In process of modeling, we assume that when one channel gets inspection and maintenance, and another channel also will have a chance to get detection and repairing. In addition, we also assume a maintenance rule of online repairing system under the condition that the system is not terminated. Likewise, we also assume that periodic detection and maintenance is perfect and can find any problem, and after repairing the system restores to the initial state. Thus, we may ignore the service arc from the state six to the state zero, as well as its service rate up. In fact, in terms of high security and high reliability system, it is meaningless to solve the steady state indexes.

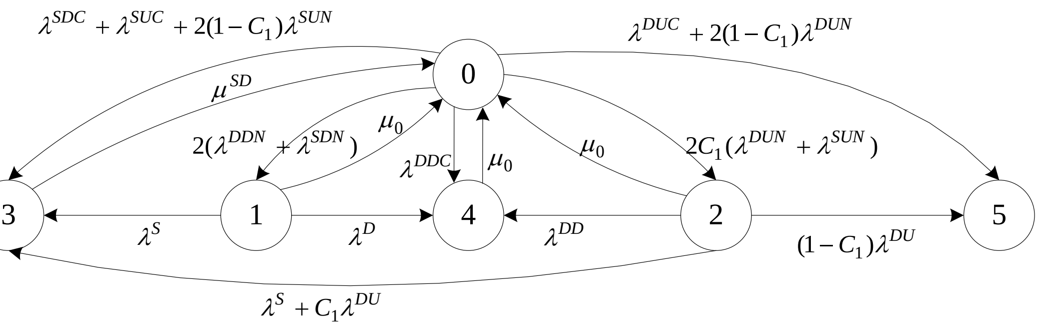

FIGURE 7 Merged isomorphic Markov model of enhance mode

According to Figure 7, we can acquire its state transition matrix P below

$$P=\begin{bmatrix} 1-\left(\lambda^{DC}+\lambda^{SC}+2\lambda^{DN}+2\lambda^{SN}\right) & 2\left(\lambda^{DDN}+\lambda^{SDN}\right) & 2C_1\left(\lambda^{DUN}+\lambda^{SUN}\right) & \lambda^{SDC}+\lambda^{SUC}+2(1-C_1)\lambda^{SUN} & \lambda^{DDC} & \lambda^{DUC}+2(1-C_1)\lambda^{DUN} \\ \mu_0 & 1-\left(\mu_0+\lambda^S+\lambda^D\right) & \lambda^S & \lambda^S & \lambda^D & 0 \\ \mu_0 & 0 & 1-\left(\mu_0+\lambda^S+\lambda^D\right) & \lambda^S+C_1\lambda^{DU} & \lambda^{DD} & (1-C_1)\lambda^{DU} \\ \mu_{SD} & 0 & 0 & 1-\mu_{SD} & 0 & 0 \\ \mu_0 & 0 & 0 & 0 & 1-\mu_0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

In accordance with the matrix, the transient availability at any moment can be calculated based on Markov chain method in a detection cycle. Assume that the initial state is S_0, and the n-step state transient probability is p^n, and then the transient probability at n moment is $S_n=S_0P^n$. According to S_n, we may solve PFD and PFS. The PFS is the probability of state three, and PFD is the probability sum of state four and five, and the availability is the probability sum in state zero, one, and two.

TABLE 2 Failure rates values

Failure rate type	Numerical value ($\times10^{-5}$ h^{-1})
λ^{SDN}	0.98568
λ^{SDC}	0.07992
λ^{SUN}	0.10952
λ^{SUC}	0.00888
λ^{DDN}	0.24642
λ^{DDC}	0.01998
λ^{DUN}	0.02738
λ^{DUC}	0.00222

If the security failure rate is expressed by $\lambda^S=1.184\times10^{-5}$ h^{-1}, the dangerous failure rate $\lambda^D=0.296\times10^{-5}$ h^{-1}, and the diverse failure rates are listed in Table 2, 90% of the safety and dangerous failures can be found by self-diagnostic program, and the diagnostic coverage rate of comparison program is 99.9%, and online maintenance rate μ_0 equals 0.1. If the system generates a safety failure, then it could restart within 24 hours.

As $t=8760$, under the conditions of the fundamental mode with $C_1=0$, the enhanced mode with $C_1=99.9\%$ we calculate the security and reliability indexes of the fundamental mode and the enhanced mode, as shown in Table 3.

TABLE 3 Security and reliability indexes values of diverse modes

Types	PFS($\times10^{-5}$)	PFD($\times10^{-4}$)	MTTF(h)
Fundamental mode	3.752355	6.814555	799033
Enhanced mode	3.351301	3.144774	894919

Seen from Table 3, the security and availability indexes of the enhanced mode are higher than the ones of the fundamental mode. For the hardware requirements, the enhanced mode is the highest, and from the hardware and software demands and technology implementation difficulty degree, generally, the fundamental mode is lower than the enhanced one. Hence, for modern railway train control system, it is very necessary to select the suitable redundant structures combining the requirements on safety and reliability, and cost, and the difficult-easy degree in technology realization.

5 Conclusion

In this paper, we have presented the supplement collision avoidance system for Chinese railway, namely Collision Avoidance System overlay Train Control System (CASOTCS), which is located completely on board and uses basically the information about position, speed and direction as well as additional data broadcasted by other CASOTCS with direct vehicle-to-vehicle radio communication. The on-board computer can analyze all the received context information, self-position and movement vector and an electronic track map to detect possible collisions, display an alert signal, and provide the driver the most convenient strategy to avoid the potential danger. After the comparison of the reliability and safety between the traditional train control system and the enhanced CASOTCS, the reliability block diagram and isomorphic Markov model have been established. According to the relevant analysis and calculation, we have found that the enhanced train control system by adding collision avoidance system has the better reliability and safety than the traditional one.

In recent years, the Chinese railway systems have gone through a massive phase of upgrading and expansion, especially after the establishment of Chinese Train Control System (CTCS). Collision avoidance system has the ability to increase safety and efficiency. The key issues to complete this system discussed in this paper will be further researched and a prototype should be realized to show the feasibility of the strategy.

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Author

Junting Lin, born in August, 1978, Lanzhou City, Gansu Province, P.R. China

Current position, grades: the Lecturer of School of Automation & Electrical Engineering, Lanzhou Jiaotong University, China.
University studies: received his B.Sc. in Automatic Control from Lanzhou Jiaotong University in China. He received his M.Sc. in Communication and Information System from Beijing Jiaotong University in China.
Scientific interest: His research interest fields include Train Control System, Vehicle to Vehicle communication
Publications: more than 50 papers published in various journals.
Experience: He has teaching experience of 12 years, has completed three scientific research projects.

Xiaoming Wang, born in November, 1954, Lanzhou City, Gansu Province, P.R. China

Current position, grades: the Professor of School of Automation & Electrical Engineering, Lanzhou Jiaotong University, China.
University studies: received his B.Sc. in Railway Signal Control from Lanzhou Railway Institute in China. He visited Ryerson Institute of Technology as senior visiting scholar.
Scientific interest: His research interest fields include Railway Signal Control System, Computer-based Interlocking system.
Publications: more than 160 papers published in various journals.
Experience: He has teaching experience of 52 years, has completed twenty six scientific research projects.

Jianwu Dang, born in May, 1963, Lanzhou City, Gansu Province, P.R. China

Current position, grades: the Professor of School of Automation & Electrical Engineering, Lanzhou Jiaotong University, China.
University studies: received his B.Sc. in Railway Signal Control from Lanzhou Railway Institute in China. He received his M.Sc. in Computer Science from Southwest Jiaotong University in China. He received his Ph.D. in Communication and Computer Engineering from Southwest Jiaotong University in China.
Scientific interest: His research interest fields include Train Control System, Intelligent Transportation System and Fuzzy Neural Network.
Publications: more than 170 papers published in various journals.
Experience: He has teaching experience of 28 years, has completed fifty scientific research projects.