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Monitoring Train Control System for the Next Generation Using GSM

M.Krishnavani(krishnavaniece28er@gmail.com),K.Mahalakshmi(mahaecesmart27@gmail.com)
S.Sowmiya(sowmiyaselvaraj1995@gmail.com), S.Sivaranjani(sivaranjanishivaa@gmail.com)
Guided by
S.Sasikala ,AP/ECE,(sasiecekala@gmail.com)
Department of Electronics and Communication Engineering
Bharathiyar Institute of Engineering for Women,Deviyakurichi.

***Abstract*—In railway system,there are many problems can occur.The most important one of them is occurred by existing operating processes which allow human errors to occur.**
This paper concentrates to design process and architecture for the next generation of train control system by using GSM and to detect the object at a particular distance to protect the objects from the accident. In previous methods, the accidents are mostly occurdue to signaling system failures. This can be overcome bymonitoring and detecting the problemsin the train control systems.

I. INTRODUCTION

RAILWAY accidents, such as collisions, conflicts, andderailments, happen all over the world and cause greatlosses to society. According to published reports,48seriousrailway accidents happenedbetween 1971 and 2011 in China.Of these accidents, 6 were caused by collisions, 15 by conflicts,and 8 by derailments. The other 19 out of the 48 accidentsoccurred for other reasons, such as fire or explosion. In total,885 people were killed and 2668 were injured [1].

Serious accidents have also occurred in other parts of theworld, e.g., the Eschede high-speed train accident in Germanyin 1998, a train derailment accident in 2005 in Japan, and a LosAngeles, CA, USA, train collision accident in 2008.Some railway accidents occur due to signaling system failures.On July 23, 2011, a collision occurred between two trains on the Yongwen High Speed Line in China, due to the signalingsystems outputting erroneous signals after the tracksideequipment is struck by lightning. The accident resulted in 40deaths and more than 170 serious injuries [2]. On February 14,1994, the 146-passenger train had a side of conflict with the3109 freight train when passing through Zhang Ming Stationon schedule, which caused the derailment of several carriagesand resulted in one death. The reason for the accident is atrack circuit failure leading to interlocking failures. The signalworkers wrongly set another route for the 146-passenger trainwith the occupied switch by the 3109 freight train.

There are other railway accidents that occurred due tohuman errors or improper operations. Recently, several useful signal processing techniques havebeen developed on fault diagnosis, such as fast Fourier transform (FFT), short time Fourier transform (STFT), adaptive order-tracking techniques, Wigner-Ville distribution (WVD), and wavelet transform (WT). Although these analysis methods are often applied in sound and vibration signal processing. The investigation conducted afterward showed that asignalman illegally sealed a connection-terminal point switchusing a diode in his maintenance work, which destroyed thesignaling equipment's interlocking logic. The 324-passengertrain's route was set simultaneously to the 818-passenger train,which resulted in a serious accident with a death toll of126 people and 230 people injured. Christo Ananth et al. [11] discussed about Intelligent Sensor Network for Vehicle Maintenance System. Modern automobiles are no longer mere mechanical devices; they are pervasively monitored through various sensor networks & using integrated circuits and microprocessor based design and control techniques while this transformation has driven major advancements in efficiency and safety. In the existing system the stress was given on the safety of the vehicle, modification in the physical structure of the vehicle but the proposed system introduces essential concept in the field of automobile industry. It is an interfacing of the advanced technologies like Embedded Systems and the Automobile world. This "Intelligent Sensor Network for Vehicle Maintenance System" is best suitable for vehicle security as well as for vehicle's maintenance. Further it also supports advanced feature of GSM module interfacing. Through this concept in case of any emergency or accident the system will automatically sense and records the different parameters like LPG gas level, Engine Temperature, present speed and etc. so that at the time of investigation this parameters may play important role to find out the possible reasons of the accident. Further, in case of accident & in case of stealing of vehicle GSM module will send SMS to the Police, insurance company as well as to the family members.

Precautionary action could have been taken, which wouldhaveavoided the accident if the failed state had been identified.The aim of railway signaling systems is to ensure safe andefficient train operations. To ensure safety, relay- or computerbasedinterlocking systems provide an adequate operationaltrain route (i.e., to avoid collisions). Additionally, systems such as automatic train protection (ATP) are used to prevent speedingand to keep headway between trains. To ensure efficientoperation with no conflicts, route setting and conflict avoidanceare used. The operation of the train and signaling systems ismonitored by centralized traffic management systems, whichguarantee safe train operation with speeding prevention, adequateheadway, and the ability to manage train routing.. For example, during the accidenton the Yongwen Line, the signaling system did not reacha "fail-safe" state when a failure occurred, which led to the traincollision. Previous accidents caused by signaling system failurehad occurred on China's network. A train accident occurredon the Jiaoji Line in China when the signaling system did notenforce a speed restriction correctly. Such incidents, althoughrare, suggest that it is necessary to reconsider the design ofrailway signaling systems.NGTCS achieves system integration, parallel monitoring,and system-level "fail-safe" through a system engineering [3]–[5] design process and the application of parallel monitoringtechnology. Compared with the parallel control and managementtheory

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proposed in [6]–[8], in this paper, parallel processesare used to understand and manage a complex problem,and the concept of system-wide monitoring is introduced tospecifically focus on ensuring system safety.

II.CONSTRUCTION PRINCIPLES

The Chinese high-speed train control system includes the Chinese Train Control System (CTCS), computer-based interlockin(CBI), centralized traffic control (CTC), and someother signaling assistance systems, such as the signaling microcomputermonitoring system (MMS), dynamic monitoringsystem (DMS), train number tracking and wireless trackingsystem, and wireless transmission system for scheduling transmission,power systems. Nowadays, the Chinese high-speedrailway implements two control systems, namely CTCS-2 andCTCS-3. The main physical differencebetween the two CTCSs is that CTCS-2 employs track circuits to transmit train control information, with movement authority(MA) provided by an automatic block through a train control center (TCC), whereas CTCS-3 adopts GSM-R communications to transmit the train control information to the trains, andthe MA is provided by the radio block center (RBC). GSM is a digital cellular communication system that prevailsthroughout Europe and much of the rest of the world. At present,cellular communication system has become a new trend for many varieties applications, especially railway application (called GSM-R). GSM system is divided into three parts: mobile station, base station subsystem and network subsystem. At present, the commercial GSM-R rail communication systems can provide all the services required:

1. Train control systems, where data exchange between trains and track-side traffic control centre is required
2. Voice communication between all users (train drivers, traffic controller, track-side workers and train personnel)
3. Emergency call handing
4. Data messages exchange
5. Communication recording
6. Integration with other existing (or future) systems

A. Deficiencies in the Existing Train Control System

High-speed train signaling systems have the followingdisadvantages in their architecture, integration process, andoperation.

1) The high-speed train signaling systems require the integrationof a number of subsystems, such as the aforementioned signaling subsystems and support systems.Correct system integration is a key technology to ensuresystem safety. Train control functional requirement specification,a system requirement specification, functionalinterface specification (FIS) and form-fit FIS are usedas key standards for system integration . Thedevelopment of current high-speed train control systems focuses on the interface between different subsystemsand devices. However, these subsystems and devices areusually developed at different times; hence, it is difficultto ensure that they operate in the most efficient way.Consequently, subsystem monitoring and alerts, critical safety control parallel monitoring, and system-level "failsafe"design are generally not considered.

2) In current train control systems, the train tracking intervaland speed protection are achieved using ATP systems.The train operation will be affected if ATP cannot calculatethe correct train tracking intervals

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and safe brakingdistances due to signaling system failures, data acquisitionfaults, communication transmission errors, and otherissues.

3) The interlocking system is the only system to set trainroutes. However, interlocking operations, operation logic and track occupation are not monitored at a system level;furthermore, incorrect operations made by signalers, incorrect trainroute setting, consistency with the timetable,and the interlocking device state are also not monitored.

4) The process of setting and transmitting TSR data isnot adequately monitored. Although the methods forthetransmission and management of TSRs have beenchanged in CTCS-2 and CTCS-3, safety issues still exist.The accident that occurred on the Jiaoji Railway onApril 28, 2008, happened due to this safety defect.

5) Nowadays, train dispatchers monitor train positions,speeds, signaling states, block occupation, and systemdevices through CTC screens and monitors. Due to heavyworkloads, it is almost impossible to monitor train operations manually without any oversights.

6) Various rules and regulations exist to guide operationaland maintenance staff. Variability in the level and adequacyof training may result in staff having insufficientexperience to deal with atypical events, which may increase the risk of errors being made. Any illegal orincorrect events may lead to accidents.Overall, ATP, CBI, and CTC are all independent subsystems. The functions and application of these systems are not supervised. Train safety will be affected if any of the subsystems or “fail-safe” systems fail, which could have serious consequences. The architecture of the European Train Control System(ETCS) and CTCS are quite similar. The deficiencies in the CTCS also exist in the ETCS. CTCS has been chosen as a casestudy because more related information can be accessible by the author. The study of CTCS has universal significance.

B. Principles of NGTCS

The principles of NGTCS are as follows:

1) Implementation of systems theory and parallel monitoring, optimization of system architecture, full data sharingand fusion, and maximization of system performance;

2) Parallel monitoring of train tracking interval, train route setting, train speed protection, and TSR protection;

3) Decentralized autonomous train control technology integrated with system-level heteronomous monitor(when any subsystem fails, the parallel monitoring should raise an alarm to alert staff of an abnormal condition);

4) Process Control& Safety Assurance System (PCSAS)It ensures on-line vehicles safe. It collects data, monitors thework status ofequipment’s, even timely alerts or alarms when irregular cases arise. On the one hand, data about on-line equipment are transferred to OMIS, on the other hand, command from OMIS are taken and the work status equipment controlled are made to the high point.

5) Implementation of an independent parallel monitoring regime, using different data acquisition technologies, Transmission methods, and software applications to avoid common-mode errors;

6) Monitoring of incorrect behavior by workers during driving, operation, maintenance, and management. It is necessary to parallel monitor not only safety-critical functions but also human behaviors. It is also important toImplement, heteronomous monitoring for system states, train operations, and system applications.

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III. BASIC STRUCTURE OF NGTCS

The NGTCS has an architecture similar to most modern train control systems, but with the addition of parallel monitoringhardware. However, the majority of the new key functionality is achieved through modifications to existing software. Basedon the framework of current control systems, the new system is designed to meet requirements such as data acquisition, data transmission, data processing, and alarm control. The system will achieve system-wide failure monitoring, data sharing and integration, dual-channel structure, and common-mode cause error avoidance. It is able to implement ATP-and-CTC-based tracking-interval parallel monitoring,CBI-CTC-based train route setting, onboard-ATP-and-trackside- ATP-based train speed limit protection, ATP-and-CTC-based temporary speed limit protection, and MMS-and-DMS-based control operation.Fig. 1 shows the structure of the NGTCS. The basis architecture of the SVM is in high dimensionalspace to find a super-hyperplane level as divided into the twoclass, in order to ensure have minimum classification error rate. SVM is a set of similarity overseen learning methods. Advantage of SVM is able to process the non-linear\ distinguishable case. The main distinction is that using the unravellinghyperplanedetached by two or more of the feature is not the same class to process the information to carve class of data mining problems. In the input training data, find data can be separated by a maximum margin distinction hyperplane. One of the important reasons for the wide application is SVM capacity to handlenonlinearly separable data.CBI-and-CTC-based train route setting is used to get the right train route. Train route setting includes four processes: traffic plan, staff operation, interlocking application, and train route occupation and releasing. The parallel monitoring of train route setting can be implemented in each process through a virtual image technique, of which one side is real operation and the other side is technical standards and regulations. Onboard-ATP-and-trackside-ATP-based train speed limit protection is used to obtain and perform MA and speed instructioncorrectly. The parallel monitoring of train speed limit protection can be implemented through each independent calculation and result comparison in accordance with the safety requirements of the target distance and speed at the same time. ATP-and-CTC-based temporary speed limit protection can device the parallel monitoring of setting up, transmission, employment, and feedback in temporary speed limit, which can guarantee the correct execution of temporary speed limit.

MMS-and-DMS-based control operation, integrated with the status information about onboard and trackside train controlequipment and information of human operating from different operating scenarios, realizes the system-level fault diagnosis and the real-time alarm.

IV. KEY TECHNOLOGIES OF THE NGTCS

The key technologies of the NGTCS include system monitoring,objectivefinding, information exchange and Video communication.

1)Communication Links between On-board Monitors and the Control Centre

The path circuit train control system will not be available to convey information from trackside to on-board units inQinghai-Tibet

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line largely due to the bad environment along the line. There are two explanations under research. One is anConstant radio based on cab signal system. Instead of track circuit, an intermittent radio link between the on-board units and the station is used to
bender and receive the train control evidence within a radius of 3km from the station. The control centre is connected with the station by the optical fibre network. The extra is realtime,unceasing communication between the on-board units and the control centre. Until now, the specialists of China'Ministry of Railways are inclined to choose the second solution. So the paper focuses on the latter.

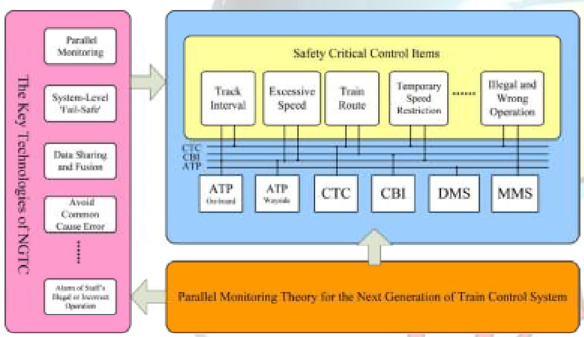

Fig. 1.Basic structure of the NGTCS.

• Parallel monitoring is expected to use methods, such asSystem level troubleshooting, data sharing, data completenessChecking, interlocking logic, and output arbitration,to improve the monitoring effectiveness.

• The implementation of parallel monitoring should notaffect the original functionality or the enactment of thesystem.The introduced parallel monitoring system is not used asa control equipment and only provides monitoring and alarm for both the process of principal control equipment and theHuman activities. The behavior of parallel monitoring systemdoes not endanger traffic safety but increase system capabilityof danger identification. The other factors such as reliability, thecompleteness of data acquisition, and the effectiveness and realtime of monitoring will be considered. The parallel monitoringsystem might exist with a misinformation phenomenon and the description of false alarm is also varied. It is required to reducefalse alarm both by understanding the rules of rail operatorsandsignalingcapability and by improving the monitoring modelsand algorithms.

B. System-Level "Fail-Safe"

In current signaling systems, the "fail-safe" functionalityis widely implemented at the device and component levels.However, the "fail-safe" functionality has not been previouslyapplied at the system level. ATP, CBI, and CTC use self-directedcontrol methods, in which each system works individualisticallywithout supervision from any of the other subsystems. Thismeans that, currently, if one of the subsystems has a functionaldisappointment, none of the other subsystems are aware of the problem. In the train collision that occurred on July 23, 2011, the "failsafe"function did not implement following the ATP subsystemfailure. If the "fail-safe" functionality had been implemented atthe system level, rather than at the device level, the accidentmay not have occurred.System-level "fail-safe" considers the system layer, the devicelayer, and the component layer. The detail of the systemstructure is shown in Fig. 2. The system-level "fail-safe" functionality draws on the theory

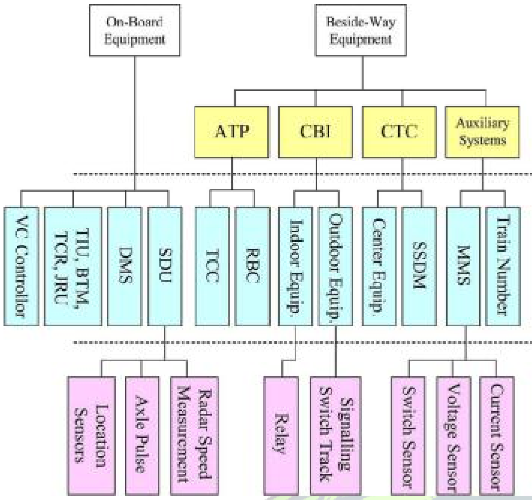

Fig. 2.System structure of the system level "fail-safe" in NGTCSOf system-level fault detection and analysis.Different hardware and software performthe same task and compare the results with each other toachieve the fault detection. Alternatively, the system can alsodetect failures by checking between internal systems devices.It is necessary to consider reliable application channels ormonitoring patterns at the system layer in order to achievethe system-level "fail-safe". The channels or designs shouldconsider consistency checking standards in order to ensurethe precision of the outputs. System-level diagnosis is thepremise of achieving the system-level "fail-safe". The parallelmonitoring pattern between subsystems provides a hardwarebase for the system-level diagnosis.The methods of system-level diagnosis include monitoringbetweensubsystems, data wholeness detection and analysis,train-operation-case-based (DMS andMMS) real-time data analysis and failure-database-based smart diagnosis systems.

C. Alarm for Illegal or Incorrect Operations by Workers

As shown above, illegal or incorrect operations by railwayworkers are one of the most significant causes of railwayaccidents. It is necessary to improve the skills of workers toavoid these types of accident. In fact, according to currentrailway regulations, a number of specific arrangements havealready been put into practice.In the parallel monitoring system, not only the devices butalso the workers' operations will be supervised. Based on therailway regulations, all illegal and incorrect operations will beadvised.Moreover, simplifying system structures, such as using onedesign of system to control all types of trains, improves theSystemreliability and safety. For example, CTCS-2I can takethe place of CTCS-2 and CTCS-3 for both 200- and 350-km/h trains.

V. PARALLEL MONITORING TECHNIQUES ORIENTEDTO SAFETY-CRITICAL CONTROL ITEMS

A railway signaling system provides MAs and train routeinformation while ensuring train safety and monitoring trainoperation. The control objectives are train speed, train position,railway points and signaling aspects. The safety criticalaspects of the signaling system include train tracking interval,interlocking, train speed restriction, TSR and so on. Parallelmonitoring achieves a double application control for all critical Subjects.

A. Parallel Monitoring of Tracking Interval Based onATP and CTC

Train collision accidents still happen worldwide in trainoperations. Based on some reports, signaling system failure isOne of the most significant causes of such

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accidents. In currentsignaling systems, ATP carries out train-tracking-interval control.In order to avoid train collision accidents, it is necessary forATP to ensure the minimum safe distance between two trains.However, some trains applying ATP or other similar supervisorysystems still have collisions. Therefore, it is impossibleto ensure train tracking intervals by only using ATP as ATP mayoutput incorrect commands.

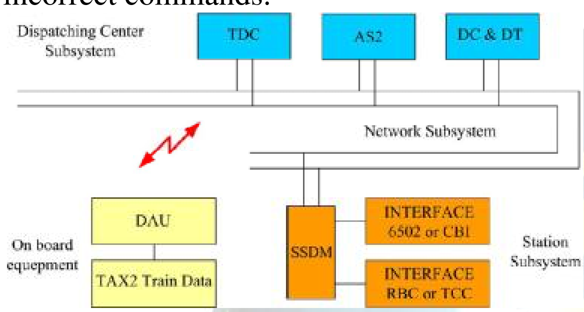

Fig. 4. Hardware diagram of CTC train-tracking-interval alerting and control system.

The ATP-and-CTC-based train-tracking-interval parallelmonitoring system has some special functions based on current CTC systems, such as real-time train-tracking-interval calculation,alarm control, and output control. Dual-channel parallel monitoring can be achieved using this upgraded CTC systemcombined with current ATP systems.In order to achieve a tracking interval alert and controlfunction, one application service (AS2) and one train datacollection system (TDC) are added into the CTC subsystems.The trains' data acquisition units (DAUs) are added to each train and connected to the interface of the railway safety informationmonitoring device (TAX2). A GSM-R wireless channel isimplemented for communication between the DAUs and TDC.Fig. 4 shows the hardware diagram of the CTC train-trackingintervalalerting and control system.TDC obtains dynamic parameters such as number, operationspeed, position, weight, length, and formation of each train using DAV. AS2 calculates the train-tracking-interval distancebased on the dynamic parameters. If the train's actual trackinginterval distance is smaller than the limitati\on, AMA or dispatchcommand and dispatch telephone (DC and DT) will be transmittedto the driver through the station self-discipline machineto reduce the train speed. Fig. 5 shows the diagram of the ATPand-CTC train-tracking-interval calculation.In order to achieve CTC train-tracking-interval alerting andcontrol, it is necessary to add some hardware andcontrolsoftware to the current CTC systems. CTC is a higher levelsystem of interlocking and control systems. It is able to commandandcontrol station signaling devices and trains directly.Moreover, this system is able to replace manual train operationsupervision, reduce working intensity and improve supervisionefficiency.Based on ATP-and-CTC-based train-tracking-interval parallelmonitoring and the flying geese paradigm, CTC achieves trackinginterval control for all trains on one line, which is similar to the flying geeseformation control. ATP achieves the trackinginterval control for each pair of trains, which is similar to theflying geese tracking interval control. As a result, the ATP andCTC method obtains reliable train-tracking-interval control.

5) Storage and display of the signaling-device dynamic-statedata and safe route process data;

6) Tracking the correspondence between train routes andtrain numbers to avoid incorrect route setting.The conditions of mirrored virtual train route setting shouldbe equal to or more critical than the real-scene train route setcriteria, which ensures validity

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and precision of comparingoutput of parallel monitoring. The basic conditions correspondwith the mirrored virtual train route.

1) The data acquisition and transmission channel of reflectedsimulated train route setting is independent of real trainroute setting, which is used to avoid common-mode causeerrors.

2) The conditions and logic checking links of the mirroredvirtual train route setting process have more stringentrequirements.

3) Interlocking of four aspects in the train route setup processmust be implemented widely.

4) Human behaviors will be checked in the mirrored virtualtrain route setting process. Any violation or wrong operation
will be immediately warned.

5) The mirrored virtual train route setting process can collateand make use of interlock static data coming fromdesign units, construction units, and signaling equipmentmaintenanceunits.

Based on CBI and CTC train route parallel monitoring, theCTC system adds an application service (AS3) to create a
mirror virtual station for parallel comparison of route settings.Alarms should be applied if anything unusual occurs, such as

Fig. 5. Diagram of the ATP-and-CTC train-tracking-interval calculation

Illogical train routes, illegal staff operations, or device failures,to avoid accidents.

1) Mirror Virtual Station: The mirror virtual station is set ata CTC center. It archives the following three types of data, whichare refreshed regularly based on the device state and time period:

- The data of signaling devices provided by MMS, trainnumbers and track occupation;
- Staff operation, route setting, train occupation and routeunlocking data;
- The interface data of interlocking, TCC, RBC, CTCand MMS.

2) Route Parallel Comparison: Using the mirror virtual station,AS3 checks the logical condition of the linkingroute.It also checks the correspondence between processing trainsand scheduled trains, particularly for route setting after systemfailures and power outage.and management. NGTCS improves thesafety of the current interlocking systems. It achieves interlockingbetween the traffic plan, staff operations, and interlockingapplications and track occupation and between station signalingand interstation interlocking.

B. Parallel Monitoring of Train Speed Based on Onboard ATPand Wayside ATP

The current ATP uses self-discipline control methods, monitoringthe train operation speed independently. Onboard ATPdevices calculate train permitted speeds based on tracksideMAs, line data, TSRs, and train performance data. The systemmanages the actual speed against the calculated speed.Thetrain should implement braking to reduce the speed if the actualspeed exceeds the calculated speed. Therefore, train operationsafety will be affected if any failure happens during the datareceiving or calculation. Parallel monitoring is introduced in, which is similar to the monitoring that is proposed inthis paper. Onboard ATPAnd trackside ATP calculate the trainacceptable speed independently, and the onboard ATP comparesthe two results. If the same result is obtained, it can be furtherapplied to the train operation.In the parallel monitoring of train-speed based onboard ATPand wayside ATP, some existing system problems are expected to be resolved, such as information transmission errors betweenon-board to wayside ATP,

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common-mode cause errors in thecalculation, and MA error of RBC.

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C. Parallel Monitoring of TSR based on ATP and CTC

The accident occurred on the JiaojiRailway Line was a typicalaccident that happened because the train did not apply TSRssuccessfully. The TSR applications used in current train controlsystems have two conditions. For non-high-speed railway lines, a traditional telegram method (TSR scheduling commandMode) is still implemented. The TSR application is done by thescheduler, drivers, LKJ monitor devices, and so on. If anyone takes responsibility, the application can be successfully made.However, due to careless management, irresponsible staff, andother problems, the speed restriction application will not always be implemented, which causes some accidents. For high-speed railwaycontrol systems, such as CTCS-2and CTCS-3, thespeed restriction is transmitted to the train onboard ATP usingabails or GSM-R.When using the traditional telegram method, it isimportantto strictly implement current TSRscheduling orders and toapply TSR regulations. Based on current TDCS systems orCTC systems, this means achieving TSR alarms, receipt confirmations,supervision applications, and responsibility soundings.This method is able to improve the application andmanagement of TSR scheduling orders.For automatic system application methods, implementingATP-and-CTC-based TSR parallel monitoring can achieve responseregulations between TSR trains and CTC. Furthermore,the online signature regulations for dispatchers, drivers, andother workers can also be achieved.

VI. CONCLUSION

The NGTCS improves train control system efficiency and system safety. It is also provide video and data communications. Ultrasonic sensor can be used to monitor and detect the objects to prevent accidents. GSM perform the important role in this project. Thus the next generation train control system will be smart and safe. Critical subjects is able to improve the reliability and the safetyof the entire train control system.

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