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## **Automatic train control standard for Ethiopia**

A proposal submitted in partial fulfillment of the requirements  
for the Degree of Master's in Railway Electrical Engineering

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## Abstract

Railway transportation, which is needed in the achievement of effective development, is an efficient, cost-effective and it is environmental friendly transport system. In addition to the low railway network connectivity in Ethiopia like other developing countries, the available one is not modern; has low capacity and is insufficient to facilitate transit trade; and also Ethiopian railway transport has not standardized guidelines to design the control system.

In this study an attempt is made to standardize guidelines for railway automatic train control system specifically standardization of equipments, interfaces, procedures of exchange of signals and transmission techniques for conventional (main) lines in Ethiopia. To achieve such objectives the research had a methodology of a task involving literature review discussion and comparison of different country standardization practice; and adaptation of the standards of the different countries according to the context of our country for railway system in Ethiopia.

Standardization of guidelines for the automatic train system for Ethiopia context is done based on topography, economy of the country (cost of the control system), interoperability future development of the railway system of the country ,capacity of the control system ,level of safety , culture of the people and different literature reviews.

In this automatic train control standard the research suggests two levels of train control system which are European Train Control System (ETCS) level 1 and Communication Based Train Control system (CBTC) according to the above parameters.

**Key Words:** Automatic train control, Track equipments, On board equipments, Interface signal, European Train Control System (ETCS) level 1 system, Communication based train control system (CBTC).

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## Abbreviations

AC = Alternating Current

AREMA = American Railway Engineering and Maintenance of Way Association

ATACS = Advanced Train Administration Control System

ATC = Automatic Train Control

ATO = Automatic Train Operation

ATP = Automatic Train Protection

ATS = Automatic Train Supervision

ATS-P = Automatic Train Stop device

ATS-S = Automatic Train Stop device

AWS = Auxiliary Wayside System

BTM = Balise Transmission Module

CBTC = Communication Based Train Control

CENELEC = European Committee for Electro technical Standardization

CTCS = Chinese Train Control System

D-ATC = Digital Automatic Train Control

DC = Direct Current

DCS = Data Communication System

DMI = Driver Machine Interface

EC = European Commission

EI = Electronic Interlocking

EJTC = Japanese Train Control System

EMC = Electromagnetic Compatibility

EMI = Electromagnetic Interference

EMU = Electrical Multiple Unit

EOA = End Of Authority

ERTMS = European Rail Traffic Management System

ETCS = European Train Control System

EVC = European Vital Computer

FRS = Functional Requirements Specifications

FS = Full Supervision

GEBER = Guaranteed Emergency Brake Rate  
GPS = Global Positioning by Satellite  
GSM-R = Global System for Mobile Communication –Railway  
IEC = International Electro technical Commission  
JRU = Juridical Recording Unit  
KMPH = Kilo Meter Per Hour  
LEU = Line side Electric Unit  
LRT = Light Rail Transit  
MA = Movement Authority  
MEMU = Main line Electric Multiple Unit  
MMI = Man Machine Interface  
MTBF = Mean Time Between Failures  
MTBFF = Mean Time Between Functional Failures  
MTBHE = Mean Time Between Hazardous Events  
MTBSF = Mean Time Between Service Failures  
MTTR = Mean Time To Repair  
MTTRS = Mean Time To Restore Service  
OCC = Operation Control Center  
OS = On Sight  
PHA = Preliminary Hazard Analysis  
PTC = Positive Train Control  
RCC = Regional Control Center  
RE = Railway Electrification  
RF = Radio Frequency  
SF = System Failure  
SIL = Safety Integrity Level  
SRS = System Requirements Specification  
STM = Specific Transmission Module  
TC = Track Circuit  
TIU = Train Interface Unit  
UIC = International Union of Railways

# 1. Introduction

## 1.1. Background

Transportation infrastructures are very important as significant drive for the growth of both economy and society of any country around the world. In addition these infrastructures play crucial roles in the effort to achieve the goals of poverty eradication and sustainable development. Universally it is also witnessed that both cargo volume and loads are going on increasing from year to year with alarming rate all over the world. Such growth demands better transportation means for efficient and reliable transport of commercial and industrial products without delay.

Railway transportation is one of the important infrastructure facilities that are needed in the achievement of effective development; and provides an efficient, cost-effective and environmental friendly transport system which can quickly haul large volumes of goods which are not easily transported through motor vehicles for long distances

To get the above advantages railway safety is crucial and necessary. So to keep railway safety Automatic Train Control (ATC) is important. The ATC network provides for the safe and efficient movement of trains through a series of track circuits and integrated logic for routing controls and speed controls. Major subcomponents of the ATC network include Automatic Train Operation (ATO), Automatic Train Protection (ATP) and Automatic Train Supervision (ATS).

- ❖ ATO:-is a system that uses integrated logic between the wayside system where the train speeds and braking are regulated automatically without required intervention from the operator. ATO is desirable because of the efficiency and consistency of accelerating and braking provided by the train's on-board ATC system.
- ❖ ATP: - is the system that provides safe train separation through the same network but where the operator is in direct control of the train speed and braking. It should be noted that while the train is in “manual” control, the ATP is still active and any violation of speed command by the operator will cause the train to automatically reduce speed, thereby resulting in the safe separation of trains or automatic train protection [8].

- ❖ ATS:-Automatic Train Supervision – subsystem responsible for the centralized supervision and control of train movements including the back office server functions associated with Positive Train Control (PTC) [1].

The foundation of ATC network is the track circuit which determines occupancy of trains within a track section and, through the integrated logic, regulates speed to insure safe braking for trains approaching the train which is occupying that track section.

Obviously, the performance of the track circuit is critical to insure safe braking of following moves. Track circuits are designed under a “fail safe” system (as is the entire ATC network) so that failures of the system result in the most restrictive application.

The ATC systems today not only enhance safety but also increase speed and capacity of the network and facilitate condition based maintenance and energy saving [8].

## **1.2. Statement of the Problem**

In developing countries like Ethiopia, the rail network connectivity is not only low but also it is not good enough to facilitate transit trade; of course most section of the existing line is more or less it is not functional. There are vast movement of people, huge import and export of goods which are not efficiently supported by railway transport.

In addition to less availability of railway transport in Ethiopia, the available one is not modern and does not work; has low capacity and is insufficient to facilitate transit trade; and also Ethiopian railway transport has no standardized guidelines to control train and to keep its safety.

So in this study an attempt was made to standardize guidelines for Ethiopian railway Automatic Train Control (ATC) (Automatic train control standards for Ethiopia).

## **1.3. Objective of the research**

Since the railway transport is becoming a reliable and regular form of transporting bulk goods and train travel brings much safety, convenience and comfort to passengers than other means of transportation system; this study was done in this sector in order to do further research in the development of modern system of railway transportation in Ethiopia.

The main objective of this research was standardizing guidelines for railway Automatic Train Control (ATC) or having Automatic Train Control standards (ATC standards) for Ethiopia to safe people and the train itself.

The specific objectives of this study are:

- ❖ To standardize line side and onboard equipments.
- ❖ To standardize the procedures for the ground and on-board exchange of signaling information between the ground-based and on-board equipment
- ❖ To standardize the transmission techniques to be used and the interface that used between the onboard and wayside equipments.

## **1.4. Research Methodology**

The research methodology for this study involved the following major tasks: literature review; discussion and comparison of different countries standardization practice; and adaptation of different countries standardization. Finally conclusions and recommendations for future work are presented.

## **1.5. Scope of the research**

Standardization for the Automatic Train Control (ATC) for railway system of Ethiopia is limited to conventional (main) line that is not including Light Rail Transit (LRT). For this automatic train control standard for main line, the study basically concentrates on automatic train control equipments, interfaces and method of communication and signaling.

## **2. Literature review**

### **2.1. History of automatic train control system**

The evolution of railway signaling for mass transit applications has involved basically four generations of train control philosophy, with each generation providing an incremental improvement in operational performance.

The first generation of train control systems philosophy includes track circuits for train detection, with wayside signals to provide movement authority indications to train operators and trips stops to enforce a train stop if a signal is passed at danger (intermittent ATP). With this train control philosophy, virtually all of the train control logic and equipment is located on the wayside, with train borne equipment limited to trip stops. Train operating modes are limited to manual driving modes only and the achievable train throughput and operational flexibility is limited by the fixed-block, track circuit configuration and associated wayside signal aspects. This train control philosophy is representative of the technology currently in service.

The second generation of train control technology is also track circuit-based, but with the wayside signals replaced by in-cab signals, providing continuous ATP through the use of speed codes transmitted to the train from the wayside. With this train control philosophy, a portion of the train control logic and equipment is transferred to the train, with equipment capable of detecting and reacting to speed codes and displaying movement authority information (signal aspects) to the train operator. This generation of train control technology permits automatic driving modes, but train throughput and operational flexibility is still limited by the track circuit layout and the number of available speed codes.

The third generation in train control philosophy continued the trend to provide more precise control of train movements by increasing the amount of data transmitted to the train such that the train could now be controlled to follow a specific speed/distance profile, rather than simply responding to a limited number of individual speed codes. This generation of train control technology also supports automatic driving modes, and provides for increased train throughput. However, under this train control philosophy, the limits of a train's movement authority are still determined by track circuit occupancies.

The fourth generation of train control philosophy is generally referred to as Communications Based Train Control (CBTC). As with the previous generation of train control technology CBTC supports automatic driving modes and controls train movements in accordance with a defined speed/distance profile. For CBTC systems, however, movement authority limits are no longer constrained by physical track circuit boundaries but are established through train position reports that can provide for “virtual block” or “moving block” control philosophies. A geographically continuous train-to-wayside and wayside-to train RF data communications network permits the transfer of significantly more control and status information than is possible with earlier generation systems. As such, CBTC systems offer the greatest operational flexibility and can support the maximum train throughput constrained only by the performance of the rolling stock and the limitations of the physical track alignment [23].

## **2.2. Automatic Train Control system (ATC)**

The term ATC refers to the train control system in main line and terminal territory yards. Yard signaling, although a signal system function and interfaced with the ATC system, is not normally considered to be part of an ATC system. ATC is divided into three functional sets:

### **2.2.1. Automatic Train Protection (ATP)**

The functional set responsible for the safety-critical functions including those of interlocking, train detection, signal aspects, broken rail detection, hazard detectors, and movement authorities (including speed limit and cab signal commands) that are sent to the train and acted upon by the on-board train control to enforce safe limits. The ATP functional set includes the enforcement of the safety-critical functions. For main train operation, train safety must be assured by an automatic system that enforces speeds at all times, including the slowing of a train for an obstruction of the line ahead. Such obstructions can include a train ahead, a reduction in the civil speed limit (permanent or temporary), or an unset or unlocked switch in an interlocking ahead of the train.

The basic safety-critical functions of the ATP functional set are:

- ❖ Enforce all speed limits on a train to prevent over speeding through curves switches, work zones, and other features that require speed supervision and enforcement to ensure safe operation.
- ❖ Ensure trains are separated to avoid rear end and side swipe collisions.

- ❖ Prevent derailments and collisions from movements through incorrectly set and/or unlocked switches and from conflicting train movements by setting and locking switched routes through interlocking and only authorizing safe train movements through the interlocking.

The train control system will also provide safe enforcement of other functions including ATC Responses to hazard event detectors and sensors (provided by other subsystems) including:

- ❖ Earth quake
- ❖ Excess wind speed
- ❖ High water levels
- ❖ Excessive rain fall
- ❖ Under pass bridge strikes
- ❖ Land slide bridge strikes
- ❖ Intrusion at track side and in tunnels
- ❖ Intrusion from overhead bridges and at tunnel portals
- ❖ Intrusion at stations
- ❖ Dragging equipment
- ❖ Rail breaks

Although the majority of the listed hazard event sensors will be specified by other disciplines many will be interfaced to at least one of the subsystems of the ATC, and the ATC will invoke the system response. In some cases, the ATS functional set will log the event and to display an event and/or an alarm to the operators for their further action; in other cases the ATP system will directly cause the train to enforce a braking activation and possibly stop trains in an emergency. Each sensor interface must be identified and the response of the ATC system to each interface agreed with operations and other disciplines.

The ATC wayside equipment will include double-rail track circuits for detection of train and broken rail. Track circuits are an approved means of detecting broken rails. A break in the rail must cause a false occupancy in a track circuit which in turn will result in a restrictive command being given to an approaching train. For track circuits to reliably detect broken rails and for the ATC system to protect trains, the ATC system must normally allow only one train in a track circuit at any one time [1].

### **2.2.2. Automatic Train Supervision (ATS)**

Train supervision involves monitoring the movement of individual trains in relation to schedule and route assignments and overseeing the general disposition of vehicles and flow of traffic for the system as a whole. The train supervision system may thus be thought of as making strategic decisions which the train operation system carries out tactically. In addition train supervision includes certain information processing and recording activities not directly concerned with train safety and movement but necessary to the general scheme of operations. Train supervision functions are:

- ❖ Schedule design and implementation
- ❖ Route assignment and control
- ❖ Train dispatching
- ❖ Performance monitoring
- ❖ Performance modification
- ❖ Alarms and malfunction recording
- ❖ Recordkeeping

### **2.2.3. Automatic Train Operation (ATO)**

Train operation consists of those functions necessary to move the train and to stop it at stations to board and discharge passengers. Train movement, as controlled by train operation functions, is under the direction of train supervisory functions and always within the constraints of train protection functions. Train operation involves the following functions

- ❖ Speed regulation
- ❖ Station stopping
- ❖ Door controlling
- ❖ Train starting

## **2.3. Automatic train control equipments**

The ATC system will consist of elements and subsystems that must be closely integrated to provide an overall solution for train control and operations. The ATC system must be closely integrated with other system elements, such as rolling stock, intrusion detectors, and hazard detectors, to ensure the necessary level of safe operation. The ATC subsystems will consist of the following equipment.

### 2.3.1. ATC on board equipments

This subsystem consists of a combination of vital and non-vital equipment located on the passenger train sets and maintenance vehicles. Vital equipment is used to fulfill the ATP functions; non vital equipment is used to fulfill all non ATP functions such as ATO and displays.

The equipment includes processors, firmware, software and electronics, operator displays operator switches, data radios and antennas, transponder/balise antennas, code pick-up antennas, network components, GPS receiver and antennas, tachometers and other sensors and all connections between train control elements and interfaces between train control and the train subsystems including propulsion and brakes.

Sensors and processors are used to determine position and speed, computer equipment, and operator controls and displays are some of the on-board equipments.

Depending on the train control technology selected, the on-board equipment may also include data radios and antennas with which to communicate with the wayside and central control subsystems.

The on-board subsystem may also include antennas and decoding equipment to detect digital signals transmitted to the train through the rails. The on-board package will receive data through the radio or the rails that define the movement authorities within which the train can safely operate.

The actual speed of the train will be continuously compared with the authorized speed. If the train is to operate in ATO, the ATO functional set will handle any changes in speed called for. If the train approaches an over speed condition the ATP functional set will generate a warning to the train operator. If an appropriate action is not taken, the on-board system will intervene to ensure that the train movement stays within safe limits.

The on-board ATC will use sensors to determine the train's position to a high level of resolution both laterally (which track the train is on) and longitudinally, as well as accurately measure speed. The enforcement of the Movement Authority limits enables the on-board system to provide the required PTC protections.

The onboard ATO functional set will regulate train performance when selected. Commands received from the ATS functional set may also provide for pacing trains at a lower speed than their maximum speed or increasing speeds from the pacing speed called for by the normal schedule. Under no circumstances can these ATO functions allow the train to operate faster or further than the safety-critical limits determined by the PTC functions of the ATP functional set.

The on-board ATC subsystem will interface with the rolling stock subsystems to support ATP, ATO, and ATS functional sets.

In addition to interfaces required for the ATC system functions, additional train interfaces will provide remote monitoring capabilities of rolling stock subsystems.

Remote monitoring allows for early diagnosis of trouble. Monitoring can be done using the office subsystem as part of the ATS functional set. Alarms and event indications can be displayed at the Operations Control Center and the Regional Control Centers, or at ATS remote workstations at other locations.

On board passenger information systems, including audible and visual announcements of the real-time performance and other information to the passengers may be provided from the office subsystem through the ATC data communications subsystem or by an independent data communications subsystem.

The on board ATP functional set equipment will interface to wireless or rail inductive antennas that receive movement authority commands from wayside ATP functional set equipment. A data radio subsystem will provide data transmission between the train and wayside equipments [1].

### **2.3.2. ATC wayside equipments**

This subsystem consists of mainly vital equipment located in housings along the right way of which includes station equipment rooms, train control equipment houses, and signal equipment cases and cabinets. The equipment includes track circuits, switch machines wayside signals, interlocking equipment, and transponders (or balises), much of which is considered to be conventional signal system equipment.

This equipment includes ATP electronics that is either integral to or interfaces with the track circuit and interlocking equipment and to other sensors including intrusion, seismic, and other detectors that will allow the train control system to react to an event and bring the train to a safe speed if necessary.

The ATP processors obtain track circuit occupancy status, interlocking route status, and sensor device status in order to output messages to the trains that define the safe limits (including distance to go and target speeds) for train movement.

Equipment will be housed in a distributed fashion along the rail line to provide continuous coverage including along aerial structures, through tunnels, in yards, and in stations.

Interlocking functions including route setting, route locking, approach locking, and sectional release will be performed by wayside microprocessor interlocking equipment.

The wayside subsystem will be linked by the data communication subsystem for the supervision and remote control from the Operations Control Center (OCC) and the Regional Control centers (RCCs) [1].

### **2.3.3. ATC data communication subsystem**

This system communicates data, commands, indications and alarms between ATC subsystems and locations. This consists of connected networks of wireless, fiber optic, and hardwired equipment.

The Data Communication System (DCS) will carry vital (ATP) and non-vital (ATO, ATS and management) information. The DCS itself does not have to be a vital subsystem. Coding and other techniques in the other ATC subsystems ensure that the data received is of sufficient integrity and currency that it can be treated as accurate for vital applications. ATP equipment will reject any data for a vital function that cannot be validated.

### **2.3.4. ATC office**

The ATC office subsystem supports the majority of the ATS functional sets. It consists of a centralized or a distributed computer control system with dispatcher workstations that provides the overall train operation management functions including remote routing and supervision functions.

It includes announcements of events including critical alarms and a logging capacity for all events. It generates many system performance reports. Many ATS functions supported by the office subsystem are automated, including setting of routes at interlocking, regulation of train movements in accordance with the schedule, movement planning, and the recovery of the service from minor interruptions and failures.

At any time, dispatchers can take manual control of route setting and schedule regulation functions from their ATS workstations in accordance with the rail management plans and procedures. Recovery from major interruptions and failures will likely require manual intervention of the dispatchers. The general arrangement of control positions by function and responsibility, including responses during failures and incidents, will be described in the concept of operations document.

The office subsystem architecture can be centralized or distributed to provide reliable computing power and the required workstations that allow supervisors to dispatch the services, monitor subsystem performances, and intervene to manually supersede automated processes in the event of incident and emergency.

The territory controlled by each work station can be adjusted by an appropriate official such as the Chief Dispatcher to adjust to workload demands as they fluctuate. As workstations can be in centralized or distributed facilities, or at remote locations, the ATC system can support a flexible approach to the overall supervision of the rail operations.

The office subsystem communicates with wayside locations, remote workstations, trains other ATC elements and sensors including intrusion, through the data communications subsystem.

The Office subsystem will provide workstations primarily within the Operations Control Center (OCC) and the Regional Control Centers (RCCs) [1].

## **2.4. Wayside ATC equipments housings**

ATC equipment will require wayside housings whose size and type will depend on the location. The larger “house” enclosures (that maintainers can enter) are needed at interlocking; smaller wayside cases (where maintainers can access the equipment inside but cannot enter the case) will be adequate near track circuit boundaries.

Other locations which may also require wayside housings including interface locations with event sensors including roadway underpass impact sensors, seismic detectors, and wind speed measurement equipment, etc.

ATC housings must accommodate ATC communications equipment. Such equipment includes fiber drop and network equipment as well as data radios.

## **2.5. Wayside ATC power supplies**

Alternating current power supply for ATC wayside equipment will be straight forward at stations and inter locking, where utility feeds are probably available. However, track circuit equipment at approximately one mile intervals requires ac power, and in remote, desert, and mountainous regions, a utility supply line could be difficult or expensive.

Alternatives to utility feeds are being considered, including dedicated signal power feeds from adjacent ATC sites that have utility power feeds, drops from the OCS, solar panels, and wind turbines. In each case, the sources will be supplemented with local batteries.

## **2.6. ATC standards and practices**

### **2.6.1. European railway ATC standards**

The goals of ETCS (European train control system) can be described as the following seven aspects. The first one is interoperability which means that trains can be interoperable across borders and able to read signaling in different countries in Europe. It also requires the “operator interoperability” and “supplier interoperability”.

The second one is safety. ETCS applications, even with level 0, will improve the safety of train operation by providing ATP or cab signaling. The third one is capacity. The line capacity can be increased by from 10% to 30% after ETCS application in comparison with the existing line without ETCS. ETCS can especially improve the line capacity in busy areas since the ETCS can provide smoother train operation.

The fourth one is availability. Under the ETCS standardization, there is no needs for a train to be installed more kinds of on-board systems, which means less equipment imply fewer interface and less connection.

Moreover, tele-diagnosis and maintenance help dramatically increase the reliability and maintenance of the system. The fifth one is cost-effectiveness. ETCS means fewer products. In this way, its manufacturing cost and maintenance cost could be decreased dramatically.

The sixth one is less on-board equipment. It means there is only one on-board system where a single and standardized Man-Machine Interface (MMI) is provided. The last one is open market. It means that monopolies for railway signaling in Europe will be broken. It is also the strong wish of the European Community from the start of the ETCS project [23].

The different possible correlations between the track and the train are reflected in the existence of several levels of ETCS. These are level 0, level STM, level 1, level 2, and level 3.

The definition of the level depends on how the track is equipped, in which way the information is transmitted to the on-board equipments and how it is processed.

The levels 3, 2 and 1 are compatible in a descending system. This means that a train equipped with ETCS level 3 can be operated in lines with level 1 and 2, and that a train equipped with level 2 can be operated in lines with level 1 [12], [13], [14].

**ETCS level 0:-** The level 0 corresponds to ETCS vehicles operating in non-ETCS route or in lines that are in commissioning. In this level of operation the movement authority is given to the driver through trackside signals whether optical or other signaling equipments external to ETCS.

The ETCS onboard equipment doesn't supervise the train movement, with the exception of the maximum speed allowed of that the line or specific line sections. The supervision of the train's integrity and detection is made by a rail signaling system external to the ETCS scope.

In level 0, there isn't any communication between the track and the train, with the exception of Eurobalises, which announce and command the signaling level transition. Consequently the train continues to read the Eurobalises but ignores all the receiving information, with exception of some special data. In the Man-Machine Interface (MMI), the only information shown regarding the supervision of the vehicle's movement is the allowed speed [15].

In this level the ETCS track equipments: nonexistent track equipments, with the exception of Eurobalise for detecting level transition. The ETCS track equipment has no main function.

The ETCS on board equipment of this level is on board equipment, with Eurobalise payload data. The main functions of this on board equipment are:

- ❖ To monitor the maximum speed
- ❖ To monitor maximum speed in a restricted area
- ❖ To read the payload data in search for level transition or special command
- ❖ Nonexistent on board signaling [15].

**Level STM:** - The level STM is used when trains equipped with ETCS are operating in track lines equipped with nationwide signaling and supervision systems.

The payload data to be transmitted is produced by the national signaling system and which is sent to the train by the standard channels of that same system. When receiving the information, the train converts it on-board, making it intelligible for the ETCS. Depending on the functionality and performance of the national signaling system, the optical signals may be exempt.

Specific Transmission Module (STM) is the device that allows the ETCS on-board equipment to receive the nationwide signaling transmission. The monitoring level is similar to the nationwide system, in which the management of the trains detection and integrity is executed by external equipment to the ETCS.

This level of operation does not use ERTMS / ETCS transmissions between the rail track and the train, with the exception of the information from the Eurobalises regarding the level transition or other specific commands. However, the Eurobalises must be read. The on-board ETCS supervision functions are supported. The use of the on-board ETCS functionality may diverge, depending on the configuration of the STM level.

The information given to the driver depends on the functionality of the nationwide system, in which the report of active STM is a part of the payload data. The train should possess the data so it avoid stopping during level transitions and supervise the maximum permissible speed [16].

ETCS track equipment: the level STM uses the transmission from the nationwide signaling system, which doesn't belong to ETCS. The use of Eurobalise is to announce the level transition. This equipment has no main function.

ETCS on board equipment: are on board equipment, with Eurobalise transmission and STM compatible with the nationwide signaling system. The main functions of these equipments are the following:

- ❖ Depends on the nationwide signaling system and STM implementation
- ❖ To read the Eurobalises to detect the level transition or special command
- ❖ On board signaling depends on the nationwide signaling system [16].

**ETCS level 1:-** ETCS level 1 is a cab signaling system that can be superimposed on the existing signaling system. The movement authority is generated by the track equipment and transmitted to the train by the Eurobalises.

This level of ETCS provides a continuous supervision of the train speed and also avoid against the violation of the movement authority. The vehicle detection and the train integrity supervision is accomplished by track equipments of the adjacent nationwide system (track circuits, blocking, etc), being these systems aliens to the ETCS scope. The track equipment does not know to which train is sending out the information.

During an operation in an ETCS level 1, if a signal changes to “clear” mode, the approaching train does not receive that information until passing over the group of Eurobalises. For that same reason, the driver will have to observe the signal to know when the train can proceed. After passing the Eurobalises group and its respective signal, the train has permission to proceed of the next stopping place, in a maximum safe speed.

Additional Eurobalises can be installing between main signals, for the purpose of transmitting intermediate information. As a result, the convoy will receive new data before reaching the signal. This level can also be installed a semi-continuous infill using Euroloop or Radio infill way, allowing the train to inform the driver continuously, as soon as the data is available. The signals are required in ETCS level 1, except if it is being operated in a semi-continuous infill way.

Euroloop or radio infill improves the safety of this level and allows operating without the maximum safe speed when approaching an already “clear” signal [17].

ETCS track equipments: are Eurobalise to transmit information from the track to the train where the balise should be able to transmit different data and Euroloop or Radio in-fill for semi continuous in-fill transmission. The main functions of this track are:

- ❖ To determine authorities according with adjacent signaling system.
- ❖ To transmit movement authority and information from track to the train.

ETCS on board equipments:

- ❖ On-board equipment, with Eurobalises transmission
- ❖ Euroloop transmission if an Euroloop system is required
- ❖ Radio infill transmission if a radio infill system is required

The main functions of the ETCS on board equipments are:

- ❖ To receive the movement authority and the route information from the track transmitted by groups of Eurobalises
- ❖ To select from all maximum safe speed permitted ,the most restrictive for the line ahead to calculate the safe speed profile ,taking in consideration the acceleration or braking of the train and the route characteristics
- ❖ To compare the train actual speed with the permitted one and the braking command ,in case of need
- ❖ On board signaling for the driver [17].

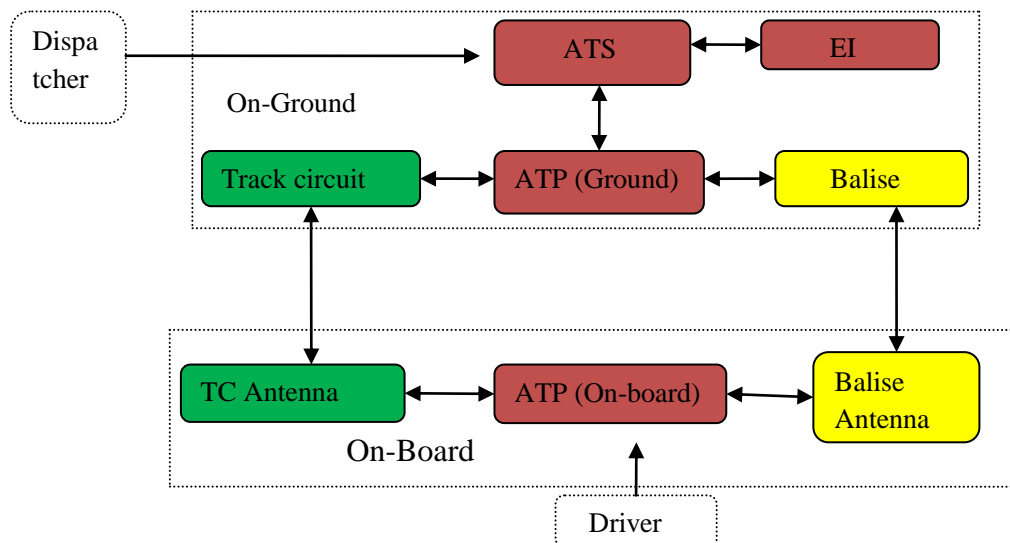


Figure 2.1 Configuration and Characteristics of ETCS level 1

**ETCS level 2:-** ETCS level 2 is a radio-based signal and train control system that is superimposed on the existing signaling system. The movement authority is generated by the track equipment and transmitted to the train by Euro radio.

ETCS level 2 continually monitors the train speed for protecting against the infraction of the movement authority by the trains. The vehicle detection of the vehicles and the train integrity

supervision is executed by the track equipment of the underlying national system (track circuits, blocking, etc), being these systems outside to the ETCS scope.

This level of ETCS is a Euro radio-based system for the communication between track and train. Eurobalises are also used as main equipment to report the trains exact position and direction. The Radio Block Center, which sends out the data to the trains, knows exactly which vehicle controlled by this system, through the ETCS train's identity, provided by its onboard equipment. In this level the use of trackside signaling may be exempt [18].

ETCS track equipments are: RBC (Radio Block Center), Euro radio for bi-directional communication between track and train, and Eurobalise for train location. The main function of this track equipments are:

- ❖ To acknowledge each train operating in ETCS in the RBC area ,through the ETCS train identity
- ❖ To follow in a RBC area each ETCS train location controller
- ❖ To determine movement authority according to the underlying signaling system
- ❖ To transmit movement authority and route information for each train individually
- ❖ To turn over the train control in the limits area of different RBC

ETCS on board equipments are: On-board equipment, with Eurobalises and Euro radio for transmission.

The main functions of this equipment are:

- ❖ To read the Eurobalises and report the trains position to the RBC ,according with detected balises
- ❖ To receive the movement authority and route information transmitted by Euro radio
- ❖ To select, from all maximum safe speeds permitted, the most restrictive for the line ahead
- ❖ To calculate safe speed profile ,taking in consideration acceleration or braking of the train and route characteristics
- ❖ To compare the train actual speed with the permitted one and the braking command ,in case of need

## ❖ Onboard signaling for the driver [18].

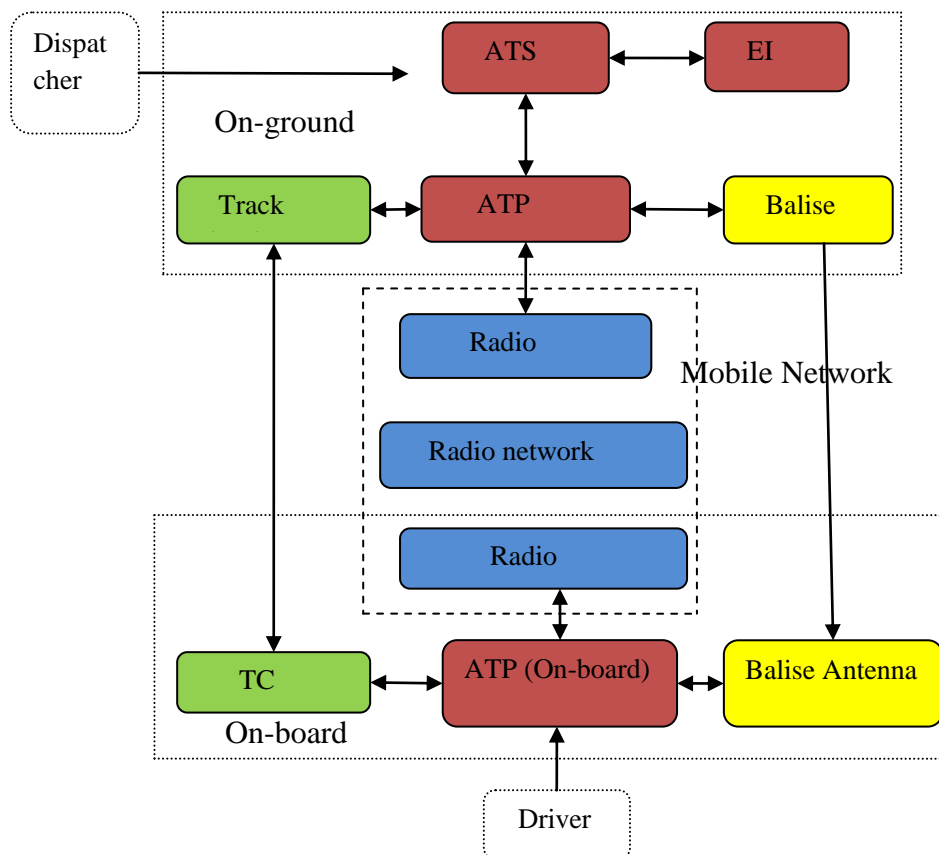


Figure 2.2 Configuration and Characteristics of ETCS level 2

**ETCS level 3:-** ETCS level 3 is a radio-based train control system. The movement authority is given by the track equipment and transmitted to the train by Euro radio.

This level continually monitors the train speed, protecting against the infraction of the Movement Authority by the trains. The vehicle detection of the vehicles and the train integrity supervision is accomplished by RBC in cooperation with the train, which reports on its position and integrity.

This level of ETCS is a Euro radio-based system for the communication between track and train. Eurobalises are also used as main equipment to report the trains exact position and direction. The Radio Block Center, which sends out the data to the trains, knows exactly which vehicle controlled by this system, through the ETCS train's identity, provided by its onboard equipment. In this level the use of trackside signaling is not considered [19].

The track equipments of this ETCS level are RBC (Radio Block Center), Euro radio and Euro balise.

The main functions of these equipments are:

- ❖ To acknowledge each train operating in ETCS in the RBC area ,through the ETCS train identity
- ❖ To follow in a RBC area each ETCS train location controller
- ❖ To determine movement authority according to the underlying signaling system
- ❖ To transmit movement authority and route information for each train individually
- ❖ To turn over the train control in the limits area of different RBC

The on board equipments of this level are on board equipment with Eurobalise and Euro radio, and train integrity system.

The main functions of this equipment are:

- ❖ To read the Eurobalises and report the trains position to the RBC ,according with detected balises
- ❖ To receive the movement authority and route information transmitted by Euro radio
- ❖ To select from all maximum safe speeds permitted, the most restrictive for the line ahead
- ❖ To calculate safe speed profile ,taking in consideration acceleration or braking of the train and route characteristics
- ❖ To compare the train actual speed with the permitted one and the braking command ,in case of need
- ❖ Onboard signaling for the driver [18].

### **2.6.2. Chinese railway ATC standard**

There are very similar features between Chinese Railways and European Railways in terms of train operation mode and train control.

In order to ensure the safety and efficiency of train operation and to meet the requirements of modern technical development in railways, the concept of Chinese Train Control System (CTCS ) was put forward in 2002 as the technical standard of Chinese train control systems by the Chinese Railway Ministry. However, there are more than six kinds of signaling

systems and they are not interoperable in the Chinese Railways due to the reasons of historical and technical development.

The existing signaling systems cannot be interoperable, and the direction of the new signaling systems is not clear. CTCS is based on the situation of the Chinese Railways. It is different with ETCS, but it can learn from ETCS. There are very similar features between CTCS and ETCS since there are a lot of similarities in Chinese Railways and European Railways in terms of operation modes and signaling systems.

Like Europe, Chinese Railway is facing to remove the incompatible obstacle of the different signaling systems on the network. The European Railway needs ETCS, and the Chinese Railway needs CTCS. It is needed that signaling systems for high speed lines and conventional lines, passenger lines and freight lines are unified as standardization, i.e. CTCS. CTCS will be divided into the several levels, referring to ETCS. CTCS is planned to be divided into the following five levels.

**CTCS level 0:-** It consists of the existing track circuits, universal cab signaling (the digital microprocessors-based cab signaling that is compatible with the six kinds of track circuits on Chinese Railway Network, designed by the research team of Northern Jiao tong 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 (balise) 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. It is also called “a points and continuous system”.

**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.

**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.

### 2.6.3. Comparison of CTCS and ETCS

All the working concerning ETCS and CTCS are based on the configuration. The configuration of railway signaling system could be classified as the four parts.

- ❖ On board system
- ❖ Way side system
- ❖ Control center system
- ❖ Communication network including mobile communication [20].

As control center system, by the telecommunication network including mobile transmission, it has all the data for the system to calculate and control. For wayside system, it consists of sensors, actuators (signals and point machines) and RBC (Radio Block Center) etc. The communication network connects reliably and safely the control center with on-board system in trains, sensors and actuators installed along the line and at stations.

The on board system consists of on-board vital computer units, MMI, train speed measurements unit, train position unit, train integrity checking unit, radio receiver, train data recorder unit, train speed control interface etc.

Background and goals for ETCS and CTCS are very similar. They are respectively the development requirements of the European railway network and Chinese railway network. The key technical issues, such as safety, reliability, vital computers for onboard system and control center, easy and less cost investment and maintenance, are the same in ETCS and CTCS.

Both ETCS and CTCS have put moving block systems as its highest level and the final target. This is the result of modern mobile communication development. Based on reliable and fail-safe communication, train control system (moving block system or train control system based on communication) become a close loop safety control system to ensure train operation safety and efficiency.

In CTCS, track circuits still play a very important role. On Chinese Railway Network, track circuit is mostly used and the basis of train control systems. It is not possible to construct CTCS without track circuit. This is the reality of Chinese Railway. The so called “a point and continuous mode” will be the special feature of CTCS. Moreover, MMI with Chinese characters is different with the MMI in ETCS.

In ETCS, balise is a very important device. The communication between onboard train system and wayside systems, positioning can be realized by balise. In CTCS, it is not decided what is used for position after track circuit is removed. Generally there are a lot of common points between ETCS and CTCS. However, they are different.

Table 2.1. Level comparisons of ETCS and CTCS

CTCS		ETCS	
Level 0	Track circuits(Train detection) + Wayside signal	Level 0	Track circuits or Axle counters (Train detection) + Train signal(or Wayside signal)
Level 1	Existing Track circuits + Train signal		
Level 2	Track circuits(Train Operation Information Transmission) + Balise(Track Information) + Fixed Block	Level 1	Track circuits or Axle counters (Train detection) +Balise(Train Operation Information and Track Information) + Fixed block
Level 3	Track circuits(Train detection) + Balise(Track Information) + GSM-R(Train movement authority) + Fixed block	Level 2	Track circuits or Axle counters (Train detection) + Balise(Train Operation Information and Track Information) + GSM-R(Train movement authority) + Fixed block
Level 4	Balise(Track Information) + GSM-R + Moving block	Level 3	Balise(Track Information) + GSM-R + Moving block

#### 2.6.4. Japanese railway ATC standard

A train control system has been developed by the Japanese National Railway and East Japan Railway. This Japanese train control system is called “East Japan Train Control system” (EJTC). This control system has four levels. Each level system is used on appropriate lines according to characteristics of the railway. Also, for these systems, the level is determined by

fixed block system or moving system, train detection by the track circuit or train position recognition with an on board via the track circuit or by radio ,and so on. The four levels of the EJTC are the following.

**LEVEL 0 -ATS-S:-**In this level a block section where a train is present, a track circuit detects the train, and some control device (relay logic, ATS or interlocking systems) turns the signal for the section to red. The ATS secures the braking operation even if a driver is not able to brake. It sends a bell or chimes to encourage confirmation of the signal and issues an alarm in form a red display when the train is approaching a stop signal. If the driver doesn't confirm the situation within a set of 5 seconds, the brakes are automatically engaged and the train will be stopped. In this level the block system in ATS and ATC is based on fixed block section that consist of track circuit and signal devices.

**LEVEL 1-ATS-P:-**The ATS-P was developed to correct the weakness of the ATS-S. By using digital information from a transponder, ATS-P transmits information about signal aspects and the distance to the next stop signal from the track side to the train and uses this information to generate a train speed checking pattern. The train speed and this pattern are then compared in a computer and the brakes are engaged if the speed of the train is exceeding the speed of the pattern. This level doesn't require driver verification, and when the train speed is approaching the danger speed pattern, it draws the attention of the driver by sounding an alarm. The system engages the service brake at maximum power automatically when the speed pattern is on the verge of the danger pattern.

**LEVEL 2-D-ATC: -** In this level the ground side should only transmit information on the position at which the train must stop and the train should recognize its own position and calculate the distance to the stopping point transmitted from the ground. The train then should take the roadway curves, gradients and such into consideration and apply appropriate braking.

**LEVEL 3-ATACS: -** In this level of control the ground controller in each area has such functions as train location, interval control, switching control, level crossing control and security for maintenance work. The radio based station exchanges information with the on board computer. The on board computer controls brake according to the control data supplied by the ground controller and also transmits data on the train location to the ground controller through the on board mobile radio station.

The basic difference between the levels of EJTC and ETCS is transmission technology used in level 2. ETCS level 2 uses radio as a transmission media where as EJTC uses coded track circuit as a transmission media. The difference and similarities between the levels of ETCS and EJTC are shown in table below.

Table 2.2. Level comparison of EJTC and ETCS

	EJTC Level 0	EJTC/ETCS Level 1	EJTC Level 2	ETCS Level 2	EJTC/ETCS Level 3
Signal system	Way side signal		Cab signal		
Block system	Fixed block system				Moving block
Train detection	By track circuit				Train itself
Transmission to train	Transponder(Balise +Loop coil)			Wireless	
Transmission to ground	Nothing	On-Board antenna		Wireless	
Position recognition	Nothing		On-Board On-Board		
Control method	Point control		Continuous control		

The comparison among the levels of the standards of the ETCS, CTCS and EJTS is presented in the following table.

Table 2.3 Level comparison of ETCS, CTCS, and EJTC

ETCS	EJTS	CTCS	Signal	Data transmission method	Track occupation detection	ATP
Level 0	Level 0	Level 0	Track side signal	Non electronic	Track circuit/axle counter	Intermittent ATP
Level 1	Level 1	Level 1		Balise with or without infill		
-	Level 2	Level 2	In-cab signaling	Coded track circuit		Radio communication and balise
Level 2	-	Level 3		Radio communication and balise		
Level 3	Level 3	Level 4				

## 2.7. Forms of data transmission

The forms of data transmission from the operational aspect can be distinguished into

- ❖ Intermittent transmission which include
  - Spot transmission
  - Interrupted linear transmission
- ❖ Continuous transmission

In systems with continuous transmission there is irrespective of possible short sections without connection such as radio holes basically a continuous data link between track and train .Data are usually transmitted by data telegrams in short time intervals.

In systems with intermittent transmission, transmission is possible only at selected locations determined by the trackside equipment. The technical solutions for continuous and interrupted linear transmission are similar [21].

### 2.7.1. Spot transmission

For spot transmission there are various trackside devices which transfer the relevant data to the train. The classification of this transmission depends on the following parameters.

- ❖ Technical principle of transmission
- ❖ Type of power supply
- ❖ Uni or bilateral transmission
- ❖ Switchability of data content
- ❖ Size of transmitted data
- ❖ Redundancy
- ❖ Longitudinal position along the track
- ❖ Lateral position in the track

Intermittent transmission is effected by the following technical principles

- ❖ Mechanical
- ❖ Galvanic
- ❖ Optical
- ❖ Inductive

**Type of power supply:** In most cases, trackside devices need energy for transfer of information. They receive this energy constantly from a trackside power source or short time from the passing train. There are also devices which transfer the information without power.

**Uni or bilateral transfer of information:** In the majority of systems, data are only transferred from trackside to train. Some modern devices such balises provide the possibility of bilateral transfer with connection with the control center.

**Switchability of data content:** Transmitters can be classified into

- ❖ Fixed data transmitters, which transmit the same information content.
- ❖ Switchable transmitters, whose information content can be switched by trackside input information.

Both types of transmitters are used in the same train protection.

**Size of transmitted data:** Older trackside devices can only transfer on bit. Modern types can transfer detailed data by the same trackside transmitter.

**Redundancy:** The information can be supplemented by redundancy or even completely repeated during the transfer in order to detect and correct errors

**Longitudinal position:** Installation localities of devices along the track vary. To fulfill the attentiveness check function a transmitter in proximity to the distant signal is required, where as the train stop function requires a transmitter between in proximity to the main signal. For braking supervision additional transmitters between these two points are applied in some systems such as PZB90 and ATS-S. For continuous speed profiles information has to be upgraded in regular intervals along the whole line.

**Lateral position:** Spot transmitters are installed mainly in the track, either centrally or in proximity to the right or the left of rail. There are also cases with transmitters above rail level. As information depends on movement direction the devices usually operate for one train direction only or transmit different information content for each direction. Their location in proximity to the left or to the right rails allows the train to detect the transmitter only for its direction. With transmitters located in the middle direction have to be determined in another manner, for example by suppression for one direction or by the data contents containing direction information [21].

### 2.7.2. Linear transmission

Linear transmissions are a kind of transmission which includes continuous as well as interrupted linear forms. As in the same way of spot transmission linear transmission classification depend on some parameters. These parameters are following.

- ❖ Technical principle of transmission
- ❖ Uni or bilateral transmission
- ❖ Size of transmitted data
- ❖ Length of transmission cycle
- ❖ Reaction time on new information
- ❖ Usage of technical addition
- ❖ Centralization of information generation and therefore possibility of operative change of the information

- ❖ Expenses for equipment

**Technical principle of transmission:** The principle for all practical important linear transmitters is inductive. The information can be transferred through the following as the most important technical means

- ❖ Track circuit
- ❖ Cable loop
- ❖ Radio

**Uni or bilateral transmission:** By bilateral data transfer, in addition to the train receiving data about movement authorities, permitted speed and others, it can transfer back the information about its current speed, position, condition of track system, train completeness and so on. The cab signaling through track circuits provides only for unilateral data transmission where the loop and the radio can function in both directions.

**Size of transmitted data:** Depends on the channel capacity. Radio gives a wide frequency band for information interchange. Cable loops can transfer the information on frequencies up to 50-100Hz. Channel capacity of track circuit is limit to 20Hz. Thus the linear media can transfer data from few bits up to detailed movement authority and profile data.

**The length of transmission cycle:** Is also important, particularly for transmission of urgent messages. High train speeds demand short cycles less than one second for low speed cycles in several seconds can acceptable.

**Reaction time:** The check of integrity of messages before decision making is necessary.

**Technical addition:** Track circuit in the area of isolated joints and radio in mountain areas cannot always guarantee a full coverage with trackside transmission. In these cases some additional trackside antennas such as cable loops can be necessary.

**Centralization:** Systems with continuous transmission can be centralized or dispersed. The centralized systems allow easy operative changing of information.

### 2.7.2.1. Technical principle of transmission

When data are transmitted through track circuit information can be coded by

- ❖ Constant signal frequency

- ❖ Modulated signal

When cable loops are used two types regarding the assembly are the most important in practical terms

- ❖ A cable loop crossed periodically for position purpose
- ❖ Cable with one conductor and return wire stacked on the rail base

When radio communication used there is a European standard called GSM-R [21].

### 2.7.3. Classification of systems

The train protection systems which are applied among the railways can be classified roughly into five groups according to their function and the type of transmission.

- ❖ Systems with intermittent transmission and without braking supervision
- ❖ Systems with intermittent transmission at low data volume and with braking supervision
- ❖ Systems with continuous transmission of signal aspects by coded track circuit
- ❖ Systems with intermittent transmission at high data volume and dynamic speed supervision
- ❖ Systems with continuous transmission at high data volume and dynamic speed supervision

#### **Systems with intermittent transmission and without braking supervision**

Systems without braking supervision have basically two supervision functions. They provide for an attentiveness check at the signals which can show “Caution” (distant and combined signals) and /or a Train stop function. The means of data transmission of these systems are simple. The gain in safety resulting from the application of these train protection systems is limited [21].

#### **Systems with intermittent transmission at low data volume and with braking supervision**

In these systems in addition to the attentiveness check and train stop functions the braking supervision process is supervised in different forms but without calculating a dynamic speed profile. For data transmission resonant circuits are used in most cases. Each track circuit

resonant circuit is adjusted to a certain frequency out of a stock of several defined frequencies with the frequency coding the information. The trackside resonant circuits can be switched effective or ineffective, or they can be switched between different active statuses (different frequencies) depending on signal aspects.

A disadvantage of many of these systems is that the ineffective (permitting) status cannot be distinguished from the absence of a trackside transmitter which results in non fail safe behavior of the system. Therefore, these systems are not suitable for cab signaling and have to work in the background as long as the driver is operating the train correctly [21].

### **Systems with continuous transmission of signal aspects by coded track circuit**

Systems in this category transmit the aspect of the trackside aspect signal ahead to the train through the rails. The required track circuits are mostly also used for track clear detection and transmission of block information. The signal aspect ahead is repeated in the cab in simplified form. The supervision functions reach from simple acknowledgement checks up to braking supervision with standardized fragments. The advantages of this system are

- ❖ In contrast to most systems of the above two systems, these systems can be designed fail safe.
- ❖ The train continuously receives the newest information in each position of the way [21].

### **Systems with intermittent transmission at high data volume and dynamic speed supervision**

In this category systems are modern for intermittent transmission. Due to the failsafe behavior and the possibility to supervise the complete dynamic speed profile these systems are a safe solution up to high speeds. These systems are similar in their basic functional principles to a large extent, but due to different data coding, amount of detailed information and antenna they are incompatible with each other. The main trackside transmission media are the following.

**Transponder balises:** they work without trackside power supply by using energy sent from the vehicle unit to send data telegrams back to the vehicle.

**Inductive loops with limited extension:** They are usually powered from the trackside.

### **Locally limited radio transmission devices**

According to the data contents, transmission media can be divided into the following

- ❖ **Static data transmission media:** The information content is independent from trackside input such as signal aspects and only transmits static data.
- ❖ **Switchable transmission media:** The information varies depending on the status of trackside, especially on signal aspects [21].

### **Systems with continuous transmission at high data volume and dynamic speed supervision**

The basic difference between this system and the former system is continuous or quasi-continuous data link between track and train. In this system the technical transmission media that are used are the following.

- ❖ Coded track circuits
- ❖ Cable loops
- ❖ Radio transmission

The main data required for the generation of the movement authorities and the static speed profiles are the static and dynamic data.

**Static data:** These data are mostly stored in the trackside control center and alternatively, in closed networks where each train moves always on the same lines, they can be stored on the train.

**Dynamic data:** These data change dynamically and are transmitted from the interlocking system to the line side control center and sometimes from the train control system itself.

The movement authority and static speed profile is mostly generated in the line side control center and transmitted to the train, but also the train can contribute.

To calculate the dynamic speed profile static speed profile, braking related characteristics of the line, braking performance of the train and momentary position of the train are needed. The dynamic and static speed information is displayed to the driver [21].

### 3. Selection parameters of standards

The selection parameters of the standards from the highest priority to the lowest priority are level of safety, cost, capacity, future development of railway system, topography of the country, interoperability, and culture of the people respectively.

**Level of safety:** It means the maximum safety that we get from the system. The standard should give the maximum safety level according to the railway system type. That means it should support the safety of the people, the train itself, the infrastructure of the railway system. In this research, for the selection of the standards level of safety has the greatest value and the highest priority than the other parameters.

**Cost:** Indicates the price of the equipments. The equipments that we install on the train and on the ground should consider the economic aspect of the country with consistent of safety. The standard that should be selected has the responsibility of the minimization of the cost of the equipments. For the selection of the standards the cost factor has given the second highest value and priority in this research.

**Capacity:** The capacity of the railway infrastructure means the capacity of the railway line. As the number of passengers increase the number of the train increase but the railway line will not increase which might increase the contingents of the line. This defect decreases the operation of the train. Therefore the standard to be selected has to increase the capacity of the line.

**Future development of the railway:** As we said before there is plan to interconnect the whole Africa and there will also be the expansion of railway system in the country. That is there is an increase of railway, number of train, interconnected the country with other African countries so the standard should help these developments.

**Topography of the country:** This means the geography of the country. Most part of the country is mountainous. The equipments that we install and the technology that we use should be according to the topography of the country and this depend on the standard that we have.

**Interoperability:** Interoperability refers to the ability of a transport network to operate trains and infrastructures to provide, accept and use services so exchanged without any substantial

change in functionality or when we say interoperability it is the compatibility of the standards among other countries. In the development of the railway infrastructure in Ethiopia, there is plan to interconnect East Africa countries and the whole Africa. So each Africa country will use their own train control system which causes missing of the interoperability like Europe countries. Therefore the preparation of the standards considers the interoperability case.

**Culture of the people:** When we say the culture of the people how is the honesties of the people. When we consider the culture of Europe, America, China regarding the honesties because they are civilized and they illiterate they are somewhat more honesty. But in our country there are some people who will distract the infrastructure and steal the equipments. So the standard that should be selected considers the life of the people and the behavior of the people.

According to the above parameters ETCS level 1 system B is cost wise, has high safety level protect the infrastructure as level 1 train control system. Most of the equipments of this control system that we install are buried underneath they are not exposed for the destructors. As far as our knowledge the cost of the equipments of this control system is low and the level of safety is high to that of other control system ( ETCS level 0 ,2 STM and 3 ) as level 1 train control system, most other Africa countries will install it which decreases the interoperability problem of the country. From the point of view of capacity as the number of train increases this train control system, since this train control system gives smooth train operation, has the ability to increase the capacity of the line. From the point of view of the topography since all the equipments of this control system are easily installed and work without any communication and signal transmission problem this control system fit to the topography of the country. Therefore according to the above parameters this train control system (ETCS level system B) will be a preferable standard for our level 1 train control system. As far as our knowledge the railway system of our country doesn't need level 0 as train protection since the level 0 of train control system is high cost comparing to that of level 1 and the functions that we get from level 0 is very limited to that of our need. Also level 2 and level 3 (which means ETCS level 2 and 3) are not the relevant train control system as level 1 train control system since these two levels have wide functions that compared to our need. Since these two levels (ETCS level 1 and 2) use GSM-R for communication of information , data and for detection of train which is not available in our country these train control system are not referable as train control system for our railway system . Also according to the above

parameters Communication Based Train Control system (CBTC) will be a preferable standard train control system as level 2 train control system for our train control system. As described in the parameters above CBTC has high flexibility which means respond to operation loads, traffic incident management, give 24 hour operation. It also reduces the operating cost that means reduce the amount of energy, staff and maintenance cost. CBTC also optimize the capital cost of the railway which means reduce civil construction and train acquisition costs as well as it increase train security. Train location determination is high; it is a continuous and bidirectional system, and vital train born and wayside process provide continuous automatic train control protection, which all these things gives the system high level of safety in other words CBTC has a high level of safety to the other systems. CBTC has the ability of increase the capacity of the railway line. The equipments of this control system are installed on a mast and around the operation control center and local control center which makes controlling equipments from destructors easy and simple. CBTC is based on radio data network and mobile communication and these systems are available in our country. Also these two systems (Radio data network and mobile communication) are installed in most part of our country considering the topography of the country these systems make the control system easily fit with the topography of the country.

## 3.1. ETCS level 1 system B

### 3.1.1. Characteristics of ETCS level 1 system B

The primary characteristics of an ETCS level 1 system B include the following:

- a. Good train location determination, dependent of track circuits
- b. Train-borne and wayside processors performing vital functions
- c. Intermittent, good capacity, bidirectional wayside-to-train data communications

### 3.1.2. Categorization of ETCS level 1 system B

This standard recognizes that different configurations of ETCS level 1 system B are possible depending on the specific application. For example, an ETCS level 1 system B may

- a. Provide ATP functions only, with no ATO or ATS functions.
- b. Provide ATP functions, as well as certain ATO and/or ATS functions as required to satisfy the operational needs of the specific application.
- c. It is used in conjunction with other auxiliary wayside systems.

### 3.1.3. System structure of ETCS level 1 system B

This system consists of on board and line side equipments with wayside signals

#### 3.1.3.1. On-board equipments

**European vital computer:** The train is equipped with a computer commonly referred to as the European Vital Computer (EVC). This is the heart of the control system onboard equipment. It is the EVC that provides the supervision of the train's movements against all the inputs received from the trackside (balise groups and In-fill balise), onboard odometer the driver and other stored information, and provides outputs to the driver through the in-cab display; the train's braking system, other train functions through the Train Interface Unit (TIU) [31], [42], [44].

**Train interface unit:** The Train Interface Unit (TIU) is the means by which the system controls the train's onboard functions. The main interfaces include the following:

- a. Train braking system: An interface to the trains braking systems, both service and emergence. The service brake interface is not safety critical. The emergence brake interface is safety critical.
- b. Train control: The control system is able to command the change of traction, the raising/lowering of an overhead pantograph and command the air tightness function to activate/deactivate where certain trackside data has been received.
- c. Engine control: An interface is included to cut the traction power. This is used when the on-board equipment of the system is applying either the service or emergency brake and needs to ensure that tractive effort is no longer being applied.
- d. Cab status information: This includes determining the position of the direction controller and whether the cab desk is open or closed [31], [41], [42], [44].

**Balise reader:** This control system fitted trains are equipped with a balise reader. It energizes the balise, enabling the balise to transmit its telegram to the train. The balise reader then receives the telegram and passes it on to the EVC via a Balise Transmission Module (BTM) [44].

**Driver Machine Interface (DMI):** The control system onboard equipment communicates with the driver via the Driver Machine Interface (DMI), an in-cab display, located in a prime position on the driver's desk. The DMI will provide the driver with all necessary information needed to determine:

- a. The distance that the train has permission to travel
- b. The maximum speed which the train should not exceed
- c. The point at which the driver needs to start braking

The DMI screen may be touch-sensitive and/or have buttons to permit the driver to input train information, request permission to move and acknowledge certain events [43], [42], [44].

**Odometer:** The odometer system on board the train provides the train with both speed and distance travelled information. Typically, the EVC receives input from tachometers and also from speed radar mounted underneath the train. The EVC uses this information to calculate the train's speed and position so that it can supervise the train properly. The EVC can also use this information to periodically report its position to the system trackside equipment. This standard requires the odometer to have accuracy no worse than  $\pm (5m+5\%)$  of the distance travelled since the passing of a balise group [44].

**Juridical recorder unit:** This standard includes an onboard data recorder, called the Juridical Recorder Unit (JRU). This is designed to withstand the most severe of expected train accidents so that after such an event, it is possible to reconstruct the events that could have contributed to the accident. To enable this to happen, the JRU records all the messages and telegrams sent and received by the train, driver interactions and certain EVC commands [44].

**Balise transmission module:** is a device that used to transmit telegrams/dates' from the balise to the on board computer (EVC).

### 3.1.3.2. Trackside equipments

**Line side electronic unit (LEU):** A Line-side Electronic Unit (LEU) controls the telegrams transmitted to the train via controlled balises. It is power supply and interfacing system with signaling.

**Balise:** The balise is a data configurable transponder that is mounted in the four-foot. The balise needs no external power supply as it is energized by the passing train. Once energized the balise transmits an electronic telegram back to the train. A balise can either send the same fixed telegram in each transmission or it can be connected to a local switching unit to enable it to transmit a different message according to the inputs received. The balises could be

- ❖ **Switchable balise:** These balises are interfaced to signal aspect through LEU. The telegrams/ data transmitted by these balises depend on the aspect of the signal. These are provided at a location near the signal. The Permanent Speed Restriction & track topography related information is also transmitted by these balises within the telegram/data related with signal aspect.
- ❖ **Infill balise:** These balises are also interfaced to signal through LEU. The telegrams/ data transmitted by these balises depend on the aspect of the signal. These are provided in advance of the signal to update the movement authority in advance. These balises cannot effect change of mode of on board system.
- ❖ **Fixed balise:** These balises are provided wherever required. These balises transmit fixed telegrams/ data only. These can be used for enforcing Temporary Speed Restriction etc.
- ❖ **Repositioning data balise:** These balises are provided wherever required to correct the previously given information [44].

**Cable:** Communication link (data cable) between the LEU & the balise.

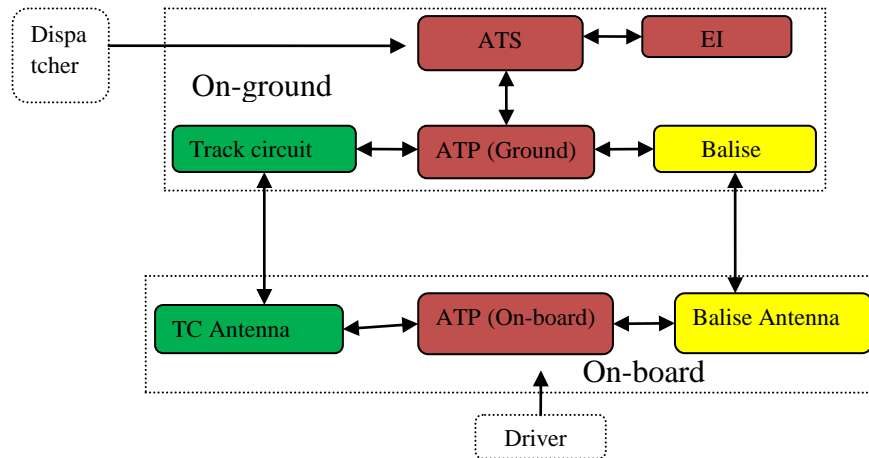


Figure 3.1 Configuration and Characteristics of ETCS level 1 system B

### 3.1.3.3. Technical requirements

The on-board and the line side equipments of the control system (ETCS level 1 system B) should have at least the following specifications for safety and efficient movement of train:

- A. The design of the system shall be robust and of state-of-art technology. The design shall be modular up to card level for ease of maintenance and fault troubleshooting. All the cards shall be suitably protected and enclosed to avoid dust ingress. Suitable housing/cabinet shall be provided to withstand shocks, vibrations, electromagnetic induction and electrical surges etc.
- B. The equipments shall be so constructed as to prevent unauthorized access to the system both at track side and on board. All equipments shall be provided with easily accessible test points to facilitate fault localization. Provision shall be made for isolating functional areas with each module to assist with testing and fault localization. Application software of on board & trackside / line side equipments shall have user-friendly design tools to enable carrying out of configuration changes by the railways.
- C. Immunity to Interference/EMI/EMC/Surge/Transients etc: The on board as well track side systems of train control system shall be immune to the following interference currents generated by locomotive/EMU etc. [29], [37].

Table 3.1 Immunity to interference

<b>Interference current</b>	<b>Overall limit</b>
Psophometric current AC traction	10.0A
Psophometric current DC traction	2.0A
DC Component in AC mode	4.7A
Second harmonic component (100Hz) in AC traction	8.5A
1400 to 5000Hz	400mA
More than 5000Hz up to 50000Hz	270mA
50Hz component in DC mode	2.4A

- D. The track side system shall be immune to electro-magnetic interference generated by thyristor/chopper-controlled locomotives, traction return currents. Electromagnetic compatibility of the entire on-board equipment as well as track side equipments including interlinking cables shall comply with European Standards EN 50121 for Railway Applications – Electromagnetic Compatibility, as applicable and on-board equipment shall also comply with EN50238 for Railway Applications – Compatibility between rolling stock & train detection system. Adequate provisions should be made in the design for suppression of internal transients, spikes and to withstand external transients, spikes and surges as per limits laid down in IEC- 60571 [29], [37].
- E. The track-side system shall be electromagnetically compatible to work in conjunction with the relay based interlocking, electronic interlocking, field signaling equipment, signaling cables and power supply arrangements as laid down in specification IRS: S 36 & IRS: S23 [29], [37].
- F. Surge suppresser and proper earthing arrangement shall be provided in power supply system of on board as well as track side systems to protect against transient voltages lightning and spikes etc. as per site/ local requirements in addition to their compliance.
- G. The on board equipment shall work on the DC power supply available in the locomotive (which is normally 72V DC in Diesel locomotives & 110V DC in electric locomotives/EMU/MEMU, with a variation of -30% / +20% over nominal voltage and a ripple factor of up to 15%) as input & shall derive other voltages required for the working of its sub-systems [24], [42], [46].

- H. Design of trackside system shall be such that in the event of simultaneous display of two conflicting aspects caused by defective components like signal lamp, information corresponding to either the more restrictive of the two aspects or the most restrictive aspect of that signal shall be passed on to the EVC. Likewise, in the case of blank signals, the information corresponding to most restrictive aspect of that signal shall be transmitted to EVC. LEU and balise constituting track side system shall be designed in such a way that for any disconnection, low insulation or short circuit fault in connecting cable, a visual indication shall be given to the EVC and the information corresponding to most restrictive aspect of that signal shall be transmitted to EVC. These failures shall be on safe side [34], [35].
- I. The track side equipments of the train control system shall work on DC power supply. A nominal 110V AC 50 Hz power supply (with variation of +20%, -30%) shall be made available by the railways at the signal location. A suitable conversion from 110V AC supply to DC supply shall be provided by the supplier to work the track side system on DC power supply. There shall be a suitable DC back-up with charging arrangement to manage power outages for the minimum duration of half an hour. Purchaser can specify the duration of backup in case it is required for more than half an hour. The track side and on-board equipment shall not in any way infringe the schedule of dimensions being followed by the Ethiopian Railway System.
- J. The design of on board & track side systems shall take into account switching transients that may occur, in either the system or outside, of any magnitude, up to and including interruption due to short circuit of 25 KV system. The design shall also take into account supply related surge & transient. On board as well as track side systems and system design shall take into account effect of lightning [29], [37].
- K. The on board system shall be capable of operating efficiently in spite of dust, dirt mist, torrential rains, heavy sand or snow storms, presence of oil vapors and radiant heat etc., to which rolling stock is normally exposed in service. The system shall be suitable for traction application under the following environmental conditions [36] [40], [30].

Table 3.2 Environmental specifications

Atmospheric temperature	Maximum temperature of metallic surface under the Sun: 75 degree Celsius and in shade: 55 degree Celsius Minimum temperature: - 10 degree Celsius (Also snow fall in certain areas during winter season)
Humidity	100% saturation during rainy season
Reference site conditions	i) Ambient temperature: 50 degree Celsius ii) Humidity: 100% iii) Altitude: 1776 m above mean sea level
Rain fall	Very heavy in certain areas.
Atmospheric conditions	Extremely dusty and desert terrain in certain areas. The dust concentration in air may reach a high value of 1.6 mg/m <sup>3</sup> . In many iron ore and coal mine areas, the dust concentration is very high affecting the filter and air ventilation system
Coastal area	Humid and salt laden atmosphere with maximum pH value of 8.5 sulphate of 7 mg per liter, maximum concentration of chlorine 6 mg per liters and maximum conductivity of 130 micro Siemens / cm
Wind speed	High wind speed in certain areas, with wind pressure reaching 150 kg/m <sup>2</sup>

- L. Drivers' Machine Interface (DMI), which shall be user friendly, easy to operate, shall be as per UIC/UNISIG specifications & shall have at least the following:
- i. Audio warning & visual indications for warning over speed, service & emergency brake applications.
  - ii. Display of current mode of the system, current speed of the locomotive, target distance, target speed and release speed, when necessary, selected set of train characteristics.
  - iii. Selection menu for the driver to carry out required operations like start-up selection/change of mode, alarm resetting, acknowledgement, over-ride operation etc.
  - iv. Any other indications & selection menu as necessary for the operation of the system & to meet requirement of this specification.

- v. Selection menu to select/ enter the minimum train parameters like type of train, no. of coaches/ wagons etc. to select the set of minimum eight predefined train characteristics [44],[43].
- M. The minimum requirement of MTBF (which indicates the availability of subsystems of equipments) of each sub-system of track side as well as on board system shall be given in the following table below [24], [32], [33].

Table 3.3 Minimum requirements of MTBF of equipments

Sub system	Minimum MTBF( hrs)
EVC with JRU	25,000
DMI	20,000
BTM	25,000
Balise antenna	100,000
Tachometer	25,000
TIU	15,000
LEU	60,000
Balise	100,000

- N. Line-side Electronic Unit (LEU) shall also conform to the latest specifications issued by UIC/UNISIG and shall be suitable to work with Ethiopian Railway Signaling System. LEU shall be capable of receiving minimum 10 signal inputs. It shall be capable of delivering minimum four separate channels so that at least four data balises may be driven up to 2500m. The manufacturer/ supplier shall mention the maximum number of inputs & maximum number of channels an LEU can handle. Balise controlling interface cable shall meet the requirement mentioned in UNISIG specification for balise.
- O. The balise shall be either class-A or class-B based on the limits of debris on the top of the balise as per the following table [34].

Table 3.4 Layers (debris) on top of Balise in mm

Material	Description	Layer on top of Balise (mm)	
		Class B	Class A
Water	Clear	100	200
	0.1% NaCl(Weigh)	10	100
Snow	Fresh , 0° C	300	300
	Wet ,20% Water	300	300
Ice	Non porous	100	100
Ballast	Stone	100	100
Sand	Dry	20	20
	Wet	20	20
Mud	Without salt water	50	50
	With salt water,0.5% NaCl(Weigh)	10	50
Iron ore	Hematite( Fe <sub>2</sub> O <sub>3</sub> )	20	20
	Magnetite (Fe <sub>3</sub> O <sub>4</sub> )	2	20
Iron dust	Braking dust	10	10
Coal dust	8% sulphur	10	10
Oil and Grease		50	50

- P. The fixing arrangement of the balise on the sleeper shall be such that it does not require any drilling and does not cause any damage to the sleeper. The routing/fixing arrangement of its cable normally shall not restrict the use of track maintenance machines. However, if required, the manufacturer/ supplier shall specify the precautions needs to be taken by the purchaser during use of track maintenance machine.
- Q. This control system shall conform to the Safety Integrity Level (SIL) 4 as per CENELEC standards or equivalent.

- R. The control system shall be capable of working in all electrified as well as non electrified territories. It should be suitable for use on AC/DC EMUs/DMUs/MEMUs/ single or multiple electric locomotives. The system shall be suitable for single, double or multiple line sections on suburban/ non-suburban section.
- S. The control system shall be capable of functioning in 25 KV AC RE, 1500V DC RE, 750V DC RE areas as well as in DC/AC RE areas where some lines may be working on AC RE while other lines on DC RE.
- T. The size of the entire on-board equipment (excluding DMI) which is to be provided inside locomotive's machine room shall not be more than 1350mm x 560mm x 550 mm (Height x width x depth). The DMI to be provided in Driver's cab shall not exceed in size by 360mm x 450mm x 150mm (Height x width x depth).
- U. Suppliers shall specify the number of sub-systems in which there on board system can be split. Supplier shall also submit sizes of such sub-systems.
- V. The LEU shall be suitable to install in railway signaling equipment housings classified as A1, A2, A3, B1, B2, B3 and B4 as detailed in SPG 1856 Environment Conditions [34].

Suitability is defined as meeting the life expectancy, reliability, availability and maintainability requirements while continuously operating in the given environment with regular occurrences of average and extreme values.

Physically the LEU shall be:

- ❖ Be suitable for use in a location case which provides a degree of protection to IP23 or better.
- ❖ Fit in an existing single width location case that is half full with existing equipment. The maximum size to fit in an existing single width location case is estimated as 330mm deep, 450mm wide and 600mm high.
- ❖ Desirably be such that two or three LEUs can be fitted in the space estimated above.

Electrically the LEU shall

- ❖ Not provide a galvanic path from any power or interface circuit to earth of less than 100Mohm when measured at 500Vdc.

- ❖ Not provide a capacitive path from any power or interface circuit to earth of more than 20nF. Capacitance values to earth for each circuit type shall be similar (+/-50%).

The LEU electrical power supply interface shall:

- ❖ Work when supplied with 120Vac nominal at 50Hz. Expected supply limits are 120Vac +10%, -20%.
- ❖ Meet electrical safety requirements when used on a 120Vac nominal 50Hz electrical power supply using the IT system of earthing as detailed in IEC 60364 Electrical Installations in Buildings.
- ❖ Be rated for insulation co-ordination over voltage category II as per EN 60664-1 and preferably category III in a PD2 (or more severe) environment.
- ❖ Have a power load less than 40VA and desirably less than 20VA.
- ❖ Allow the LEU to continue operating with a voltage interruption with 0% residual voltage (of 120Vac supply) for at least 10 cycles at 50Hz. Compliance is tested in accordance with AS 61000-4-11 Electromagnetic compatibility (EMC) Part 4.11: Testing and measurement techniques –Voltage dips, short interruptions and voltage variations immunity tests.
- ❖ Allow the LEU to continue operating with a voltage dip with 40% residual voltage (of 120Vac supply) for 10 cycles at 50Hz. Compliance is tested in accordance with AS 61000-4-11 Electromagnetic compatibility (EMC) Part 4.11: Testing and measurement techniques –Voltage dips, short interruptions and voltage variations immunity tests.

LEU must have safety critical inputs which shall:

- ❖ React to input changes from off to on, and on to off in less than 1 second.
- ❖ Have a configuration option for the stability time for inputs. Unstable inputs causing a failed telegram to be sent to the balise.
- ❖ Update the telegram sent to the balise within 2 seconds of the actual source input.
- ❖ Be rated for insulation co-ordination over voltage category II as per EN 60664-1 and preferable category III in PD2 environment. This includes any interface terminals.

- ❖ Have interface terminals suitable for safety critical cable as defined in SPG 1013 Cables for Railway signaling Application-Single Conductor Cables for indoor use when terminated with a pre-insulated pin connector, red or a pre-insulated boot lace ferrule.
- ❖ Have labeling on all interface terminals and any associated plugs.
- ❖ Have terminals and plugs that are not readily broken apart by hand
- ❖ Have terminals rated for a working voltage of at least 3 times the nominal working voltage of the circuit with a preferred minimum rating of 250Vac.
- ❖ Have terminals rated for at least 4 times the nominal maximum current of the circuit with a minimum current rating of 4 amps. Circuit fuse rating is typically 4 amps.
- ❖ Have vibration resistant terminals which are preferably screw less type with direct pressure (tension clamp) [34], [42], [44].

LEU Reliability, Availability and Maintainability criteria include:

- ❖ The expected life of the LEU shall be at least 15 years.
- ❖ The predicted Mean Time To Fail (MTTF) for the minimum compliant LEU configuration shall be at least 10 years. A MTTF for a typical LEU of greater than 25 years is preferred.
- ❖ Preventative maintenance actions (other than visual inspection) should not be more frequent than once per year.
- ❖ A hazard control measure shall be built into the LEU to prevent operation of the LEU when application data intended for a different LEU is installed.
- ❖ A hazard control measure should be provided to prevent operation of the LEU when an incorrect version of the application data is installed.
- ❖ LEU configuration settings that may need to be set or checked by a maintainer during equipment replacement must be clearly labeled. LEUs that provide active indications of correct operation without use of additional equipment are preferred [34].
- ❖ LEU shall be able to manage at least 32 telegrams of the maximum length [46].

The balise interface shall:

- ❖ Support connection to two or more controlled balises.

- ❖ Be able to drive any UNISIG supplier's balise with the distance between LEU and the balise ranging from 10m to 800m. The signal at the balise must meet the UNISIG SUBSET-036 requirements.
- ❖ Preferably not require a circuit fuse for cable distances up to 800m in a 1500Vdc Electric Traction environment [34].

Balise acceptance criteria:

- ❖ Only the compact or reduced size balise is accepted.
- ❖ Class A and Class B balise.
- ❖ Balise mounting shall meet the requirements of Class B in UNISIG SUBSET-036.
- ❖ Controlled (also known as transparent, variable, commutable) balises are accepted with and without a plug connection for the external cable.
- ❖ The balise provides for transverse mounting on a concrete bearer with fixings on the centre line of the long axis of the bearer. Transverse mounting has short sides of the balise parallel with the rails.
- ❖ Fixing hole size for a concrete bearer to be 20mm diameter or less.
- ❖ Maximum depth/height of the balise shall be less than 65mm.
- ❖ Suitability for the balise to be mounted directly on the sleeper with no need to increase height to meet Class B mounting requirements. The use of padding under the balise for vibration damping and strain relief is accepted [34].

The information provided to the on board system by switchable data balise should be

- ❖ Balise ID
- ❖ Balise version
- ❖ Movement authority

Cables from LEU to balise shall:

- ❖ Be designed for outdoor use in either pit and pipe or direct burial cable routes.
- ❖ Be resistant to rodent attack.
- ❖ Comply with the technical specifications' set by the LEU supplier for operation with the cable distance between LEU and balise ranging from 10m to 800m. The connected balise may not be from the same supplier.
- ❖ Have a Fire Safe, Low Smoke Zero Halogen (LSZH) version suitable for tunnel installations [34].

### 3.1.3.4. Interfaces between track side and onboard equipments

The on-board interfaces are [45]

- ❖ Odometer
- ❖ Key management system
- ❖ Driver Machine Interface (DMI)
- ❖ Information recorder

Odometer interfaces [45]:

- ❖ On-board equipments
- ❖ Environmental conditions
- ❖ EMC

Information recorder interfaces [45]:

- ❖ JRU downloading tool
- ❖ On-board equipment
- ❖ Environmental conditions
- ❖ EMC

Balise interfaces [45]:

- ❖ LEU balise
- ❖ The control system-ID management
- ❖ Environmental conditions
- ❖ Track side signaling
- ❖ EMC

### 3.1.4. Range of application

The performance and functional requirements of this control system defined in this standard are intended to be applicable to the full range of transit applications for main line including heavy rail, and commuter rail transit systems.

### 3.1.5. Train configuration

This control system shall be capable of supporting a variety of train configurations, including the following:

- ❖ Fixed-length unidirectional trains comprised of one or more basic operating units
- ❖ Fixed-length bidirectional trains comprised of one or more basic operating units

- ❖ Variable-length unidirectional trains
- ❖ Variable-length bidirectional trains

### 3.1.6. Operating modes

The train which is equipped with an ETCS level 1 system B will operate in the following modes. These are full supervision mode, On-sight mode, staff responsible mode, trip mode reverse mode, unfitted mode and system failure mode.

**Full supervision mode:** The full protection of the train is applied in Full Supervision (FS) mode, including the provision of an MA. To be in FS mode, the onboard equipment of this control system needs permission from the trackside equipment and needs to know the track gradient profile, the track line speed and the distance that it can travel. The gradient and speed information only be known from the front of the train (for example, it only knows the gradient information forwards from a signal) then the train will transition into FS mode, but include a message on the DMI indicating that gradient and speed information is not available for the whole length of the train. This message will remain until the train reaches a location where gradient and speed information is available for the whole length of the train. In this mode, the on-board equipment shall display the train speed, the permitted speed, the target distance and the target speed to the driver [44].

**On-sight mode:** The full protection of the train is also applied in On Sight (OS) mode, including the provision of an MA. The difference with FS is that the interlocking is permitting the train to move when it does not know that the track ahead is clear of an obstruction. The driver is now responsible for ensuring the train is driven at such a speed that it can be brought to a stand prior to meeting any obstruction. The onboard equipment of this control system also supervises the train to a ceiling speed. To be in OS mode, the onboard equipment needs permission from the trackside equipment and needs to know the track gradient profile, the track line speed and the distance that it can travel. The gradient and speed information only be known from the front of the train (for example, it only knows the gradient information forwards from a signal) then the train will transition into OS mode, but include a message on the DMI indicating that gradient and speed information is not available for the whole length of the train, This message will remain until the train reaches a location where gradient and speed information is available for the whole length of the train. The

authority to use this mode shall come from track-side only (this mode cannot be selected by the driver) [44], [46].

**Staff Responsible mode:** Staff Responsible mode (SR) is offered to the driver when the onboard equipment of the control system does not have all the data necessary to enter FS or OS mode, typically at the start of a mission when the train has an invalid or unknown position. The SR is also entered as a consequence of the driver selecting override. In SR mode, the onboard equipment supervises the train to a ceiling speed. It is possible to limit the distance travelled in SR either through a distance limit or through a balise group. Where a distance limit is provided, the train's speed will be dynamically supervised down to a zero speed at the end of this distance. Where a balise group is provided this will cause the train to trip if it passes over it in SR mode [44], [46].

**Tripe mode:** If the onboard equipment of the control system determines that the train has exceeded its permitted MA, it applies the emergency brakes and enters Trip (TR) mode. To exit TR mode, the driver needs to acknowledge that the train has been tripped. A continuous emergency brake demand is made in TR mode [44], [46].

**System failure mode:** If the onboard equipment of the system detects failure of the control system, it enters System Failure (SF) mode. A continuous emergency brake demand is made in SF mode [44].

**Reverse mode:** In this mode, the driver is permitted to change the direction of movement of the train and drive from the same cab. This mode shall be permitted by trackside [44].

**Unfitted mode:** In this mode, train movement is allowed in the sections not equipped with the control system track side equipment. The train is supervised against a ceiling speed which will be the lowest of the maximum permitted speed for the traction unit or the maximum permitted speed of the train as entered by the driver [44] ,[46].

### 3.1.7. Hazard identification and risk assessment process

Hazards shall be resolved through a design process that emphasizes the elimination of the hazard. The effectiveness of the hazard resolution strategies and countermeasures shall be monitored to determine that no new hazards are introduced. In addition, whenever substantive

changes are made to the system, analyses shall be conducted to identify and resolve any new hazards.

As a minimum, this train control system shall address the following critical/catastrophic system hazards through the implementation of the ATP functions defined.

1. Train to train collisions (rear-end, sideswipe, head-on): hazard to be addressed through train separation assurance, rollback protection, parted consist protection route interlocking protection, and traffic direction reversal interlocks.
2. Train-to-structure collisions: hazard to be addressed through end-of-track protection and restricted route protection.
3. Train derailments: hazard to be addressed through over speed protection, route interlocking protection, and broken rail detection.
4. Collisions between trains and highway vehicles: hazard to be addressed through grade-crossing warning devices.

## **3.2. Functional requirements**

This level of train control system shall include the capability for providing ATP, ATO, and ATS functions. ATP functions shall provide fail-safe protection against collisions, excessive speed, and other hazardous conditions. ATP functions shall have precedence over both the ATO and ATS functions. ATO functions shall control basic operations that would otherwise be performed by a train operator and shall do so within the protection limits imposed by ATP. ATS functions shall provide system status information and the means to monitor and override the automatic control for various functions of the system.

### **3.2.1. ATP functions**

All ATP functions shall be vital functions and shall be designed and implemented in accordance with 3.1.7. This control system shall be capable of providing bidirectional ATP [46].

#### **3.2.1.1. Train location and /train speed determination**

An ETCS level 1 system B train location/train speed determination shall be a required ATP function for any ETCS level 1 system B configuration. An ETCS level 1 system B shall establish the location, speed, and travel direction of each this control system equipped train [46].

### 3.2.1.2. Static train speed profile calculation

This system shall collect all relevant information concerning train and line speed. The system shall calculate the permitted speed for the train for all locations of the authorized movement. This static train speed profile shall also respect maximum line speed and track speed and special speed levels for special classes of trains. The system train borne equipment calculates the static train speed profile on the basis of infrastructure data and train data [46].

### 3.2.1.3. Dynamic train speed profile calculation

Based on all relevant data, the system shall calculate an emergency braking curve and a service braking curve. It shall be possible to permit/inhibit the service brake intervention by trackside. When changing to a lower speed level, the front end of the train shall respect the dynamic train speed profile. When changing to a higher speed level the rear end of the train shall respect the static train speed profile. It shall be possible to define certain locations (e.g. tunnels) where speed increase is related to the front of the train. The braking curves shall ensure that the train complies with its speed requirements. Where failure to apply the full service brake is detected the emergency brake shall stop the train in rear of the danger point [46].

### 3.2.1.4. Release speed calculation

The release speed shall be calculated on board, based on either:

- ❖ Safety distance and overlap
- ❖ Accuracy of odometers
- ❖ Deceleration performance of the train
- ❖ Or given from trackside

The release speed given from the trackside shall take priority over the release speed calculated on board. The release speed shall be indicated on the DMI. If the release speed is calculated on board it shall ensure that the train will stop before reaching the danger point. When the train is stationary or after a certain time (e.g. the time for "route releasing" of the overlap), the release speed calculation shall be based on the distance to the danger point (if calculated on-board). The condition for this change shall be defined for each target as infrastructure data. Each railway shall have the possibility of allowing a different release speed for every signal. The release speed shall be programmed as a fixed value & transmitted

to on-board equipment via the track side equipment. The release speed shall be based on the aspect of the signal, route of the train (main line or turnout route) on which it is going to travel, gradient ahead & any other relevant considerations [46].

### **3.2.1.5. Supervision of movement authorities and speed limits**

A train shall be supervised to its static and dynamic train speed profiles. Within the braking curve area, a warning shall be given to the driver to enable him to react and avoid intervention from the system at least 5 sec. before the intervention. If the train or the shunting movement exceeds the permitted ceiling speed by a certain harmonized margin, the train borne equipment shall execute a brake intervention until the actual speed does not exceed permitted speed; then the driver shall be able to release the brake. The driver shall be able to release the emergency brake application when stationary. The driver may release the emergency brake when the actual speed is below the permitted speed [46].

### **3.2.1.6. Roll away and reverse movement protection**

To protect a traction unit from roll away and unwanted reverse movements the train borne equipment shall monitor the direction of movement in relation to the permitted direction. The train borne equipment shall apply the emergency brake after a distance, defined by a national value, is travelled by the train. The roll away/reverse movement intervention shall be indicated on the DMI. When the traction unit has come to a standstill, the driver shall be able to release the emergency brake. After releasing the emergency brake the system will provide the supervision appertaining when roll away protection was initiated. When using more than one traction unit this function shall be disabled in all but the leading traction unit [35], [46].

### **3.2.1.7. Train trip**

When a traction unit passes a stop-signal the emergency brake shall be triggered. Operation of the train trip shall be indicated on the DMI. The emergency brake shall be applied until the traction unit is stationary. When the traction unit is stationary the driver shall be required to acknowledge the train trip condition. This acknowledgement will release the emergency brake. After the acknowledgement the driver shall be able to continue the movement. After the acknowledgement the train shall be able to be driven backwards for a certain distance [35], [46].

### **3.2.1.8. Control of pantograph and power supply**

The system on-board equipment shall be capable of receiving information about pantograph and power supply from the trackside. The system train borne equipment shall indicate on the DMI the information regarding pantograph and power supply. The information regarding lowering and raising of the pantograph and opening/closing of the circuit breaker shall be provided separately and in combinations [35], [46].

### **3.2.1.9. Balise Tracking / Balise Linking**

The train control system equipment shall be capable of identifying missing balise and give suitable audio & visual indication to the driver accordingly. This event shall be logged by the system. The System shall be capable of taking following actions under such condition:

- ❖ Apply service brake to bring the train to a halt.
- ❖ Apply emergency brakes to bring the train to a halt [35], [46].

## **3.2.2. ATO functions**

The ETCS level 1 system B wayside-to-train communications interface shall be sufficient to support all required ATO functions.

### **3.2.2.1. Automatic speed regulation**

The starting, stopping, and speed regulation of the train as it travels along the track shall be automatically controlled by the system so that the speed, acceleration, deceleration, and jerk rates are within specified passenger comfort limits and the train speed is below the over speed limits imposed by ATP.

The system shall support multiple ATO speeds, acceleration, and service brake rates in accordance with the train operator or ATS inputs.

### **3.2.2.2. Platform berthing control**

The control system shall be capable of implementing any of the following platform berthing control modes:

- i. Where the platform length is approximately equal to the train length, the control system shall allow a train to enter a station platform only if there is sufficient room to fully berth or if the preceding train has a movement authority that shall allow it

to fully leave the platform area and it has begun to move out of the station (i.e. within ATP constraints, train movement shall be controlled to minimize the likelihood of the train coming to a stop when only partially within the station platform limits).

- ii. Where the platform length is longer than the train length, the system shall support multiple stopping positions within the platform area.
- iii. Where the platform length supports multiple train berthings, the control system shall allow a train to enter a platform while another train already occupies an alternative berth.
- iv. Where the platform length is shorter than the train length, the system shall support platform berthings consistent with the door opening control protection.

### **3.2.2.3. Door control**

The control system shall be capable of automatically controlling train doors during passenger boarding and discharging. Automatic door control may be limited to the following:

1. Automatic door opening only (with or without passenger door open requests)
2. Automatic door closing only
3. Neither automatic door opening nor closing

### **3.2.3. ATS functions**

It consists of a centralized or a distributed computer control system with dispatcher workstations that provides the overall train operation management functions including remote routing and supervision functions. It includes announcements of events including critical alarms and a logging capacity for all events.

#### **3.2.3.1. Control mode**

In the main line stations, ATS subsystem has two types of control mode which are central control and station control. In the normal situation, central mode is used to monitor the whole line. The authorized operator can send operation command in the dispatcher workstation.

When under the local control, station operator can send control command in local workstation. When the communication between station and operation control center is good station control request must be authorized by control center. Under the emergence situation, local

station operator can switch the control mode without central authorization. Local route control is prior to central control and manual control is prior to automatic control.

### 3.2.3.2. Human machine interface

ATS human machine interface is the interface to be used by central dispatcher and local operator. Through human machine interface, the operator obtains the line operation information and inputs control command to ensure the necessary control of running. All human machine interface in ATS support bilingualism showing and provide necessary aiding information, which convenient for users to interact with system.

This function is used to supervise the present state of signal equipment and train state of the whole line. The displaying information is included as follows:

- Track layout
- Station control/central control
- Equipment working state
- Signal, switch and track state
- Automatic fleet route state
- Automatic turn back route state
- System control mode and state
- Automatic route state according to train schedule
- Train location, train number and train state
- The destination of out depot train
- Train running early, late and normal information
- Operation result
- Departure information of station and depot
- Switch split alarm
- Track number, signal number and switch number(displayed when needed)
- Platform information
- Power supply state

### 3.2.3.3. Train identification and train tracking

An ETCS level 1 system B-equipped train shall be assigned train identification. This train identification shall indicate the type of train and other pertinent information about the train.

An ATS system shall have the capability to automatically track, maintain records of, and display on the ATS user interface the locations, identities, train schedule, and other pertinent data for ETCS level 1 system B equipped trains operating in track circuit.

The front and rear position of trains shall be tracked based on the system train location reports, and the train location shall be displayed on the ATS user interface.

#### **3.2.3.4. Train routing**

An ATS system shall have the capability to permit ETCS level 1 system B equipped trains to be manually and automatically routed based on train location reports and in accordance with the train service data, predefined routing rules, and any ATS user-directed service strategy.

Where applicable to the specific track configuration, automatic routing shall facilitate the proper merging and diverging of trains at junctions, turn back of trains, the movement of trains from/to storage areas, and the rerouting of trains in response to service disruptions and/or planned outages. Train routes shall be indicated on the ATS user interface and may also be indicated to the train operator.

An ATS system may also include a means to control and limit movement authorities of these control system-equipped trains. The movement authority limits of the system shall be capable of being displayed on the ATS user interface, and any uncommanded reductions of authority limits shall be alarmed. Movement authority limits may also be indicated to the train operator on their displays.

#### **3.2.3.5. Passenger information system interface**

An ATS system may interface with wayside and/or train-borne passenger information systems to trigger automatic passenger information messages, such as train arrival information, based on train location reports.

#### **3.2.3.6. System fault reporting**

Failures and out-of-tolerance conditions detected by, or input to, the system that can impact the on-time performance of the transit system or result in some other loss of specific system functionality may be automatically indicated on the ATS user interface display. Any alarms shall be categorized and prioritized into critical and noncritical alarms and logged. All critical alarms shall require acknowledgment.

### **3.2.3.7. Schedule regulation**

An ATS system may have the capability to automatically monitor and regulate the performance of trains in relation to schedule. An ATS system may include an automatic dispatching function (based on train identities, system train location reports, schedule, and service strategies implemented by authorized ATS users).

Schedule regulation for ETCS level 1 system B equipped trains shall be by means of dwell time variance (including train holds) and may also be by control of run times between stations (e.g., through adjustments to train acceleration and service brake rates, and speeds).

The desired station departure time and desired speed profile between stations may be indicated to the train operator on their displays and, when operating in ATO mode, shall be implemented automatically by the control system using automatic speed regulation function.

## **4. Communication Based Train Control System**

### **4.1. General requirements**

#### **4.1.1. Characteristics of CBTC systems**

The primary characteristics of a CBTC system include the following:

- a. High-resolution train location determination, independent of track circuits
- b. Continuous, high capacity, bidirectional train-to-wayside data communications
- c. Train-borne and wayside processors performing vital functions

#### **4.1.2. Categorization of CBTC systems**

This standard recognizes that different configurations of CBTC systems are possible depending on the specific application, a CBTC system may:

- a. Provide ATP functions only, with no ATO or ATS functions
- b. Provide ATP functions, as well as certain ATO and/or ATS functions, as required to satisfy the operational needs of the specific application
- c. Be the only train control system in a given application or may be used in conjunction with other auxiliary wayside systems

### **4.2. System architecture (structure) of CBTC**

A CBTC system should comprise the following major subsystems, as shown in Figure 4.1:

- a. CBTC ATS equipment
- b. CBTC wayside equipment
- c. CBTC train-borne equipment
- d. CBTC data communication equipment

The CBTC system is assumed to interface with an external separate interlocking subsystem and possibly with other external wayside equipment. Interlocking functions may be incorporated within the CBTC wayside equipment [49].

#### **4.2.1. CBTC ATS Equipment**

The CBTC ATS equipment includes equipment installed at central and/or wayside locations responsible for ATS (non vital) functions such as identifying, tracking, and displaying trains

providing manual and automatic route setting capabilities, and regulating train movements to maintain operating schedules. The ATS subsystem also controls interlockings, by requesting route clearance and displaying the status of track circuits, switches, and signals, and communicates with the zone controllers to implement control actions affecting equipped trains such as blocking sections of track or setting temporary speed restrictions [20].

The line is broken down into multiple controlled zones including associated interlockings and radio transmission cells. Each zone is controlled by a zone controller. Zone controllers receive information from and send commands to interlockings. A zone controller also communicates with all equipped trains within its particular zone through the radio communication network. The train communicates various data to the zone controller including its location and the status of equipment on board. The zone controller in turn communicates commands and data to the train including the movement authority. The movement authority is the section of track through which the train is authorized to proceed subject to maximum speed and other limits both permanent and temporary.

Zone controllers can also detect and track unequipped trains by virtue of track circuit occupancies. The zone controller then manages a “map” of all trains (both equipped and unequipped) in its zone and is able to define movement authorities for all equipped trains [20].

#### **4.2.2. CBTC wayside Equipment**

The CBTC wayside equipment consists of a network of processor-based, wayside controllers installed at central and/or wayside locations. Each wayside controller interfaces to the CBTC train-borne equipment via the CBTC data communication equipment and may also interface to external interlockings and CBTC ATS equipment.

The wayside intelligence for CBTC-related ATP functions, such as movement authority setting based on the tracking of both CBTC-equipped and unequipped trains, as well as other allocated wayside ATP, ATO, and ATS functions resides in the wayside controllers. Train location determination is a train-borne function for CBTC-equipped trains and a wayside function for unequipped trains [49].

The CBTC wayside equipment also includes any track-based equipment necessary to provide a unique absolute positioning reference to the CBTC train-borne equipment.

Trackside CBTC equipment also consists of the track-mounted localization transponders used to provide position fixes to equipped trains. Other trackside equipment consists of conventional signal equipment of the AWS including signals, single rail track circuits, and switch machines [20].

### **4.2.3. CBTC train-borne Equipment**

The CBTC train-borne equipment consists of one or more processor-based controllers and associated speed measurement and location determination sensors. Other parts could be radio receiver and transmitter unit, position unit, MMI unit, locomotive engine interface, recorder unit etc [20].

The CBTC train-borne equipment interfaces to the train subsystems (including train operator displays) and also interfaces to the CBTC wayside equipment and the CBTC ATS equipment via the CBTC data communication equipment.

The CBTC train-borne equipment is responsible for CBTC train location determination, the enforcement of permitted speed and movement authority limits, and other allocated train-borne ATP and ATO functions.

### **4.2.4. CBTC data communication equipment**

The CBTC data communications equipment includes equipment located at central and wayside locations, as well as on-board trains, to support wayside-to-wayside and wayside-to-train data communications (as well as intra-train data communications for those applications where the train-borne equipment consists of multiple processor-based controllers). The data links between the major CBTC subsystems should support bidirectional data transfer and should have sufficient bandwidth and exhibit sufficiently low latency to support all defined ATS, ATP, and ATO functions. The data links should include a protocol structure to support timely and secure delivery of train control messages [49].

The CBTC data communications equipment should not of itself perform any CBTC functions and is not required to be vital.

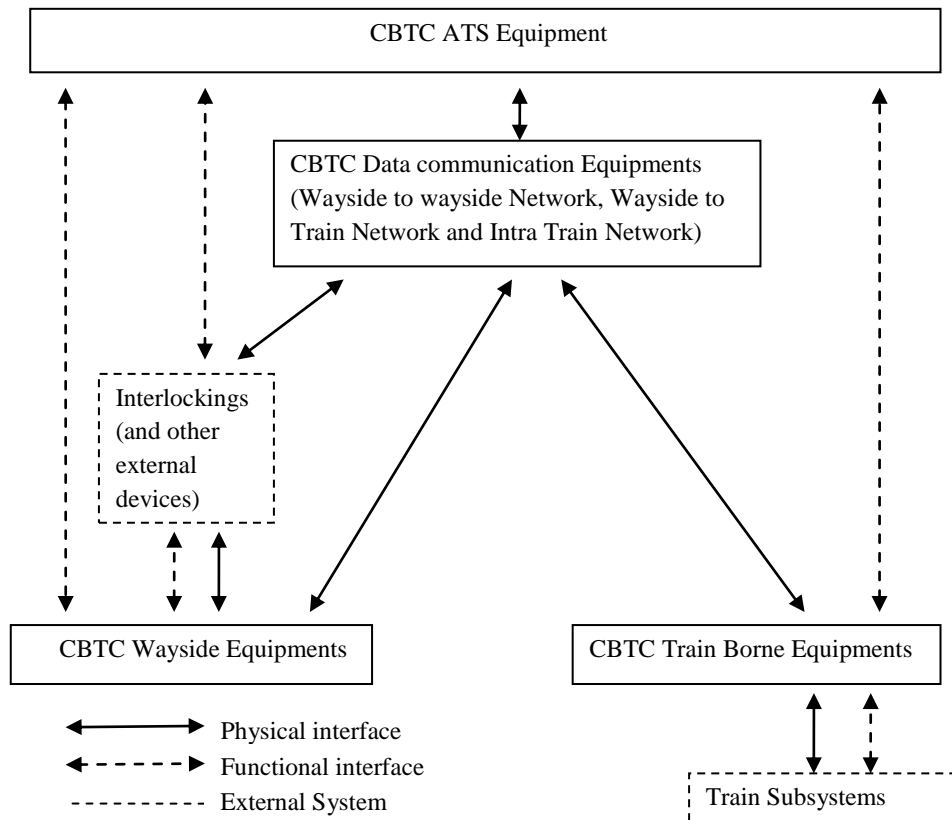


Figure 4.1 Major subsystems of CBTC [49].

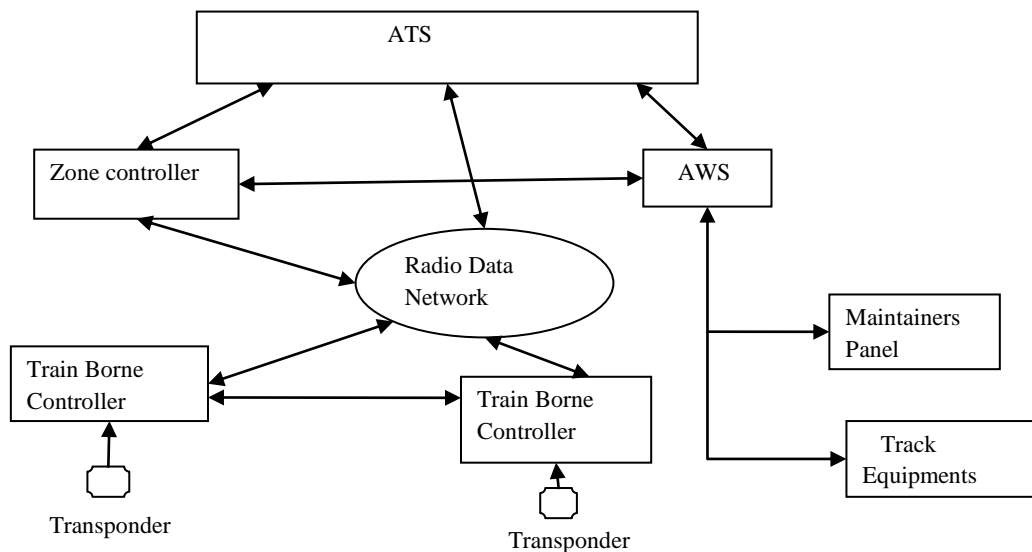


Figure 4.2 System architecture of CBTC [20].

### 4.3. Radio Data Network

Radio-based CBTC is based on a two-way communication network consisting of three integrated networks:

- a. Backbone network
- b. Radio network

c. Train born network

The radio network comprises the train borne radio and antenna equipment and trackside radio access points. Two alternative scenarios are possible for the transmission and reception of the wireless signal by the trackside radio access points:

- a. The waveguide scenario: radio waveguides or leaky cables are installed along the track.
- b. The free propagation scenario: antennas are positioned at distinct points along the track.

For this standard the free propagation scenario is preferable which tends to be the most economical and flexible in terms of deployment and maintenance.

With the free propagation scenario, an antenna network distributed along the track is used to exchange data with the trains via their on-board vehicular antennas. A redundant radio network is implemented in order to increase operational security, reliability and availability.

In terms of hardware, train-to-track radio networks consist of two parts: the trackside equipment and the train borne equipment.

### **4.3.1. Trackside Equipment**

Trackside equipment is built from radio access points distributed along the tracks at intervals ranging from several tens of meters to several hundreds of meters, depending on the track topology, e.g. curves, straight sections, obstacles, etc. Subject to installation constraints, the radio access points and its complementary equipment can be mounted, e.g. on a mast.

#### **4.3.1.1. Fiber optic connectivity**

The radio access points are linked by dedicated, redundant fiber optic distribution loops, thus ensuring high communication safety and availability level in a given zone area. The zone areas are linked by the backbone network and each zone is under the control of a zone controller.

While the fiber capacity of the backbone network is relatively high, that of the distribution loops is generally lower (e.g. 12 or 24 fibers), as the zone areas are limited in size. Alternatively, Cat5 or Cat6 copper cables can be used for the distribution loops in the zone areas. However, fiber optic is often preferred for its intrinsic electromagnetic immunity properties and because of unequalled low signal attenuation.

The radio access points are often directly equipped with a fiber optic connector interface which enables direct connection to the fiber optic distribution loop. Such connectors must have high IP ratings (typically IP 67/68), robust design for harsh environments, and compact footprints.

### **4.3.2. Train borne equipments**

Due to the two-way operation of the trains and redundancy requirements, both drivers' cabs are equipped with the same setup, i.e. on-board ATC equipment and radio modems.

Vehicular directional antennas are installed in the near area of each driver's cab and are connected to the radio modems via RF low-loss cable assemblies. The radio modems provide the communication signal to the on-board ATC equipment.

Both antennas and RF cable assemblies must comply with the requirements of the rolling stock industry for on-board electronic equipment (EN 50155) as well as fire safety requirements (e.g. CEN/TS 45545, NF F 16-101, DIN 5510, BS 6853, UNI CEI 11170).

#### **4.3.2.1. Connectivity components for train borne networks**

The on-board equipment in both drivers' cabs continuously checks with each other that it receives identical information from the trackside equipment. The required continuous communication is provided by a dedicated on-board CBTC bus also called backbone network.

State-of-the-art Ethernet backbones can be implemented as copper Cat5, Cat6 or fiber optic cabling. They must obviously also meet special fire and smoke requirements, according to the railway standard CEN/TS 45545 but also provide a sustainable mechanical robustness at the connection points between the train vehicles as these areas are exposed to high levels of environmental stress (dynamic movements, high temperature variations, water, etc,...).

The physical layer of backbone networks consists of single mode fiber optic cables having a relatively high capacity (e.g. 96 fibers) and specific characteristics due to the operating environment (tunnels and/or outdoor installation). In particular, these cables must be made of selected sheath materials in order to:

- ❖ Comply with stringent fire and smoke performance requirements.
- ❖ Resist fluids such as acid, alkali and tunnel-cleaning products.

- ❖ Be protected against rodents (armored cables).

In the technical rooms or at interconnect points; the fiber capacity of these cables is organized into fiber management systems in order to ensure safe, user-friendly and error-free interconnections with any type of service and application [48].

The radio networks typically operate in the 2.4 GHz or 5.8 GHz frequency ranges.

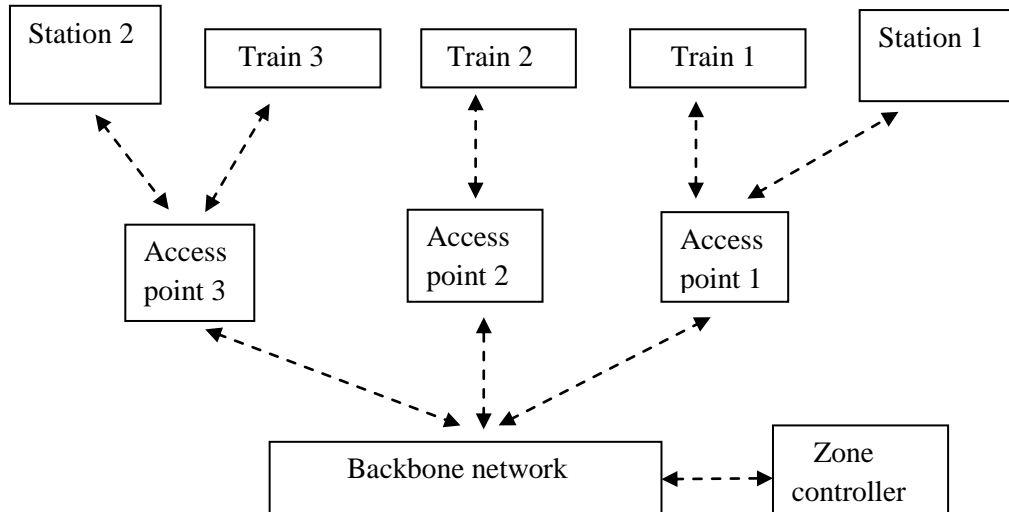


Figure 4.3 Wireless communication in CBTC system [50].

#### 4.4. User interface requirements

A CBTC system may be the only train control system in a given application, or may be integrated or interfaced with other train control systems. The CBTC user interfaces are intended to:

1. Optimize, assist, and enhance the user's performance in normal and abnormal operating conditions.
2. Provide for simplicity of design and consistency in the presentation of information and human computer interaction.
3. Be intuitive, such that minimal training is required to use the system as intended.
4. Support the user in a manner consistent with the user's skill level.

The CBTC user interface designs shall accommodate a user's expectation of logical and consistent relationships between actions and results. Information shall be integrated and presented in a format or representation that minimizes the time required to understand and act on the information, and in a form that directly supports the variety and types of decisions that the user makes.

User interface designs shall include capabilities to validate user inputs and detect user errors before they propagate through the CBTC system, and shall allow for easy recovery from error [53].

#### **4.4.1. Display requirements**

The CBTC system shall display information to users in accordance with the prescribed color and display symbol conventions in this standard. In addition, the authority the colors and display symbol conventions for compatibility with other non-CBTC systems. Where not in conflict with color codes specified herein, colors shall accommodate users with color deficient vision [53].

General guidelines for the application of colors on CBTC displays are as follows:

- a. RED-generally utilized for restrictive conditions, critical alarms and other conditions requiring immediate attention, and for conditions well out of tolerance.
- b. GREEN-generally utilized for normal or active states and for conditions that is within tolerance.
- c. YELLOW-generally utilized for minor alarms and conditions that is out of tolerance to a minor extent.

#### **4.4.2. Audible device requirements**

Non-speech signals shall be in the 200 to 5,000 Hz range and ideally in the 500 to 3,000 Hz range. Loudness of sounds used shall be consistent with the ambient sound level, but not so loud that they startle or disrupt the proper response. Loudness should also be consistent with the urgency of the message.

Loudness shall be no more than 30 dBA above ambient noise with a maximum overall level of 100 dBA.

The use of sounds that could be confused with operational or malfunction noises (e.g., train borne air brake releases or inverter operations, or audible alarms from other systems in a control center environment, etc.) shall be avoided. [53].

### 4.4.3. User interface information requirements

The CBTC train borne displays shall include both fixed and dynamic information. Information to be presented shall include certain mandatory data associated with safe train movement. Optional operations related data may also be displayed to the extent specified by the National Railway Authority. The information to be displayed, the user information inputs and the available audible alarms shall also be dependent on the operating mode of the train (e.g., manual or automatic train operations) [53].

#### 4.4.3.1. Mandatory display data

Mandatory data to be displayed on the CBTC train borne display screen(s) shall include [53]:

- a. Train operating mode.
- b. CBTC operational status (for example, as a result of verification checks of the train borne CBTC equipment performed prior to entering CBTC territory).
- c. Current CBTC-determined train speed.
- d. Current maximum authorized CBTC speed (i.e., ATP profile speed at the CBTC-determined train location).
- e. Over speed condition alarm (when the current CBTC-determined train speed is within a predefined tolerance of the current maximum authorized CBTC speed).

#### 4.4.3.2. Optional display data

Optional data to be displayed on the CBTC train borne display screen(s) may include [53]:

- a. Fixed territory related information (such as location of stations, interlockings any highway grade crossings, CBTC territory limits, and other fixed alignment related information, such as curves and grade).
- b. Train type.
- c. Train run identity/train destination.
- d. Train location and/or track designation.
- e. Train length.
- f. Reason for movement authority limit (e.g., train ahead).
- g. Target speed, i.e., value of an upcoming speed reduction permanent or temporary) or zero speed target for upcoming movement authority limit.

- h. Speed profile to an approaching movement authority limit, speed reduction or work zone.
- i. Distance to an approaching movement authority limit, speed reduction or work zone.
- j. Required brake rate to an approaching movement authority limit, speed reduction or work zone.
- k. Time to a penalty brake application if the train operator fails to respond to an upcoming speed reduction.
- l. Penalty over speed condition alarm (when the current CBTC-determined train speed exceeds the current maximum authorized CBTC speed, resulting in an immediate automatic brake application).
- m. Train route through interlocking(s).
- n. Train regulation information such as the remaining dwell time for a train at a station platform, train performance level and/or optimum train speed profile may also be displayed for trains traveling between stations, to facilitate adherence to train run-time schedules.
- o. Information related to unscheduled train stops between stations.
- p. Train properly aligned at a designated station stopping point.
- q. Station management related information such as train to stop at next station train to skip next station, train to hold at station, train door status (open/closed) and indication of on which side of the train door opening is authorized.
- r. Highway grade crossing warning related information to support the functional requirements of highway grade-crossing warning.
- s. Detected parted consist condition.
- t. Fault report-related information.
- u. Text messages from a CBTC non-train borne subsystem communicated over the CBTC wayside-to train data link.
- v. Time and date.

#### **4.4.3.3. Mandatory user information inputs**

- a. Operating mode selection.
- b. Over speed alarm condition acknowledgement.

#### 4.4.3.4. Optional user information inputs

Optional user information inputs may include [53]:

- a. CBTC user login parameters.
- b. Train type.
- c. Train length.
- d. Train run identification/train destination.
- e. Crew identification.
- f. ATO start.
- g. Performance level modifications.
- h. Highway grade crossing warning related inputs to support the functional requirements of highway grade crossing.

#### 4.4.3.5. Mandatory audible alarms

Mandatory audible alarms shall include:

- a. Over speed condition

#### 4.4.3.6. Optional audible alarms

Optional audible alarms may include [53]:

- a. Penalty over speed condition.
- b. Transitions into and out of CBTC territory.
- a. Detected parted consist condition.
- b. Approaching work zone
- c. Any train length entered by the train operator, in conflict with train length detected by the CBTC system.

#### 4.4.4. Non-train borne subsystems interface

A CBTC system may optionally include, and/or interface to, operations-related user interface facilities at a central location and/or distributed at various locations along the wayside. Certain non-train borne, operations- related user interface facilities are considered mandatory whether these functions are implemented by a CBTC subsystem, or by other non-CBTC equipment, is optional.

The non-train borne operations-related user interfaces shall be capable of displaying all information [53].

#### **4.4.4.1. User information interface requirements**

The non-train borne operations-related display(s) shall include both fixed and dynamic information and shall be fully integrated with other conventional ATS and non-ATS user interface facilities to support overall service management for the transit system, and provide for a single consistent user interface [53].

#### **4.4.4.2. Mandatory display data**

Mandatory data to be displayed on the non-train borne display screen(s) shall include [53]:

- a. Fixed territory related information such as the track plan, including interlocking configurations, location of stations, location of any highway grade crossings, and location of CBTC territory limits.
- b. Train status related information such as train attributes, train operating mode and train location (including sequence of trains on the track relative to other trains), for all CBTC-equipped train operating in the CBTC territory.
- c. Train movement authority/routing information such as CBTC movement authority information for each CBTC-equipped train, to include authority limit, route established through interlocking(s) and currently authorized travel direction.
- d. Information related to restricted train operations such as work zone information, blocked tracks/ switches and temporary speed restriction limits and values.

#### **4.4.4.3. Optional display data**

Optional data to be displayed on the non-train borne display screen(s) may include [53]:

- a. Fixed alignment related information, such as permanent operating speed limits and location of emergency access points.
- b. Current train speeds.
- c. Train crew information.
- d. Location of trains not equipped with train borne CBTC equipment and/or trains with inoperative train borne CBTC equipment may be displayed if this data is available from a secondary train location determination system capable of establishing if a section of track is occupied by one or more trains.
- e. CBTC maximum authorized speed.

- f. Service performance related information necessary to monitor and regulate the performance of CBTC-equipped train operating in CBTC territory, in relation to schedule and/or headway adherence. This may include train destinations/trip plan, train line-ups entering/leaving service, schedule status for each train (early/late), headway status, and remaining dwell times for trains at stations, as well as station management related information such as: train to stop at next station; train to skip next station; train to hold at station and train door status (open/closed).
- g. ATP profile violations, and any other events that result in a penalty brake application on a train.
- h. Failures and out-of-tolerance conditions detected by, or input to, a CBTC system that can impact the on-time performance of the transit system or result in some other loss of specified CBTC functionality.
- i. Status of elements of any auxiliary wayside system.

#### **4.4.4.4. Mandatory information inputs**

Mandatory user information inputs shall include [53]:

- a. Inputs to request and cancel routes, including ability to control and limit movement authorities of CBTC-equipped trains.
- b. Inputs to establish and remove work zones, block track sections/switches and establish temporary speed restrictions.

#### **4.4.4.5. Optional user information inputs**

Optional user information inputs may include [53]:

- a. Inputs to modify schedules/trips of one train, a group of trains and all trains including facilities to hold and release trains at stations, as well as at other locations between stations, and facilities to direct a train, or group of trains, to skip a station stop.
- b. Inputs to adjust the train service braking profiles for CBTC-equipped trains (e.g., in response to wet rail conditions).

## 4.5. Range of application

The CBTC performance and functional requirements defined in this standard are intended to be applicable to the full range of transit applications, including light rail and heavy rail.

## 4.6. Train configuration

A CBTC system shall be capable of supporting a variety of train configurations, including the following:

- a. Fixed-length unidirectional trains comprised of one or more basic operating units
- b. Fixed-length bidirectional trains comprised of one or more basic operating units
- c. Variable-length unidirectional trains
- d. Variable-length bidirectional trains

A CBTC system shall be capable of supporting a mixed fleet of trains, where specific trains and/or classes of trains, have different performance characteristics.

## 4.7. Train operating modes

CBTC-equipped trains may be operated by either a single person or a multi-person crew. A CBTC system may also be required to support operation of trains without crews.

For operation of trains with crews, the train operator will typically be stationed in the lead car of the train and will be responsible for moving the train from station to station. With a multi-person crew, the conductor(s) will normally operate from conductor position(s) within the train to operate the train's doors.

A CBTC system shall support single-person train operation by combining the conductor and train operator display information on the train operator's display. For multi-person crews conductor display information shall also be provided on separate conductor displays.

For the purposes of this standard, operation of trains without crews includes both unattended and driverless train operations. With unattended train operations, there would normally be no crew member onboard the train. With driverless train operations, there may be a crew member onboard the train, but normally not in the driving cab. This crew member, if present would normally have no responsibility for operation of the train except for failure recovery.

CBTC-equipped trains (including CBTC-equipped maintenance vehicles) shall be capable of operating in various modes, depending on whether the train is operating in CBTC territory or non-CBTC territory, and depending on the operational status of the train-borne and/or wayside CBTC equipment.

Mixed-mode operation shall also be considered a normal operating mode, to the extent specified by the National Railway Authority. Mixed-mode operation is defined as the simultaneous operation within CBTC territory of CBTC-equipped trains and trains that are not equipped with functional train-borne CBTC equipment (including maintenance vehicles). Mixed-mode operation may be used in one or more of the following ways:

- a. A regularly scheduled mode of operation within CBTC territory
- b. An infrequent, unscheduled mode of operation within CBTC territory
- c. During the transition period only, as a new CBTC system is cut-in
- d. As a result of train-borne CBTC equipment failures

#### **4.7.1. Normal train operating modes in CBTC territory**

##### **4.7.1.1. CBTC-equipped trains**

CBTC-equipped trains operating in CBTC territory shall operate, within ATP limits, under the protection of the CBTC system. The train shall be capable of being controlled manually by a train operator or automatically by the CBTC system (supervised by the train operator, if present), as specified by the National Railway authority. When operating automatically, some functions (such as door operation and train departure initiation) may continue to be the responsibility of the train operator and/or conductor(s), if present.

##### **4.7.1.2. Non-CBTC-equipped trains**

Trains not equipped with train-borne CBTC equipment and/or trains with inoperative train-borne CBTC equipment that are operating in CBTC territory shall operate under the protection of an auxiliary wayside system.

#### **4.7.2. Failure mode train operations in CBTC territory**

For light rail and heavy rail applications operating with crews, it is an operational requirement to continue to move trains safely in the event of CBTC equipment and/or data

communication failures, possibly at reduced operating speeds and/or increased operating headways when compared to normal train operations. As a consequence, a CBTC system shall be designed to support degraded modes of operation in the event of failure and to continue to provide ATP with minimum reliance on adherence to operating procedures.

This shall be achieved through functional elements of the CBTC system itself, an auxiliary wayside system. For all applications, a fall-back plan, based on failure analysis and operating procedures, shall identify train operating modes that will take advantage of the degraded modes of operation and recovery capabilities of the CBTC system. The goal of the plan shall be to eliminate hazards to passengers and staff while continuing to provide passenger service.

Specifically, failure mode train operations in CBTC territory shall address those CBTC system failures affecting the following:

- a. All trains operating within a particular area of control
- b. A particular train operating within any area of control

#### **4.7.2.1. CBTC system failures affecting all trains operating within a particular area of control**

In the event of a CBTC system failure that affects all CBTC-equipped trains operating within a particular area of control within CBTC territory (e.g., wayside CBTC equipment or wayside-to-train data communications failure), trains shall have the capability to provide continued safe operations under the control of a train operator, and

- a. With the protection of an auxiliary wayside system.
- b. Through strict adherence to operating procedures.
- c. A combination of both items a) and b).

When operating in this failure mode, ATP functions that reside within individual train-borne CBTC equipment shall continue to function to the extent safety can be assured.

#### **4.7.2.2. CBTC system failures affecting a particular train operating within any area of control**

In the event of a CBTC system failure affecting a particular CBTC-equipped train operating within any area of control within CBTC territory (e.g., train-borne CBTC equipment failure) that train shall be capable of continued safe operations under the control of a train operator and

- a. With the protection of an auxiliary wayside system.
- b. With the train speed limited by the propulsion system.
- c. Through strict adherence to operating procedures.
- d. A combination of any or all of items a), b), and c).

When operating in this failure mode, ATP functions that reside within wayside CBTC equipment and within other train-borne CBTC equipment shall continue to function to the extent safety can be assured.

### **4.7.3. Normal train operating modes in non-CBTC territory**

For the purposes of this standard, non-CBTC territory is defined as any territory that is not equipped with wayside CBTC equipment fully compatible with the train-borne CBTC equipment.

CBTC equipment installed on trains operating in non-CBTC territory shall include the necessary capabilities to support transitions into CBTC territory. Train borne CBTC equipment may also perform other ATP functions while operating in non-CBTC territory such as limiting train speed and/or providing zero speed detection.

Train-borne CBTC equipment operating in non-CBTC territory may also interface with wayside equipment that is not fully compatible with the train-borne CBTC equipment.

### **4.7.4. Failure mode train operations in non-CBTC territory**

Except where specified to perform certain ATP functions while operating in non-CBTC territory, failure of the train-borne CBTC equipment shall have minimal impact on train operation. The failure shall be indicated to the train operator.

## **4.8. Entering/exiting CBTC territory**

### **4.8.1. Entering into CBTC territory**

A CBTC system shall have precise knowledge of the limits of CBTC territory and shall include the capability to perform verification checks of the train-borne CBTC equipment prior to entering CBTC territory. The checks shall be performed sufficiently in advance of

entry into CBTC territory to verify the proper operation of the train-borne CBTC equipment (including any wayside CBTC equipment dependencies).

If the verification check is passed, an indication to this effect shall be provided. Under normal circumstances and subject to ATP constraints, it shall not be necessary for a train to come to a stop when entering CBTC territory unless required for other operational reasons.

In the event that the verification check fails, an indication of the CBTC system failure shall be provided, and train operation may revert to the auxiliary wayside signal system. The results of the verification checks shall be displayed on the ATS user interface. For trains operating with crews, the results of the verification checks shall also be indicated to the train operator.

#### **4.8.2. Exiting from CBTC territory**

For trains operating with crews, prior to exiting CBTC territory, a CBTC system may provide a visual indication to the train operator of time and/or distance until the train will be exiting the CBTC territory. When known by the CBTC system, the train operator may also receive an indication of the type of train control system into which the train will be traversing.

Under normal circumstances and subject to ATP constraints, it shall not be necessary for a train to come to a stop when exiting CBTC territory unless required for other operational reasons.

### **4.9. Train operating speeds**

A CBTC system shall be capable of meeting the performance and functional requirements of this standard, over the full range of possible train operating speeds specified by the National Railway Authority.

### **4.10. Performance requirements**

#### **4.10.1. CBTC factors contributing to achievable headways**

The required design and operating headways (i.e., the minimum and scheduled headways) for both normal and reverse directions shall be specified by the National Railway Authority.

Headway may be specified as uninterfered and/or interfered. In all cases, the design headway shall be constrained by the safe train separation requirements and the safe braking model.

In the case of an uninterfered headway, a train speed profile shall not be affected by a preceding train. All trains shall, therefore, perform at the maximum allowed speed, depending on the civil speed limits and the acceleration and braking capabilities of the trains themselves. Operation at uninterfered headways facilitates a minimum end-to-end trip time for a given set of station dwell times.

Headways may be reduced (at the expense of increased trip times) with an interfered headway where a train speed profile is affected by a preceding train such that a following train decelerates on the approach to a station and enters the station area at a reduced speed. Interfered headway may also be specified to support multiple berthings at a station platform.

The design headway for a particular line and a particular set of vehicles involves many factors that are outside the control of the CBTC system (e.g., track alignment, gradients, civil speed limits, train acceleration and braking rates, station dwell times, terminal track configurations, driver reaction times). These factors shall be specified by the National Railway Authority.

This standard addresses only those CBTC factors contributing to achievable headways, of which the most significant are the following:

- a. Location (both accuracy of measured end-of-train locations and resolution of movement authority limits for a given train), including the frequency at which location reports and movement authorities are updated.
- b. Speed, including both accuracy of speed measurement and resolution of speed limits established for a given train at a given location.
- c. Communications delays, including nominal and worst-case transmission times of command/status messages between wayside and train, and vice versa. (Command/status messages include, for example, messages related to movement authority updates and/or location report updates.)
- d. CBTC equipment reaction times, including maximum error accumulation, for both wayside and train-borne equipment, and for various operating modes, as applicable. (CBTC equipment reaction times include, for example, the time required to establish new movement authority limits following location report updates, the time

- to establish new movement authority limits through an interlocking, and the time to determine a new ATP profile following movement authority update.)
- e. CBTC system performance limitations (e.g., the maximum number of trains that can be processed by the CBTC system, within a given area of control).
  - f. CBTC automatic speed regulation algorithm.

## **4.11. CBTC factors contributing to achievable trip times**

Trip time requirements shall be specified by the National Railway Authority, consistent with train performance and track alignment characteristics.

The minimum end-to-end trip times for a defined set of station dwell times will result from uninterfered headway speed profiles. The CBTC factors contributing to achievable headways will also be factors contributing to the minimum achievable trip times.

## **4.12. System safety requirements**

### **4.12.1. CBTC System Safety Program requirements**

A System Safety Program shall be instituted during the CBTC system planning/design phase and shall continue throughout the system life cycle. The CBTC System Safety Program shall emphasize the prevention of accidents by identifying and resolving hazards in a systematic manner. A CBTC System Safety Program Plan (SSPP) shall be developed for each CBTC application. The CBTC SSPP shall be prepared in accordance with the requirements of table 4.1 below.

Table 4.1 Risk assessment of CBTC system

	Hazard severity			
Frequency of occurrence	1-Catastrophic	2-Critical	3-Marginal	4-Negligible
A-Frequent	Unacceptable(1A)	Unacceptable(2A)	Unacceptable(3A)	Undesirable(4A)
B-Probable	Unacceptable(1B)	Unacceptable(2B)	Undesirable(3B)	Acceptable with review (4B)
C-Occasional	Unacceptable(1C)	Unacceptable(2C)	Acceptable with review(3C)	Acceptable with review(4C)
D-Remote	Unacceptable(1D)	Unacceptable(2D)	Acceptable with review(3D)	Acceptable without review(4D)
E-Improbable	Undesirable(1E)	Undesirable(2E)	Acceptable without review(3E)	Acceptable without review(4E)

Implementation of the CBTC SSPP shall specifically recognize configuration management issues, given the importance of software and hardware configuration control in maintaining system safety.

#### **4.12.2. CBTC hazard identification and risk assessment process**

Hazard analyses shall be employed during the design of a CBTC system to assist in the identification and evaluation of potential hazards to assess their likelihood and severity and to document their resolution. As a minimum, a preliminary hazard analysis (PHA) shall be conducted for each new CBTC system project.

All hazards identified through the CBTC System Safety Program shall be assessed in terms of the severity or consequence of the hazard and the probability of occurrence. Risk assessment estimates shall be used as the basis in the decision-making process to determine whether individual system or subsystem hazards shall be eliminated, mitigated, or accepted. This process shall include full documentation of the hazard resolution activities.

Hazards shall be resolved through a design process that emphasizes the elimination of the hazard. The effectiveness of the hazard resolution strategies and countermeasures shall be monitored to determine that no new hazards are introduced. In addition, whenever substantive changes are made to the system, analyses shall be conducted to identify and resolve any new hazards.

As a minimum, a CBTC system shall address the following critical/catastrophic system hazards through the implementation of the ATP functions.

- a. Train-to-train collisions (rear-end, sideswipe, head-on); hazard to be addressed through train separation assurance, rollback protection, parted consist protection route interlocking protection, and traffic direction reversal interlocks.
- b. Train-to-structure collisions; hazard to be addressed through end-of-track protection and restricted route protection.
- c. Train derailments; hazard to be addressed through over speed protection, route interlocking protection, and broken rail detection.
- d. Collisions between trains and highway vehicles (where highway crossing at grade exists within the limits of CBTC territory); hazard to be addressed through grade-crossing warning devices that may include interfaces to the CBTC system.
- e. Hazards to work crews and work trains; hazards to be addressed through CBTC work zone protection functions.
- f. Hazards to passengers associated with train movement with train doors open hazards to be addressed through interface between the CBTC system and the train door system to provide door opening control protection interlocks ,zero speed detection, and departure interlocks
- g. Hazards associated with collisions with objects on the track; hazards to be addressed through interfaces between the CBTC system and intrusion detection devices.

#### **4.12.3. CBTC vital function**

To eliminate or control to a level acceptable to the authority those hazards judged to be unacceptable or undesirable through the risk assessment process a CBTC system shall include, as a minimum, the vital functions.

All vital functions of a CBTC system shall be designed and implemented in accordance with fail-safe principles. Documentation of the means used, and proof that fail-safe principles have been met and the mean time between hazardous event (MTBHE) requirements of 4.12.2 have been satisfied, shall be required for every CBTC system.

#### **4.12.4. Quantitative CBTC safety performance requirements**

For any CBTC system application, the CBTC wayside and train-borne equipment located within any contiguous portion of a one-way route that can be traversed by a train traveling at the specified maximum authorized speed for one hour or less shall have a total calculated aggregate MTBHE (total of all critical and catastrophic hazards) of at least 109 operating hours. This includes the maximum number of other trains that can be located in this contiguous portion of a one-way route under the specified peak operating headway.

System safety documentation shall support these calculations and substantiate the methodology used to arrive at the result. For the purposes of MTBHE calculations, a hazardous event shall include, as a minimum, the occurrence of any of the specific hazards identified in 4.12.2.

If the end-to-end trip time for a given route is greater than 1 h, the MTBHE requirement for that route would be adjusted proportionately.

#### **4.12.5. Basic safety design principles**

##### **4.12.5.1. Normal transit system operations with no CBTC hardware failures**

A CBTC system shall respond safely and correctly perform all ATP functions within the normal range of inputs and other operating and environmental conditions.

All conditions necessary for the existence of any permissive state or action shall be verified to be present before the permissive state or action is initiated by a CBTC system. The requisite conditions shall be verified to be continuously present for the permissive state or action to be maintained.

System safety shall not depend on the correctness of actions taken or procedures used by operating personnel.

Procedures shall not be considered a substitute for safety functions that are to be vested in specific CBTC components or equipment.

#### **4.12.5.2. Abnormal transit system operations with no CBTC hardware failures**

A CBTC system shall respond safely under conditions of abnormal system loading abnormal/improper inputs, and other abnormal external influences such as electrical mechanical, and environmental factors.

#### **4.12.5.3. Response to CBTC hardware failures**

A CBTC system shall respond safely under conditions of credible hardware failure. Failure to perform a logical operation or absence of a logical input, output, or decision shall not cause an unsafe condition, i.e., system safety shall not depend upon the occurrence of an action or logical decision.

Hazard analyses shall consider all credible CBTC hardware failure modes. Justification shall be provided for conceivable failure modes that are not considered credible. The effect of each credible CBTC failure mode shall be classified as either self-revealing or non-self-revealing as follows:

- ❖ No credible single point CBTC hardware failure, whether self-revealing or non-self-revealing, shall cause an unsafe condition.
- ❖ No credible CBTC hardware failure in combination with one or more non-self-revealing failure shall cause an unsafe condition. In the instance of a non-self-revealing failure, a subsequent failure shall not be considered independent.
- ❖ The probability of a critical or catastrophic hazard arising as a result of combinations of simultaneous independent self-revealing failures shall be considered in the calculated CBTC MTBHE.

#### **4.12.5.4. Recovery from CBTC hardware failures**

A combination of functional elements of the CBTC system itself, an auxiliary wayside system and/or operating procedures shall provide for the safety of train movement under failure conditions, including failure recovery.

### 4.13. System assurance requirements

The ability of a CBTC system to accomplish the functional requirements of this standard under normal conditions and under conditions of equipment failure, is of paramount importance. This part establishes qualitative availability, reliability, and maintainability criteria for CBTC systems and equipment in order to meet or exceed the on-time performance and fleet availability objectives of the authority and thereby minimize delays experienced by passengers. In addressing CBTC equipment failures, a distinction shall be made between the following failure types:

- a. Type 1: Those failures, or combination of failures, that impact on-time performance of the transit system.
- b. Type 2: Those failures, or combination of failures, that do not impact on-time performance of the transit system, but do result in some other loss of specified CBTC functionality.
- c. Type 3: Those failures that do not impact on-time performance of the transit system or result in a loss of any specified CBTC functionality (e.g., because of equipment redundancy).

The CBTC system availability requirement shall include consideration of all type 1 failures as well as the mean time to restore service (MTTRS) for Type 1 failures.

The CBTC system mean time between failure (MTBF) requirements shall include consideration of all Type 1, Type 2, and Type 3 failures.

While system availability, system MTBFF, and system MTBF predictions traditionally consider only hardware failures, measurements of achieved system availability, system MTBFF, and system MTBF shall also consider software errors (i.e., software fails to perform intended function) as well as hardware failures.

The following general recommended practices apply:

- a. Components and materials should be selected and appropriate standards of quality control and test procedures should be employed to ensure the lowest practical hardware failure rates for individual items of CBTC equipment (i.e., maximize the hardware portion of the system MTBF).

- b. Unless non-redundant equipment is sufficiently reliable to satisfy the overall system availability requirements, appropriate levels of equipment redundancy should be employed such that the failure of a single component, processor, or device will not render the CBTC system unavailable or an operationally critical function non operative (i.e., maximize the system MTBFF).
- c. A CBTC system should incorporate degraded modes of operation to minimize the operational impacts of equipment failures and to permit train movements to continue safely (i.e., maximize system availability).
- d. CBTC system downtime or unavailability of an operationally critical function should be minimized through the use of local and remote diagnostic capabilities and appropriate operating and maintenance procedures (i.e., minimize mean time to repair (MTTR)).

#### 4.13.1. System availability requirements

Quantitative CBTC system availability requirements shall be established by the National Railway Authority with appropriate consideration of the impacts of CBTC system and subsystem failures on the operation of the transit system. CBTC system availability calculated as the following

$$\text{CBTC system availability} = \frac{\text{System MTBFF}}{\text{System MTBFF} + \text{System MTTRS}}$$

Where, system MTTRS is the sum of the system MTTR and the mean travel times for maintenance personnel to travel to the site of a failure. With this approach, the National Railway Authority would typically specify the following:

- a. The quantitative CBTC system availability requirements.
- b. The average travel times to be assumed for maintenance personnel to travel to the site of a failure.
- c. The boundaries of the CBTC system covered by the availability requirement.
- d. The type of CBTC failures to be included in defining the system MTBFF.

For a given CBTC system configuration, the predicted CBTC system availability could be determined analytically from estimates of subsystem MTBFFs and MTTRS.

Actual CBTC system availability could be determined from measurements of actual in-service system MTBFF and MTTRS, with appropriate adjustments for factors that are not included within the specified boundaries of the CBTC system.

As specified by the National Railway Authority, system availability analysis/modeling shall be used to predict the system availability for a given CBTC system configuration, based on equipment reliability/ maintainability calculations, equipment redundancy provisions, and other defined assumptions.

As specified by the National Railway Authority, system availability demonstration tests shall be performed to determine actual CBTC system availability over a defined period, to a given confidence level.

#### **4.13.2. Equipment reliability requirements**

Quantitative CBTC system and subsystem MTBF and MTBFF requirements shall be established by the National Railway Authority, consistent with the CBTC system availability requirement.

##### **4.13.2.1. Design life**

CBTC equipment shall have a design life of 30 years. The ability of a CBTC system to remain in operation to the end of its design life will be driven largely by long term availability of spare parts. Specific requirements with respect to spare part availability shall be defined by the National Railway Authority and does not form part of this standard.

#### **4.13.3. Equipment maintainability requirements**

A CBTC system shall be designed to minimize required maintenance (both preventive and corrective) by maximizing the system MTBF and by including features that provide for ease of maintenance by maintenance personnel.

The mean time to repair/replace a failed piece of in-service CBTC equipment (i.e., first-level repair) shall include on-site diagnostics, the replacement of failed components, and the testing of the repaired units, subsystem, or system, but shall exclude travel time to the site. A separate MTTR requirement may be defined for second-level repair (i.e., shop repair of a failed line replaceable unit).

The first-level MTTR shall be no greater than 30 min. The second level MTTR, if specified shall be no greater than 2 h.

Achievable repair times will be driven by equipment diagnostic provisions and available test equipment, as well as the quality of the maintenance manuals and training. A CBTC system shall, therefore, include maintenance and diagnostic capabilities to detect and react to CBTC equipment failures. This shall include remote diagnostics capabilities as well as local built-in test equipment and other fault displays for troubleshooting, and the timely identification of failed components and functions.

Data logging capabilities shall also be provided in wayside and train-borne CBTC equipment. The logged data shall be capable of being analyzed to be able to recreate the sequence of events leading to an incident. This will allow maintenance personnel to identify the cause of any failure and/or miss-operation of CBTC equipment that cannot be identified by the in-built diagnostics of the equipment. The scope of logged CBTC events shall be established by the National Railway Authority.

A CBTC system design shall include capabilities to permit periodic verification of ATP hardware, software, and data, including verification of correct response to interference on the train-to-wayside data link. To the extent specified by the National Railway Authority, a CBTC system shall also include capabilities to facilitate modifications (by the user) to CBTC system parameters, track databases, and applications software.

The supplier of the CBTC system shall identify to the authority those specific changes to CBTC system parameters, track databases, and applications software that will have no impact on system safety.

#### **4.14. Functional requirements**

A CBTC system shall include the capability for providing ATP, ATO, and ATS functions. ATP functions shall provide fail-safe protection against collisions, excessive speed, and other hazardous conditions. ATP functions shall have precedence over both the ATO and ATS functions. ATO functions shall control basic operations that would otherwise be performed by a train operator and shall do so within the protection limits imposed by ATP. ATS functions shall provide system status information and the means to monitor and override the automatic control for various functions of the system.

The CBTC train-to-wayside communications interface shall be sufficient to support all required ATP, ATO, and ATS functions. The data link shall provide continuous geographic coverage within CBTC territory and shall support train operations in tunnels, tubes, and cuts on elevated structures, and at grade. The data link shall support bidirectional data transfer and shall exhibit sufficiently low latency to support the defined performance requirements. The data link shall include a protocol structure to support safe, timely, and secure delivery of train control messages.

#### **4.14.1. ATP functions**

All ATP functions shall be vital functions and shall be designed and implemented in accordance with system safety requirements. A CBTC system shall be capable of providing bidirectional ATP.

##### **4.14.1.1. Train location/train speed determination**

CBTC train location/train speed determination shall be a required ATP function for any CBTC system configuration. A CBTC system shall establish the location, speed, and travel direction of each CBTC-equipped train operating in CBTC territory.

CBTC train location determination shall safely and accurately establish the location of both the front and rear of the train. The CBTC train location determination function shall provide sufficient train location resolution and accuracy to support the performance and safety requirements of this standard.

The CBTC train location determination function shall be self-initializing and shall automatically detect and establish the location of each CBTC-equipped train as it enters CBTC territory and on recovery from CBTC equipment failures, without requiring manual input of train location or train length data.

The CBTC train speed determination function shall provide sufficient speed measurement resolution and accuracy to support the performance and safety requirements of this standard. Speed measurement, train location resolution and accuracy parameters are given in table 4.2.

A CBTC system shall compensate for the effects of measurement inaccuracies on train location and speed determination. Specifically, if the CBTC train location/speed determination function is dependent upon wheel rotation, the CBTC system shall correct for

position errors induced by the slipping or sliding of wheels and shall correct for position errors caused by variation in wheel size due to wear, truing, or replacement.

Table 4.2 CBTC parameters [49].

Parameters	Range
Maximum number of trains that can be processed by a single wayside controller	10 to 40 trains
Resolution of measured train location (i.e., as reported to establish movement authority limits for a following train for ATP purposes)	$\pm 0.25$ m to $\pm 6.25$ m
Accuracy of measured train location during normal (non-degraded) operations (i.e., maximum error in reported train location for ATP purposes)	$\pm 5$ m to $\pm 10$ m
Accuracy of measured train location for programmed station stop (ATO) purposes—without platform edge doors	0.25 m
Accuracy of measured train location for programmed station stop (ATO) purposes—with platform edge doors	$\pm 0.05$ m ( $\pm 2$ in)
Resolution of train movement authority limits	$\pm 0.25$ m to $\pm 6.25$ m
Resolution of train speed measurement for ATP purposes	$\pm 0.5$ km/h to $\pm 2$ km/h
Accuracy of train speed measurement for ATP purposes	$\pm 3$ km/h
Resolution of train speed commands (e.g., civil speed limits)	$\pm 0.5$ km/h to $\pm 5$ km/h
Train-to-wayside message communication delays	0.5 s to 2 s (nominal)
Wayside-to-train message communication delays	0.5 s to 2 s (nominal)
Wayside CBTC equipment reaction times	0.07s to 1 s ((nominal)
Train-borne CBTC equipment reaction times	0.07 s to 0.75 s (nominal)
Rollback detection criteria	0.5 m to 2 m
Zero speed detection criteria	< 1 km/h to <3 km/h for 2 s

#### 4.14.1.2. Secondary train location determination

An auxiliary wayside system may provide secondary train location determination to establish if a section of track is occupied by one or more trains, including trains not equipped with train-borne CBTC equipment and/or trains with inoperative train-borne CBTC equipment. It

will not be necessary to determine the location of non-CBTC-equipped trains, or trains with inoperative train-borne CBTC equipment, to the same accuracy as CBTC-equipped trains.

#### **4.14.1.3. Safe train separation**

Safe train separation shall be a required ATP function for any CBTC system configuration. Safe train separation shall be provided between all trains operating in CBTC territory whether or not the trains are CBTC equipped.

A CBTC system shall provide safe train separation between CBTC-equipped trains. Safe train separation shall be based upon the principle of an instantaneous (brick wall) stop of the preceding train.

For mixed-mode operation, safe train separation shall be provided through an auxiliary wayside system and/or through strict adherence to operating procedures.

If secondary train location determination is provided through an auxiliary wayside system then for a CBTC-equipped train following a non-CBTC-equipped train or a train with inoperative train-borne CBTC equipment, a CBTC system shall limit the movement authority of the following train to the boundary of the section of track occupied by the non-CBTC equipped or failed train. The CBTC system may further limit the movement authority to the route entry point of a route occupied by the non-CBTC-equipped train or failed train.

The CBTC safe train separation function shall consist of the following:

- a. The calculation of the ATP profile (i.e., the profile of safe speed as a function of train location), derived from fixed ATP data (e.g., permanent speed limits) and variable ATP data (e.g., temporary speed limits and movement authority limit)
- b. The supervision and enforcement of the ATP profile calculated by the CBTC system

The ATP profile shall be governed by a safe braking model and shall ensure that under no circumstances (including failures) will the movement authority limit be exceeded by a CBTC-equipped train.

The movement authority limit shall be the most restrictive of the following:

- ❖ The rear of a CBTC-equipped train ahead (as determined by the CBTC train location function), with allowance for any location uncertainty.
- ❖ The boundary of a section of track occupied by a non-CBTC-equipped train or a train with inoperative train-borne CBTC equipment determined by an auxiliary wayside system.
- ❖ The end-of-track.
- ❖ The entrance to an interlocking, when the route is not verified as aligned and locked.
- ❖ The boundary of a section of track with an opposing traffic direction established.
- ❖ The boundary of a blocked track.
- ❖ The entrance to a highway grade crossing where warning devices are not confirmed to be operating.
- ❖ The entrance to a route that is detected to be unsafe for train movement.

If specified by the National Railway Authority, the CBTC safe train separation function shall support automatic close-up of trains and automatic coupling and uncoupling of trains in designated areas.

If specified by the National Railway Authority, facilities may be provided to bypass the CBTC safe train separation function to allow a train, under the control of a train operator, to travel beyond its movement authority limit (e.g., at a restricted speed), for failure recovery purposes.

If specified by the National Railway Authority, facilities may be provided to pull back (i.e. make more restrictive) a movement authority limit previously granted to a train. If the train were approaching or braking toward the original movement authority limit, the train may be in violation of the new ATP profile. Under such circumstances, a CBTC system shall initiate an immediate brake application. The brake application may be an immediate emergency brake application or a supervised service brake application.

#### **4.14.1.4. Safe braking model**

A safe braking model shall be developed for each CBTC application. The safe braking model shall, as a minimum, include consideration of the following:

- a. Location uncertainty of lead train (including rollback tolerance)

- b. Location uncertainty of following train
- c. Train length
- d. Train configuration
- e. Allowable over speed permitted by the CBTC system
- f. Maximum CBTC speed measurement error
- g. CBTC system reaction times and latencies
- h. Maximum train acceleration rate possible at the time an over speed condition is detected by the CBTC system
- i. Worst-case reaction times to disable the propulsion system and apply the emergency brakes following detection of an over speed condition by the CBTC system
- j. Guaranteed emergency brake rate (GEBR)
- k. Grade

A CBTC system shall have the capability to support multiple safe braking models to accommodate different train acceleration/braking rates for different classes and configurations of trains operating simultaneously within CBTC territory and to accommodate automatic close-up and automatic coupling/uncoupling capabilities. A CBTC system shall incorporate appropriate protection to ensure that the correct safe braking model is applied for a given train at a given location.

#### **4.14.1.5. Over speed protection and brake assurance**

Over speed protection shall be a required ATP function for any CBTC system configuration. In establishing, supervising, and enforcing the ATP profile, as governed by the safe braking model a CBTC system shall ensure that under no circumstances, including failures, will the train's actual speed exceed its safe speed. The safe speed shall be derived by considering the most restrictive of the following:

- a. The permanent speed limits on sections of track within the ATP profile
- b. Any temporary speed restrictions on sections of track within the ATP profile
- c. Any permanent speed restriction applicable to the particular class or configuration of train
- d. Any speed restrictions enforced on the train because of train-borne failure conditions

- e. The maximum speed that would allow the train to stop safely prior to the limit of the train's movement authority or to slow down sufficiently to meet appropriate permanent or temporary speed restrictions upon entering that section of track

Speed limits and restrictions shall apply when any portion of the train is within the speed limit area. Speed limit/speed restriction resolution parameters for CBTC systems are given in table 4.2.

Enforcement of the calculated ATP profile shall be achieved by comparing the CBTC-determined train speed with the ATP profile speed at the CBTC-determined train location. If the ATP profile speed at that location is exceeded, the CBTC system shall initiate an immediate brake application.

The brake application may be an immediate emergency brake application or a supervised service brake application, as specified by the National Railway Authority. In the latter case, a CBTC system shall monitor the achieved brake rate to ensure an acceptable brake rate is achieved within a predetermined time frame; if not, it shall immediately apply the emergency brakes. The safe braking model shall include appropriate allowances for reaction times associated with this brake assurance function.

#### **4.14.1.6. Rollback protection**

Rollback protection shall be a required ATP function for any CBTC system configuration. A CBTC system shall monitor actual train travel direction and shall compare measured travel direction with the CBTC established/commanded direction of traffic. Train motion against traffic for more than a specified rollback tolerance shall result in the CBTC system initiating an emergency brake application. Rollback detection criteria for CBTC systems is given in table 4.2.

#### **4.14.1.7. End-of-track protection**

End-of-track protection shall be a required ATP function for any CBTC system configuration that permits the operation of trains up to, or in close proximity to, an end-of-track terminus. End-of-track protection shall be incorporated into, or function in conjunction with, over speed protection to prevent trains from over-traveling the end-of-track or, if buffers are specified, to prevent trains from exceeding the design limits for impact with an end-of-track buffer. End-of-track protection design shall be based on the safe braking model.

#### **4.14.1.8. Parted consist protection and coupling and uncoupling of trains**

Where separate vehicles can be coupled together in a consist of two or more vehicles or units to form a train, a CBTC system shall have the capability of detecting and protecting parted trains. Parted consist protection shall be required regardless of whether the individual vehicles or units are considered to be permanently coupled or whether they are routinely uncoupled for maintenance or operational purposes.

CBTC system shall also support operating requirements for coupling and uncoupling of trains, including automatic update of the consist length within the CBTC system.

A CBTC system may assume a fixed, worst-case, maximum train length for a given class of trains operating in CBTC territory, with a reliance on operating procedures to ensure this maximum train length is not exceeded.

#### **4.14.1.9. Zero speed detection**

Zero speed detection shall be a required ATP function for any CBTC system configuration. Zero speed detection criteria for CBTC systems and applications are given in table 4.2.

#### **4.14.1.10. Door opening control protection interlocks**

If trains are operated with crews, door open control protection interlocks may be a required ATP function. For operation of trains without crews, door open control protection interlocks shall be mandatory. These interlocks, if provided, shall ensure that the following conditions are satisfied prior to enabling the opening of the train doors (and platform doors, if fitted):

- a. The train is “properly aligned” at a designated stopping point, where the designated stopping point and required tolerances shall be as specified by the National Railway Authority.
- b. There is a platform on the side of the train for which the door opening is allowed.
- c. Zero speed is detected.
- d. The train is constrained against motion.

Selective door open enable shall be possible for those applications where the train length exceeds the platform length. Facilities may be provided for a local manual bypass of the preceding door open control protection interlocks, for failure recovery purposes.

#### **4.14.1.11. Departure interlocks**

If trains are operated with crews, departure interlocks may be a required ATP function, at the option of the National Railway Authority. For operation of trains without crews, departure interlocks shall be mandatory.

These interlocks, if provided, shall prevent a stationary train from moving (e.g., by disabling the propulsion system) unless all train doors (and platform edge doors, if fitted) are properly closed and locked. [51].Facilities may be provided for a local manual bypass of the preceding departure interlocks, for failure recovery purposes.

#### **4.14.1.12. Emergency braking**

The train's emergency brake system shall be capable of bringing the train to a stop within the assured stopping distance determined by the safe braking model. Specific criteria for resetting the emergency brakes to allow normal operation to resume shall be specified by the National Railway Authority.

If conditions (as determined by ATP) are not correct for train movement, the emergency braking shall remain applied regardless of any reset signals or actions, except that facilities may be provided for a local manual bypass of the ATP functions for that train to permit manual train operation for failure recovery purposes.

Use of such facilities shall require strict adherence to operating procedures to ensure the safety of train movements. If correct ATP conditions exist after the emergency brakes have been reset, the train shall be permitted to move or continue to move; however, if the actual train speed again exceeds the ATP profile speed or a subsequent malfunction occurs emergency braking shall be applied as before.

#### **4.14.1.13. Route interlocking**

A CBTC system shall provide route interlocking functions equivalent to conventional interlocking practice to prevent train collisions and derailments. These functions shall include locking of the route in advance of the train entering the interlocking (time or approach locking) and once the train is in the interlocking (route locking).

The switches shall also be locked when the track section containing the switch is occupied by a train (detector locking). Locking functions shall also apply to moveable bridges and similar

right-of-way apparatus. Sectional release (of routes behind a train) may be provided where specified by the National Railway Authority.

A movement authority shall not be advanced into an interlocking until the appropriate route is set and locked. Once a movement authority has been advanced through an interlocking, the affected route shall not be released and conflicting routes cleared unless either the train has traveled through and is verified clear of the interlocking or the movement authority is pulled back short of the interlocking and is in effect.

Where an auxiliary wayside system is specified, interlocking functions may be provided by separate interlocking equipment, which is based on train position established by a secondary train detection subsystem. In this case, a CBTC system shall interface to and may modify the conventional interlocking functions based on train position established by the CBTC train location determination function, to safely enable the enhanced performance capabilities of a CBTC system to be realized.

#### **4.14.1.14. CBTC interfaces to a separate interlocking**

Where an auxiliary wayside system or separate interlocking is specified, a CBTC system shall interface to interlockings as follows:

- a. Time or approach locking shall apply, except in the event of a route being canceled for an approaching CBTC train (i.e., the movement authority is pulled back short of the interlocking and is in effect). In this case, if the train is greater than a safe braking distance from the entrance to the interlocking (as determined by the safe braking model) or the train stops prior to entering the interlocking, the route shall be released without running further time.
- b. Traffic locking may be overridden so that CBTC-equipped trains may move in opposing directions within their respective movement authorities on the same track at the same time.
- c. Wayside signals and their aspects are provided. A CBTC system may override the conventional aspects to cause the signal(s) to display CBTC aspect(s) only to CBTC-equipped trains.

#### **4.14.1.15. Responses to CBTC train location failures**

In the event of a failure of the CBTC train location determination function, route locking shall remain in effect until the train is proven to be clear of the interlocking by the CBTC system (i.e., the train is subsequently determined to be clear of the interlocking limits), or through operating procedures, or a combination of both approaches.

In the event of a failure of the CBTC train location determination function in an interlocking where train capable of being detected by means of a secondary system, CBTC system overrides of the interlocking functions may be released, provided route and other locking functions are maintained by the auxiliary wayside system so as to prevent the movement of a switch in front of and under the train until the train is proven to be clear of the interlocking.

#### **4.14.1.16. Response to loss of switch indication**

In the event of a loss of switch indication once a movement authority has been issued through an interlocking, a CBTC system shall pull back the movement authority to the entrance of the interlocking. If a train is already within a safe braking distance of the switch, the CBTC system shall initiate an immediate brake application.

#### **4.14.1.17. Traffic direction reversal interlocks**

Traffic direction reversal interlocks shall be a required ATP function for any CBTC system application requiring bidirectional operations, in order to support reversal of train direction at terminal stations and to support intermediate turn backs and shuttle modes of operation, for example.

It shall not be possible to extend the movement authority for a train into a section of track where an opposing traffic direction has already been established. A reversal of traffic direction within a section of track shall not be possible unless:

- a. All trains within that section of track are at zero speed and constrained against motion in the original traffic direction.
- b. The movement authorities for all trains outside of that section of track do not extend into the section and are constrained from being extended into the section in the original traffic direction.

**4.14.1.18. Work zone protection**

A CBTC system shall not grant movement authorities to trains to operate into out-of-service (blocked) tracks or through switches blocked in other than the required position and shall enforce restricted speeds on approach to and through defined work zones. A CBTC system may also include capabilities to preclude ATO mode of operation through a work zone.

**4.14.1.19. Broken rail detection**

A CBTC system may interface to an auxiliary wayside system for purposes of broken rail detection. A CBTC system's reaction to a detected broken rail shall be as specified by the National Railway Authority.

**4.14.1.20. Highway grade-crossing warning**

Where highway crossings at grade exist within the limits of CBTC territory, a CBTC system may interface to grade-crossing warning devices to permit control of such devices based on CBTC location reports and to coordinate movement authorities through the crossing based on the status from such devices. Specific requirements shall be include the following:

- a. Constant (and consistent) warning times, independent of train speed or acceleration/deceleration
- b. For trains making station stops prior to crossings, delayed activation of the warning devices until the train is ready to depart the station
- c. When a train clears a crossing in multiple track areas, continued activation of the warning devices if a second train would have reactivated the devices within a predefined time interval

**4.14.1.21. Restricted route protections**

A CBTC system shall include capabilities to prevent a train from entering a route that is unsafe for movement of that type of train due to mechanical, civil, electrical, or other predefined temporary or permanent conditions of the train or route, or through interfaces to intrusion detection devices, platform edge doors (where fitted), and/or other devices capable of detecting hazards that impact route integrity.

#### **4.14.2. ATO functions**

For operation of trains without crews, a CBTC system shall, as a minimum, be capable of providing all of the ATO functions as defined in this part, to automatically operate trains in accordance with prescribed operating criteria within the safety constraints imposed by ATP.

For operation of train with crews, the required ATO functions shall be as specified by the National Railway Authority. The CBTC wayside-to-train and train-to-wayside data communications interface shall be sufficient to support all required ATO functions.

##### **4.14.2.1. Automatic speed regulation**

The starting, stopping, and speed regulation of the train as it travels along the track shall be automatically controlled by a CBTC system so that the speed, acceleration, deceleration, and jerk rates are within specified passenger comfort limits and the train speed is below the over speed limits imposed by ATP.

Station stopping accuracy shall be as specified by the National Railway Authority. A CBTC system shall support multiple ATO speeds, acceleration, and service brake rates in accordance with the train operator (if present) or ATS inputs.

##### **4.14.2.2. Platform berthing control**

A CBTC system shall be capable of implementing any of the following platform berthing control modes:

- a. Where the platform length is approximately equal to the train length, a CBTC system shall allow a train to enter a station platform only if there is sufficient room to fully berth or if the preceding train has a movement authority that shall allow it to fully leave the platform area and it has begun to move out of the station (i.e., within ATP constraints, train movement shall be controlled to minimize the likelihood of the train coming to a stop when only partially within the station platform limits).
- b. Where the platform length is longer than the train length, a CBTC system shall support multiple stopping positions within the platform area.
- c. Where the platform length supports multiple train berthings, a CBTC system shall allow a train to enter a platform while another train already occupies an alternative berth.

- d. Where the platform length is shorter than the train length, a CBTC system shall support platform berthings consistent with the door opening control protection interlocks.

#### **4.14.2.3. Door control**

A CBTC system shall be capable of automatically controlling train doors (and platform edge doors, where fitted) during passenger boarding and discharging. Automatic door control may be limited to the following:

- a. Automatic door opening only (with or without passenger door open requests)
- b. Automatic door closing only
- c. Neither automatic door opening nor closing

If automatic platform edge doors are provided, they shall be controlled as a set with the matching train doors such that the train and matching platform edge doors open and close together. It shall be possible to manually disable the operation of any door set (both the train and the matching platform edge door) without affecting the automatic operation of other door sets. The amount of time the train is to remain in the station with doors open may be established by ATS and automatically controlled by ATO.

#### **4.14.3. ATS functions**

A CBTC may interface to, or be integrated with, an ATS system. Under such circumstances, CBTC related ATS functions shall be implemented as defined in this part in order to benefit from the characteristics of a CBTC system namely, the availability of the following:

- ❖ Train location information to a high precision, independent of track circuits
- ❖ Continuous wayside-to-train and train-to-wayside data communications link
- ❖ Train-borne and wayside data processing capabilities

The CBTC-related ATS functions defined in this part shall be fully integrated with other conventional ATS functions and other non-ATS functions to support overall service management for the transit system and provide for a single consistent user interface. The CBTC data communications network, inclusive of the wayside-to-train and train-to-wayside data communications interface, shall be sufficient to support those CBTC-related ATS functions.

#### **4.14.3.1. ATS user interface**

Each ATS user interface shall display all information and implement all control actions. The ATS user shall be able to override any automated CBTC-related ATS functions.

Certain ATS functions (such as stopping a train enroute and the application and removal of temporary speed restrictions, switch/track blocking, or work zones) can potentially introduce system hazards and the specific implementation of these functions shall be considered in the hazard analyses required by CBTC hazard identification and risk assessment process.

ATS functions are not required to be implemented in a fail-safe manner; however, the hazard analyses shall take into account, as a minimum, the probability of

- a. Safety-related commands not being executed when initiated by an ATS user.
- b. The CBTC system prematurely removing safety-related commands initiated by an ATS user.
- c. The CBTC system executing safety-related commands that were not initiated by an ATS user.
- d. Incorrect information being displayed by the CBTC system to the ATS user.

The hazard analyses shall give due consideration of the specific transit application and whether the trains are operated with or without crews. Control action confirmation shall be provided for any safety-related user interfaces/inputs and functions whose inadvertent implementation could have an adverse operational impact.

#### **4.14.3.2. CBTC train identification and train tracking**

Each CBTC-equipped train operating within CBTC territory shall be assigned train identification. This train identification shall indicate the type of train and other pertinent information about the train.

An ATS system shall have the capability to automatically track, maintain records of, and display on the ATS user interface the locations, identities, train schedule, and other pertinent data for all CBTC-equipped trains operating in the CBTC territory.

The front and rear position of trains shall be tracked based on CBTC train location reports and the train location shall be displayed on the ATS user interface. Variations in train length

may be displayed either proportionally or as a standard length icon supplemented by textual train length data.

#### **4.14.3.3. Train routing**

An ATS system shall have the capability to permit CBTC-equipped trains operating in CBTC territory to be manually and automatically routed based on CBTC train location reports and in accordance with the train service data, predefined routing rules, and any ATS user-directed service strategy.

Where applicable to the specific track configuration, automatic routing shall facilitate the proper merging and diverging of trains at junctions, turn back of trains, the movement of trains from/to storage areas, and the rerouting of trains in response to service disruptions and/or planned outages. Train routes shall be indicated on the ATS user interface and may also be indicated to the train operator and/or conductor, if present, on their displays.

An ATS system may also include a means to control and limit movement authorities of CBTC-equipped trains operating in CBTC territory. CBTC movement authority limits shall be capable of being displayed on the ATS user interface, and any uncommanded reductions of authority limits shall be alarmed. For trains operated with crews, movement authority limits may also be indicated to the train operator and/or conductor on their displays.

#### **4.14.3.4. Automatic train regulation**

##### **A. Schedule/headway regulation**

An ATS system may have the capability to automatically monitor and regulate the performance of CBTC equipped trains operating in CBTC territory, in relation to schedule and/or headway adherence.

An ATS system may include an automatic dispatching function (based on train identities CBTC train location reports, scheduled and actual headways between trains, and service strategies implemented by authorized ATS users).

Schedule and headway regulation for CBTC-equipped trains shall be by means of dwell time variance (including train holds) and may also be by control of run times between stations (e.g., through adjustments to train acceleration and service brake rates, and speeds).

For trains operated with crews, the desired station departure time and desired speed profile between stations may be indicated to the train operator and/or conductor on their displays and, when operating in ATO mode, shall be implemented automatically by a CBTC system using the automatic speed regulation function.

An ATS system may provide the capability to adjust the train service braking profiles for CBTC-equipped trains (e.g., in response to wet rail conditions). A CBTC system shall coordinate implementation of requested changes in service braking profiles to avoid conditions that would result in an emergency brake application.

## **B. Junction management**

An ATS system may include automatic train regulation functions, based on CBTC train location reports, to facilitate appropriate train meets (such as transfers between local and express tracks, and at the merge point between different lines) in order to minimize overall system delays.

### **4.14.3.5. Energy optimization**

An ATS system may have the capability to implement energy optimization algorithms for CBTC-equipped trains through the real-time control and coordination of train acceleration, train coasting, and train braking. The priority given to energy optimization versus schedule/headway regulation shall be as specified by the National Railway Authority.

### **4.14.3.6. Station stop functions**

#### **A. Stop train at next station**

An ATS system may include the means to direct a single CBTC-equipped train or a group of CBTC equipped trains to stop at the next station, even if the train is scheduled to bypass that station. For trains operated with crews, a CBTC system may indicate the ATS train stops information to the train operator and conductor on their displays. In ATO mode, a CBTC equipped train shall automatically stop at the next station.

#### **B. Hold train at station**

For trains operated without crews, an ATS system shall include facilities to hold (and subsequently release) a CBTC-equipped train at a station. For trains operated with crews, this

function is optional. If this function is provided, a CBTC system may indicate the train hold information to the train operator and conductor on their displays, and/or prevent a CBTC equipped train from departing the station in ATO mode.

### **C. Skip station stop**

An ATS system may include facilities to direct a CBTC-equipped train or group of CBTC equipped trains to pass through a station or group of stations without stopping. For trains operated with crews, a CBTC system may indicate the skip station information to the train operator and conductor on their displays. In ATO mode, the train shall automatically skip the designated stations.

#### **4.14.3.7. Door control inhibit**

An ATS system may include facilities to inhibit (and subsequently permit) CBTC control of the train doors.

#### **4.14.3.8. Restricting train operations**

The application and removal of the following functions can potentially introduce system hazards and the specific implementation of these functions shall be considered in the hazard analyses required by CBTC hazard identification and risk assessment process.

### **A. Stopping a train enroute**

An ATS system shall provide a means to stop a single CBTC-equipped train or group of CBTC-equipped trains immediately. A CBTC system shall initiate an immediate brake application on the designated trains and notify the train operator and conductor, if present, via their displays.

### **B. Temporary speed restrictions**

An ATS system shall include facilities to impose (and remove) temporary speed restrictions for CBTC equipped trains operating on any section of track in CBTC territory.

### **C. Switch/track blocking**

An ATS system shall include facilities to block (and subsequently unblock) a switch, an exit signal, a route entry point, or a section of track within CBTC territory. A CBTC system shall

prohibit CBTC-equipped trains from receiving movement authorities over blocked switches not aligned in the required position or into routes and/or sections of track that have been blocked.

#### **D. Work zones**

An ATS system shall include facilities to establish (and subsequently remove) temporary work zones for the protection of work crews and work trains. A CBTC system shall enforce restricted speeds on approach to and through defined work zones.

For trains operated with crews, information indicating that the restriction is due to a work zone shall be displayed to the train operator and conductor on their displays and the CBTC system may preclude ATO mode of operation through a work zone.

An ATS system may also provide methods of visually and audibly indicating the approach and direction of trains along the wayside to warn on-track roadway workers in areas where visibility is restricted.

#### **4.14.3.9. Passenger information system interfaces**

An ATS system may interface with wayside and/or train-borne passenger information systems to trigger automatic passenger information messages, such as train arrival information, based on CBTC train location reports.

#### **4.14.3.10. Fault reporting**

##### **A. CBTC fault reporting**

Failures and out-of-tolerance conditions detected by, or input to, a CBTC system that can impact the on-time performance of the transit system or result in some other loss of specific CBTC functionality may be automatically indicated on the ATS user interface display. Any alarms shall be categorized and prioritized into critical and noncritical alarms and logged. All critical alarms shall require acknowledgment.

##### **B. Train fault reporting**

Train-borne CBTC equipment may include interfaces to train-borne subsystems for the purposes of communicating train health data to the wayside for display on the ATS user interface displays.

## 5. Conclusion and Recommendation

### 5.1. Conclusion

This research attempted to set guidelines for automatic train control standard (or have automatic train control standard) of the railway system of Ethiopia basically concerning on track side and on board equipments, interfaces, procedure of exchange of signals between line side and on board equipments and technique of transmission. The standard guidelines for railway system of Ethiopia can be done according to the country topographical condition, level of safety, economic criteria, interoperability, future development of the country on railway system, culture of the people, and capacity of the railway line. From the study of this paper two levels of train control system standards are designed. These are European Train Control System (ETCS) level 1 system B as level 1 train control system and Communication Based Train Control system (CBTC) as level 2 train control system for the railway system of Ethiopia.

1. ETCS level 1 system B train control system is an intermittent bidirectional ATP and good capacity train control system which gives many functional requirements of safety issue. This train control system has different configuration according to the required application as well as this system helps trains to have different configuration which relies on the function they give. The application and use of this system is simple and user friendly. The range of application of this system is wide and the level of protection of train, people and the infrastructure of the railway is good and assured in different countries. This system used for trains which have speeds up to 160km/h. The equipments that this standard uses are updateable to the control system of level 2 of our standard. In this system a fixed block system is used.
2. Communication Based Train Control system (CBTC) A CBTC system is a continuous, automatic train control system utilizing high-resolution train location determination, independent of track circuits; continuous, high-capacity, bidirectional train-to-wayside data communications; and train-borne and wayside processors capable of implementing Automatic Train Protection (ATP) functions, as well as optional Automatic Train Operation (ATO) and Automatic Train Supervision (ATS) functions. This control system gives four grade level of

automation. This system is simple to install and uses the devices that used in level 1 of this standard. Moving block system is applicable in this level control system.

## 5.2. Recommendation for Future Works

The present work has attempted to standardize guidelines for automatic train control system (on board equipments, line side equipments, procedure of exchange of signals between onboard and wayside equipments, interfaces and technique of transmission). However, due to source constraints and time limitations the present research work did not cover detail information on railway system.

In view of this work, it would be desirable to consider the following recommendations for the future work for the development of modern railway system in Ethiopia.

- A. Full scale tests (functional acceptance test, routine tests and acceptance tests) should be set up and carried out in Ethiopia to determine the optimum sufficient fine content for railway automatic train control equipments, signaling and communication systems.
- B. The test procedure of equipments, signaling and communication system are very important issue which should need a special concern and detail study.
- C. The standard issues related to interlocking should be taken as a critical issue in future studies. And in addition the hazard and failures related with interlocking needs a detail investigation.
- D. The standard issues related to spare parts should be taken as critical issue in future studies.

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## 7. Appendixes

### Appendix A: Definitions:

**Dynamic speed profile:** The speed-distance curve which a train may follow without violating the static train speed profile and the end of movement authority. This curve depends on the braking characteristics of the train and the train length.

**End of Authority (EOA):** Location to which the train is permitted to proceed and where target speed is zero.

**MTBSF:** Mean Time between such failures which require restart/maintenance/ repair of system.

**Overlap Distance:** The length of track in advance of a stop signal, which must be kept clear, either for clearing the stop signal next in rear or for the purpose of granting permission to approach. The overlap distance may be different for different types of signals & signaling.

**Static speed profile:** The Static Speed Profile (SSP) is a description of the fixed speed restrictions for a part of track sent from track to train.

**Automatic train operation (ATO):** The subsystem within the ATC system that performs any or all of the functions of speed regulation, programmed stopping, door control, performance level regulation, or other functions otherwise assigned to the train operator.

**Automatic train protection (ATP):** The subsystem within the ATC system that maintains fail-safe protection against collisions, excessive speed, and other hazardous conditions through a combination of train detection, train separation, and interlocking.

**Automatic train supervision (ATS):** The subsystem within the ATC system that monitors trains, adjusts the performance of individual trains to maintain schedules, and provides data to adjust service to minimize inconveniences otherwise caused by irregularities.

**Auxiliary wayside system:** A back-up or secondary train control system, capable of providing full or partial ATP for trains not equipped with train-borne CBTC equipment and/or trains with partially or totally inoperative train-borne CBTC equipment. The auxiliary

wayside system may include train-borne equipment and may also provide broken rail detection.

**Brake, emergency:** Fail-safe, open-loop braking to a complete stop, with an assured maximum stopping distance considering all relevant factors. Once the brake application is initiated, it is irretrievable (i.e., it cannot be released until the train has stopped or a predefined time has passed).

**Brake, (maximum) service:** A non-emergency brake application that obtains the (maximum) brake rate that is consistent with the design of the brake system, retrievable under the control of master control.

**Civil speed limit:** The maximum speed authorized for each section of track, as determined primarily by the alignment, profile, and structure.

**Dwell time:** The time a transit unit (vehicle or train) spends at a station or stop, measured as the interval between its stopping and starting.

**Fail-safe:** A design philosophy applied to safety-critical systems such that the result of hardware failure or the effect of software error shall either prohibit the system from assuming or maintaining an unsafe state or shall cause the system to assume a state known to be safe.

**Headway:** The time interval between the passing of the front ends of successive vehicles or trains moving along the same lane or track in the same direction.

**Interlocking:** An arrangement of switch, lock, and signal devices that is located where rail tracks cross, join, separate, and so on. The devices are interconnected in such a way that their movements must succeed each other in a predefined order, thereby preventing opposing or conflicting train movements.

**Movement authority:** The authority for a train to enter and travel through a specific section of track, in a given travel direction. Movement authorities are assigned, supervised, and enforced by a CBTC system to maintain safe train separation and to provide protection through interlockings.

**Redundancy:** The existence in a system of more than one means of accomplishing a given function.

**Reliability:** The probability that a system will perform its intended functions without failure, within design parameters, under specific operating conditions, and for a specific period of time.

**Safe braking model:** An analytical representation of a train's performance while decelerating to a complete stop, allowing for a combination of worst-case influencing factors and failure scenarios. A CBTC equipped train will stop in a distance equal to or less than that guaranteed by the safe braking model.

**Safety critical:** (A) A term applied to a system or function, the correct performance of which is critical to safety of personnel and/or equipment.(B) A term applied to a system or function, the incorrect performance of which may result in a hazard.

**System safety:** The application of engineering and management principles, criteria, and techniques to optimize all aspects of safety within the constraints of operational effectiveness, time, and cost, throughout all phases of the system life cycle.

**System Safety Program:** The combined tasks and activities of system safety management and system safety engineering that enhance operational effectiveness by satisfying the system safety requirements in a timely, cost-effective manner throughout the system life cycle.

**Vital function:** A function in a safety-critical system that is required to be implemented in a fail-safe manner.

**Authorized speed:** The speed limit at any point along the authorized path of travel up to the target point.

**Driving Cab:** The cab where controls etc. are provided for the Driver to run the locomotive/ train.

**National Values:** These values are the values of different parameters such as maximum permitted speed, speed in shunting mode, speed in OS mode, overlap distance, permitted roll away/reverse movement distance etc. which are based on rules of train operation.

## Appendix B: Residual risk assessment:

### Risk levels

#### Unacceptable (1A/B/C/D, 2A/B/C/D, and 3A)

CBTC systems with residual risks rated at this level are considered unacceptable; hazards must be mitigated through fail-safe designs.

#### Undesirable (1E, 2E, 3B, and 4A)

CBTC systems with residual risks rated at this level are considered undesirable; depending on economic and functional requirements, CBTC systems with hazards rated at this risk level may be considered acceptable with explicit agreement from the authority having jurisdiction.

#### Acceptable with review (3C/D and 4B/C)

CBTC systems with residual risks rated at this level are considered acceptable with review; depending on economic and functional requirements, CBTC systems with hazards rated at this risk level may be considered acceptable with notification to the authority having jurisdiction.

#### Acceptable without review (3E and 4D/E)

CBTC systems with residual risks rated at this level are considered acceptable without review; additional design effort or system revision is not required to reduce the severity or probability of hazards with this risk level.

### Frequency of occurrence

#### A—Frequent

Likely to occur frequently; MTBHE is less than 1000 operating hours.

#### B—Probable

Will occur several times in the life of an item; MTBHE is equal to or greater than 1000 operating hours and less than 100 000 operating hours.

#### C—Occasional

Likely to occur sometime in the life of an item; MTBHE is equal to or greater than 100 000 operating hours and less than 10 000 000 operating hours.

#### D—Remote

Unlikely, but possible to occur in the life of an item; MTBHE is equal to or greater than 10 000 000 operating hours and less than 1 000 000 000 operating hours.

#### E—Improbable

So unlikely, it can be assumed occurrence may not be experienced; MTBHE is equal to or greater than 1 000, 000, 000 operating hours.

### **Hazard severity**

#### 1—Catastrophic

Fatality, system loss, or severe environmental damage.

#### 2—Critical

Severe injury, severe occupational illness, major system or environmental damage.

#### 3—Marginal

Minor injury, minor occupational illness, or minor system or environmental damage.

#### 4—Negligible

Less than minor injury, occupational illness, or less than minor system or environmental damage