An Introductory Handbook on Communications Based Train Control (CBTC)

End Users: Indian Railways Signal Engineers
CAMTECH/S/PROJ/2020-21/SP9/1.0
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Indian Railways
Centre for Advanced Maintenance Technology
Maharajpur, Gwalior (M.P.) Pin Code – 474 005
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Foreword

Conventional railway signalling is based on colour light signals and train detection with the help of track circuits and axle counters. Although this technology is suitable for detection and control of trains it is still not able to utilize the section capacity to its full advantage. Over the last decade, railways have seen a huge transition from conventional railway signalling systems to modern signalling systems. As there are continuous improvements in technology, we need to keep pace with the latest trends and keep ourselves updated.

Communications-Based Train Control (CBTC) is a modern communication-based system that uses radio communication to transfer timely and accurate train control information. CBTC is the choice of mass-transit railway operators today, with over a hundred systems currently installed worldwide. In India also, the CBTC technology is finding applications in Metro railways.

CAMTECH has issued this introductory handbook for Signal & Telecommunication engineers to get them acquainted with the technology used in CBTC and help them in implementing the system suitable for Indian Railways. As this is a new technology, the information given in this handbook is generic, which will be subsequently revised after gaining further experience.

I hope that this handbook will be helpful to S&T engineers of Indian Railways at least in understanding the concept of CBTC. I wish them all the success.

CAMTECH Gwalior
Date: Jitendra Singh
Principal Executive Director
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Preface

Trains are mostly worked on Absolute Block system or Automatic Block system over Indian Railways which have fixed length blocks. These systems maintain unutilized space between two trains running in the same direction. To utilize the track to its maximum capacity, modern communication based systems are used in some countries. CBTC is one such modern, radio communication-based signalling system which enables high resolution and real-time train control information, which increases the line capacity by safely reducing the distance (headway) between trains travelling on the same line, and minimizes the numbers of trackside equipment. CBTC is being introduced on Metro Railways in India. Each Metro is using different communication technology such as LTE, GSM-R, TETRA etc. with different detection devices and interlocking as standby, hence their method of operation may vary slightly from one system to another.

CAMTECH has prepared this handbook to help S&T engineers in understanding the concept of CBTC. A case study of Kolkata Metro is also added to get a better idea of the subject.

We are sincerely thankful to Metro Railway, Kolkata and M/s Efftronics System Pvt. Ltd., Vijayawada, who helped us in preparing this handbook. Since technological up-gradation and learning is a continuous process, you may feel the need for some addition/modification in this handbook. If so, please give your comments on email address dirsntcamtech@gmail.com or write to us at Indian Railways Centre for Advanced Maintenance Technology, In front of Adityaz Hotel, Airport Road, Near DD Nagar, Maharajpur, Gwalior (M.P.) 474005.

CAMTECH Gwalior

Date: Dinesh Kumar Kalame

Director (S&T)
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Issue of correction slips

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CAMTECH/S/PROJ/2020-21/SP9/1.0# XX date .......

Where “XX” is the serial number of the concerned correction slip (starting from 01 onwards).

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Disclaimer

It is clarified that the information given in this handbook does not supersede any existing provisions laid down in the Signal Engineering Manual, Railway Board and RDSO publications. This document is not statuary and instructions given are for the purpose of guidance only. If at any point contradiction is observed, then Signal Engineering Manual, Telecom Engineering Manual Railway Board/RDSO guidelines may be referred or prevalent Zonal Railways instructions may be followed.
Our Objective

To upgrade Maintenance Technologies and Methodologies and achieve improvement in Productivity and Performance of all Railway assets and manpower which inter-alia would cover Reliability, Availability and Utilisation.

If you have any suggestion & any specific comments, please write to us:

Contact person : Director (Signal & Telecommunication)
Postal Address : Centre for Advanced Maintenance Technology,
Maharajpur, Gwalior (M.P.) Pin Code – 474 005
Phone : 0751 - 2470185
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CAMTECH Publications

CAMTECH is continuing its efforts in the documentation and up-gradation of information on maintenance practices of Signalling & Telecom assets. Over the years a large number of publications on Signalling & Telecom subjects have been prepared in the form of handbooks, pocket books, pamphlets and video films. These publications have been uploaded on the internet as well as railnet.

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or click on link
https://rdso.indianrailways.gov.in/view_section.jsp?lang=0&id=0,2,17,6313,6321,6326

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Visit RDSO website at 10.100.2.19
Go to Directorates → CAMTECH → Publications → S&T Engineering
Or click on the link
http://10.100.2.19/camtech/Publications/CAMTECH%20Publications%20Online/SntPub.htm

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In front of Hotel Adityaz, Airport Road, Maharajpur,
Gwalior (M.P.) 474005
## Abbreviations

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<th>Description</th>
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<td>ABS</td>
<td>Automatic Block Signalling</td>
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<td>ACS</td>
<td>Access Control System</td>
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<td>ATC</td>
<td>Automatic Train Control</td>
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<td>ATO</td>
<td>Automatic Train Operation</td>
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<td>ATP</td>
<td>Automatic Train Protection</td>
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<td>ATS</td>
<td>Automatic Train Supervision</td>
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<td>BBRS</td>
<td>Backbone Routers</td>
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<td>BCC</td>
<td>Backup Control Centre</td>
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<td>BO</td>
<td>Block Overlap</td>
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<td>BTM</td>
<td>Balise Transmission Module</td>
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<td>BTS</td>
<td>Base Tranceiver Station</td>
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<td>CBTC</td>
<td>Communications Based Train Control</td>
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<tr>
<td>CC</td>
<td>Carborne Controller</td>
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<tr>
<td>CCTV</td>
<td>Closed Circuit Television</td>
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<tr>
<td>CBI</td>
<td>Computer based Interlocking</td>
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<td>CSS</td>
<td>Customer Switching System</td>
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<td>CTC</td>
<td>Centralized Traffic Control</td>
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<td>DCS</td>
<td>Data Communication System</td>
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<td>DMRC</td>
<td>Delhi Metro Rail Corporation</td>
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<td>DSLD</td>
<td>Double Sided Low Density</td>
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<td>DTO</td>
<td>Driverless Train Operation</td>
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<tr>
<td>FSS</td>
<td>First Stop Signal</td>
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<td>FOTS</td>
<td>Fibre Optics Transmission System</td>
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<tr>
<td>GE</td>
<td>Gigabit Ethernet</td>
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<td>GHZ</td>
<td>Giga Hertz</td>
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<tr>
<td>GoA</td>
<td>Grade of Operation</td>
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<td>GPS</td>
<td>Global Positioning System</td>
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<td>IBS</td>
<td>Intermediate Block Signalling</td>
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<td>IEEE</td>
<td>Institute of Electrical &amp; Electronics Engineers</td>
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<td>KMRCL</td>
<td>Kolkata Metro Rail Corporation</td>
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<td>LCD</td>
<td>Liquid Crystal Display</td>
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<td>LMA</td>
<td>Limit of Movement Authority</td>
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<td>LSS</td>
<td>Last Stop Signal</td>
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<tr>
<td>LTE</td>
<td>Long Term Evolution</td>
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<tr>
<td>MA</td>
<td>Movement Authority</td>
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<tr>
<td>MCS</td>
<td>Monitor &amp; Control Software</td>
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<td>MMI</td>
<td>Man Machine Interface</td>
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<td>MSO</td>
<td>Multiple System Operators</td>
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<td>NMS</td>
<td>Network Management System</td>
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<tr>
<td>OBCU</td>
<td>On Board Controller Unit</td>
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<td>PAS</td>
<td>Public Address System</td>
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<tr>
<td>PIDS</td>
<td>Passenger Information Display System</td>
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<tr>
<td>OCC</td>
<td>Operations Control Centre</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>PD</td>
<td>Primary Digital</td>
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<tr>
<td>PSD</td>
<td>Platform Screen Door</td>
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<tr>
<td>PSTN</td>
<td>Public Switched Telephone Network</td>
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<tr>
<td>PSR</td>
<td>Permanent Speed Restriction</td>
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<tr>
<td>PSC</td>
<td>Central Control Panel</td>
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<tr>
<td>RCS</td>
<td>Radio Communication System</td>
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<tr>
<td>RPM</td>
<td>Revolutions per minute</td>
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<tr>
<td>TOD</td>
<td>Train Overview Display or Train Operator’s Display</td>
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<tr>
<td>TU</td>
<td>Train Unit</td>
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<tr>
<td>RS</td>
<td>Rolling Stock</td>
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<td>SCR</td>
<td>Signal Control Room</td>
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<td>SPAD</td>
<td>Signal Passed at Danger</td>
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<td>SSLD</td>
<td>Single Sided Low Density</td>
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<td>SSP</td>
<td>Static Speed Profile</td>
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<td>STM</td>
<td>Synchronous Transport Module</td>
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<td>STO</td>
<td>Semi-Automatic Train Operation</td>
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<tr>
<td>TETRA</td>
<td>Terrestrial Trunk Radio</td>
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<tr>
<td>TFTD</td>
<td>Thin Film Transistor Display</td>
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<tr>
<td>TMS</td>
<td>Train Management System</td>
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<tr>
<td>TRS</td>
<td>Tag Reader System</td>
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<tr>
<td>TSR</td>
<td>Temporary Speed Restriction</td>
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<tr>
<td>UPS</td>
<td>Uninterrupted Power Supply</td>
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<tr>
<td>UTO</td>
<td>Unattended Train Operation</td>
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<tr>
<td>VOBC</td>
<td>Vehicle On Board Controller</td>
</tr>
<tr>
<td>Wi-Fi</td>
<td>Wireless Fidelity</td>
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<tr>
<td>ZC</td>
<td>Zone Controller</td>
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Terms & Definitions

1. Accelerator
The control used by the driver of a locomotive to regulate the speed is sometimes called the accelerator.

2. Automatic Train Protection (ATP)
Automatic Train Protection (ATP) is a type of train protection system which continually checks that the speed of a train is compatible with the permitted speed allowed by signalling, including automatic stop at certain signal aspects. If it is not, ATP activates an emergency brake to stop the train. In other words it provides Fail safe protection against over speed, collision & other hazardous conditions through train detection, train separation & interlocking. The main functions of ATP are:
- Detection and Prevention of SPAD
- Display of signal aspect, movement authority, target distance and speed.
- Continuous train control.
- Protection for Permanent and temporary speed restriction.

3. Automatic Train Operation (ATO)
Automatic train operation (ATO) is an operational safety enhancement device used to help automate the operation of trains. The degree of automation is indicated by the Grade of Automation (GoA), up to GoA level 4 (where the train is automatically controlled without any staff on board). On most systems, there is a driver present to mitigate risks associated with failures or emergencies. The primary functions performed by ATO are:
- Automatic speed regulation
- Automatic station stopping
- Train and platform door control

4. Automatic Train Supervision (ATS)
Automatic Train Supervision (ATS) is responsible for monitoring and controlling the train system to ensure that it conforms to an intended schedule and traffic pattern in order to optimize railway operations and service reliability. ATS helps to avoid or reduce damage resulting from system abnormalities and equipment malfunctions by performing the following tasks:
- Supervision of train status,
- Automatic routing selection,
- Adjustment of train operations during failures/unsual incidents
- Automatic schedule creation,
- Automatic operations logging,
- Statistics and report generation,
- Automatic system status monitoring,
- Coordination of personnel scheduling for train management.

5. Automatic Train Control (ATC)
The ATC system ensures the following key safety functions; safe train separation, prevention of over-speed derailments, fail safe train detection, broken rail detection, interlocking rules enforcement, hazard response and work zone protection. The overall ATC system is the
combination of Automatic Train Protection (ATP), Automatic Train Operation (ATO), and Automatic Train Supervision (ATS).

6. Cab signalling
Cab Signalling is a railway safety system that communicates track status and condition information to the cab, crew compartment or driver's compartment of a locomotive, railcar or multiple unit. The information is continually updated giving an easy to read display to the train driver or engine driver.

7. Data communication equipment
It communicates data, commands, indications and alarms between ATC subsystems and locations. This consists of connected networks of wireless, fiber optic, and hardwired electronic equipment.

8. Direction of movement of loco
This is the direction of the train as per Loco cab control e.g. Forward or Reverse or Neutral.

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

10. Dwell time
In transportation, dwell time or terminal dwell time refers to the time a vehicle such as a public transit bus or train spends at a scheduled stop without moving. Dwell time is one common measure of efficiency in public transport, with shorter dwell times being universally desirable.

11. Emergency brake
It is fail-safe, open-loop braking to a complete stop, maximum stopping distance is assured, brake is irreversible. It involves shutting off power and full application of brakes without any loss of time.

12. Driverless Train Operation, DTO
In Driverless Train operation (DTO) Starting and stopping are automated, but train attendant operates the doors and drives the train in case of emergencies.

13. Emergency braking distance
Emergency braking distance is the distance travelled by train before coming to a stop by sudden application of brake at one stretch.

14. Grade of Automation (GoA)
The list of automated train systems is ordered in descending order of the degree of automation. It uses the Grade of Automation (GoA) classifications specified by the standard IEC 62290-1. This list focuses heavily on trains in the classical sense used for large-scale railways for passengers and freight.

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<tr>
<th>Grade of automation</th>
<th>Train operation</th>
<th>Description</th>
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<tr>
<td>GoA 0</td>
<td>On-sight</td>
<td>Similar to a tram running in street traffic</td>
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<tr>
<td>GoA 1</td>
<td>Manual</td>
<td>A train driver controls starting and stopping, operation of doors and handling of emergencies or sudden diversions.</td>
</tr>
<tr>
<td>GoA 2</td>
<td>Semi-automatic (STO)</td>
<td>Starting and stopping are automated, but a driver operates the doors, drives the train if needed and handles emergencies. Many ATO systems are GoA 2.</td>
</tr>
<tr>
<td>GoA 3</td>
<td>Driverless (DTO)</td>
<td>Starting and stopping are automated, but a train attendant operates the doors and drives the train in case of emergencies.</td>
</tr>
<tr>
<td>GoA 4</td>
<td>Unattended train operation (UTO)</td>
<td>Starting and stopping, operation of doors and handling of emergencies are all fully automated without any on-train staff. All stations must have platform screen doors.</td>
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16. Headway
Headway is the distance between vehicles in a transit system measured in time or space. The precise definition varies depending on the application, but it is most commonly measured as the distance from the tip (front end) of one vehicle to the tip of the next one behind it. A "shorter" headway signifies closer spacing between the vehicles.

17. Mass Transit System
Mass transit system refers to public shared transportation, such as trains, buses, ferries etc that can commute a larger number of passengers from origin to destination on a no-reserved basis and in lesser time. It can also be termed as Public Transport.

18. Movement Authority
The distance upto which the train is permitted to travel without danger.

19. Moving Block Signalling
In railway signalling, a moving block is a signalling block system where the blocks are defined in real time by computers as safe zones around each train. This requires both knowledge of the exact location and speed of all trains at any given time, and continual communication between the central signalling system and the train's cab signalling system. Moving block allows trains to run closer together, while maintaining required safety margins, thereby increasing the line's overall capacity.

20. On-board Equipment
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 fulfil the ATP functions; non vital equipment is used to fulfil all non ATP functions such as ATO and displays. The equipment includes processors, firmware, software and electronics, operator displays, operator panel, data radios and antennas, transponder/balise antennas, code pick-up antennas, network components, GPS receiver and antennas, tachometers and other sensors.

21. Permanent Speed Restriction (PSR)
For various reasons, although mainly because of track geometry (curvature, etc.), it is necessary to limit the speed at which trains may travel over certain sections of the railway.
These places are subject to what are termed 'permanent speed restrictions' (PSRs). In some instances, different speeds are specified for specific types of trains.

22. **Semi-automatic Operation Mode (STO)**
In STO mode, starting and stopping are automated, but a driver operates the doors, drives the train if needed and handles emergencies.

23. **Service brake**
Service brake is a non-emergency brake application—which is reversible. It involves only the shutting off the power and the gradual application of brakes.

24. **Service braking distance**
It is the distance required to stop the train running at the maximum permissible speed of the line, at such a rate of deceleration that the passengers do not suffer discomfort or alarm.

25. **SPAD**
SPAD stands for 'Signal Passed at Danger' and occurs when a train passes a signal in the 'on' (Red) position without authority.

26. **Static speed profile**
The Static Speed Profile (SSP) is a description of the fixed speed restrictions at a resolution of 5 Kmph for a part of track sent from trackside to train.

27. **Tachometer**
A tachometer is an instrument measuring the rotation speed of a shaft or disk, as in a motor or other machine. The device usually displays the revolutions per minute (RPM) on a calibrated analogue dial or digital display.

28. **Temporary Speed Restriction (TSR)**
The object of a TSR is to reduce the speed of Rail Traffic to ensure safe passage over a Section of Track when the Track is not safe for Normal Speed. A TSR is applied by a Maintenance Representative of concerned department such as Engg. or S&T. A TSR overrides any existing higher speed.

29. **Transponder Tags or Beacons**
Transponder tags or beacons are the devices installed along the track to provide coarse position of the vehicle in a section.

22. **UTO mode**
In Unattended train operation (UTO) mode, the starting and stopping, operation of doors and handling of emergencies are all fully automated without any on-train staff. Train movement is regulated by the Operations Control Centres (OCC) and not by manual train operators.

23. **Wayside Equipment**
This equipment consists of mainly vital equipment located in housings/location box/Relay huts along the right of way (track) including station equipment rooms, train control equipment houses, and signal equipment cases and cabinets.
Chapter I
Control over movement of trains

1.1 Introduction
There are broadly two types of controls which were conceptualized:

(i) Time interval method
In this method the trains running in the same direction will be dispatched at a fixed time interval in succession. The spacing should be such that if a train stops, then, the following train driver can stop short of the preceding train. Thus by having a time interval between trains, a certain amount of control can be achieved. But it is not practicable due to following drawbacks:

(a) Different types of trains like, Express/Mail, passenger, high-speed freight and low speed freight shunting trains are running etc.
(b) The speed of all the trains are not same
(c) The terrain of the country is not same everywhere
(d) The brake power, hauling capacity, load of train is not same for all trains; and
(e) The stopping places of all trains are not the same.

Hence, it is not possible to control the movement of trains under the "Time interval method". A better method of control is called the "Space Interval Method" is adopted.

(ii) Space interval method
In this method the length of track is divided into sections called "Blocks". The entry of a train into the ‘block’ is controlled in such a way that only when it is free, a train can be allowed to enter it. This means that between two consecutive trains, there is a definite space interval. To control the entry of train into the space interval or block a track side "Signal" is required. The signals are provided at entry and exit points of the block. So, with the two controlling points and intercommunication, it is possible to control the entry of a train into a block only when it is vacant.

1.2 Conventional methods of train control
Under space interval method, for safe running of trains, different methods are adopted to control the train movement between two given points, say between two stations, mainly to ensure that no more than one train is permitted in to the block section at a time. There are following systems of train working which are mainly adopted over Indian Railways:
1.2.1 Absolute Block System

- This is the most widely used system on Indian Railways.
- The space between two stations is termed as block section. (typically 6 km or more)
- Entry into the block section is controlled through human agencies in the form of station masters at two stations.
- Train is allowed to leave a station only when block section is free of any train and line clear is obtained from station in advance.

Conditions for line clear are:

(i). On double line, the line must be clear upto First Stop Signal (FSS) plus an adequate distance known as Block Overlap (BO).

(ii). On single line, the line must be clear of trains running in the same direction upto First Stop Signal (FSS) plus an adequate distance or Block Overlap (BO), and is clear of trains running in opposite direction.

If we assume the system of working to be multiple aspect colour light signalling, the adequate distance or Block Overlap (BO) is taken as 180 metres.

![Figure 1: Absolute Block System](image)

### Limitations of Absolute Block System

Although there is space for more trains in the block section, only one train can be dealt in each direction at a time.

Where the Absolute Block Section is long (say 12 -14 km) and frequency of trains is more, a system known as Intermediate Block Signalling (IBS) system is provided.

1.2.2 Intermediate Block Signalling (IBS) System

IBS is an arrangement made on a Double Line Section for increasing the Section Capacity by splitting of a long Block Section into two Sections namely ‘Rear Section’ and ‘Advance Section’ by installing an IB Signal at the point of bifurcation of that running Line with respect to the nominated direction of traffic.
**Limitations of IBS system**

Maximum two Trains can be dealt on a lengthy Double Line Block section on each nominated running line by adopting IBS system.

A more better system in which more than two trains can be dealt is called Automatic Block System.

### 1.2.3 Automatic Block Signalling (ABS) System

- In this system the line between two stations is provided with Continuous Track Circuits or Axle Counters.

- The line between two stations is divided into a series of sections known as "Automatic Block Signalling Section".

- The length of these Automatic Block Signalling sections is normally equal to the braking distance as per the maximum speed permitted in the section.

- Entry into each automatic block signalling section is protected by a colour light Multiple Aspect Stop Signal.
Above Figure 3 illustrates the working of Automatic Block System.

Track Circuits or Axle Counters should control the aspects of the Signal such that:

- It cannot display the `OFF' aspect unless the line is clear not only up to the next stop signal but also for an adequate distance beyond it. The adequate distance referred above is termed as overlap and shall not be less than 120 meters.
- For Signal 1 to assume Yellow - line must be clear for one block and one overlap.
- For Signal 1 to assume Green- line must be clear for two blocks and one overlap.

In other words, minimum one block and overlap must be clear for allowing a train into the block section.

**Limitations of ABS System**

Although in Automatic Block Signalling System there is better utilization of section capacity as compared to the earlier two systems as more trains can be dealt, but full capacity utilization is still not done as shown in the following Figures.

*Safety Distance – Distance required for a train to apply emergency brake to stop under a worst case failure

**Figure 4: Safety distance or applying Emergency brakes in ABS system**

From the above Fig.No.4 it can be seen that, with Train B occupying Block 3, if Train A passes Signal No.2 at danger travelling at 100 Kmph and if it requires 1 Km to stop by applying emergency brakes, the block separating Train A from Train B must be at least 1 Km long to satisfy the safety requirement.
Assuming each block section of 1 Km length, From Fig. above it can be seen that as Train B clears overlap distance beyond Signal 3, Train A will be granted a permissive aspect of Signal No.2. But even if Train B moves further towards Signal No. 4, Train A cannot be granted permissive aspect of Signal No.3 until Train B clears overlap distance beyond Signal No. 4.

Instead, an artificial separation is created between Train A and B, even though Train A can move closer at slow speed and still maintain a safe braking distance. As Train B moves further within block 3, the artificial separation grows.

To summarize we can say that:

- The trains can be closer together, but the fixed blocks prevent Train A from moving.
- If a train is travelling at lower speed say 60 Kmph, it must adhere to the block separation designed for a particular speed say 100 Kmph.
- Due to static design, the signalling system cannot adjust the safety distance to the speed of the trains.
- For a high traffic density section, number of trains that can pass through the system is not optimal.

Another system of fixed block signalling is CAB Signalling which is explained below:
1.2.4 Cab Signalling

This is an enhanced fixed block signalling system. In this system:

- Trackside signals are usually not used.
- Track circuits are used to determine the location of the train.
- The speed and distance to go are displayed on the Train Overview Display (TOD) inside the cab and enforced by the on board Automatic Train Protection (ATP).
- CAB signalling allows for multiple speed profiles within the same block, which means it has the capability to allow a train to move at multiple speeds within a block.
- CAB signalling does not alter the fixed block/conventional signalling concept.
- The driver will receive an indication on the Train Overview Display (TOD) when there is a speed transition.
- Allows the train to travel at higher speeds with smaller blocks.
- Reduces the headway between trains, increasing the capacity.

![Figure 6: Multiple speed profiles in CAB Signalling](image)

**Limitations of CAB Signalling**

CAB signalling allows for smaller blocks, and therefore a marginal increase in capacity but it has similar limitations as that of previously discussed signalling systems as shown in Figure 7 below.

There is an artificial separation as train 9 moves away from signal C. Train 8 will not be given a permissive aspect until train 9 has exited block 3.
1.2.5 Centralized Traffic Control (CTC) System

In this system, Centralized Operation of Signalling Systems for a large section encompassing multiple interlocked stations and Real time Monitoring of Train Traffic is possible. CTC operator of particular territory can operate all the signals, points, routes of any station of his territory from CTC.

Limitations of CTC System

This system is particularly suitable on single line section where the pattern of traffic is such that trains follow one another in quick succession during certain parts of the day.

1.3 Need for a train control system utilizing maximum track space

From the preceding sections it is obvious that the block length determines:

- **Safety** i.e. how far apart the trains will be kept from each other
- **Capacity** i.e how many trains can pass through the system
- Capacity is affected by the separation between trains.
- Each signaling system has its own characteristic that affects train separation.
- In conventional systems mentioned above, the block design is based on the line speed i.e. single speed profile.
- The block design does not allow for multiple speed profiles within the same block.
- The track is not utilized to its maximum capacity.
- It can be seen in the earlier mentioned systems that Static speed profile cannot adjust safety distance as per different train speeds.
- Increasing the block size increases the margin for safety but reduces capacity.
- Reducing the block size decreases the margin for safety but increases capacity

Challenge for signal engineers is to calculate the block length for maximum capacity while ensuring safety.
There is requirement of a system based on continues real-time update of signal aspect or ‘Movement Authority (MA)’ which suits to the requirements of operations in countries like India.

With study of dynamic speed profile and braking characteristics of trains in the section and use of communication technology a system is developed in which it is able to stop the train before signal at Red itself, at the same time reducing the headway between successive trains.

An introduction to one such system known as Communication Based Train Control (CBTC) is given in next chapter.
Chapter II
Communications Based Train Control (CBTC)-A moving Block Signalling concept

2.1 Introduction
Communications-based train control (CBTC) is a railway signalling system that makes use of the telecommunications between the train and track equipment for the traffic management and infrastructure control. By means of the CBTC systems, the exact position of a train is known more accurately than with the traditional signalling systems. This results in a more efficient and safe way to manage the railway traffic. Metros (and other railway systems) are able to improve headways while maintaining or even improving safety.

A CBTC system is a "continuous, automatic train control (ATC) system utilizing high-resolution train location determination, independent from 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," as defined in the IEEE 1474 standard. Based on operational needs CBTC can be categorized:

- Only ATP functions without ATO or ATS.
- ATP and partial ATO and / or ATS functions.
- CBTC can be only train control system or may be used in conjunction with other auxiliary wayside systems.

In the modern CBTC systems the trains continuously calculate and communicate their status via radio to the wayside equipment distributed along the line. This status includes, among other parameters, the exact position, speed, travel direction and braking distance. This information allows calculation of the area potentially occupied by the train on the track. It also enables the wayside equipment to define the points on the line that must never be passed by the other trains on the same track. These points are communicated to make the trains automatically and continuously adjust their speed while maintaining the safety and comfort (jerk) requirements. So, the trains continuously receive information regarding the distance to the preceding train and are then able to adjust their safety distance accordingly.
Key features of CBTC

- Trackside signals are not used.
- Track circuits are not used.
- Higher precision in Train location determination - independent of track circuits
- Continuous data communication between train & wayside.
- Position is determined by a two way communication between the wayside and train:
  - Train transmits its position.
  - Wayside transmits a target point.
- The separation between two trains is not enforced by physical track circuit blocks, but a dynamic calculation by following train.
- There is no artificial separation between trains, only the bare minimum separation required to maintain the safety distance between trains.
- Safety distance is no longer a static entity enforced by fixed blocks but an adjustable distance based on a real time calculation of the train speed.
- If the train is travelling at a high speed the safety distance is long and shrinks as the train slows.
- Unlike Conventional signalling system where block length is fixed, CBTC works on Moving Block concept in which the block length is continuously adjusted as per the changing speed of preceding train.
- Implements continuous Automatic Train Protection (ATP), Automatic Train Operation (ATO) & Automatic Train Supervision (ATS) with wayside & train-borne processors by processing train status & control data.
- CBTC signalling extracts the maximum capacity per track design.
- The maximum number of trains can run through the system.

Processes of operation

CBTC works in following stages:

- High precision train location detection without track circuits, by train-borne system.
- Transmission of train location & other train status data to wayside controller/equipment.
- Wayside controller generates limit of Movement Authority (MA).
- Transmission of MA to train-borne system.
- Determination and enforcement of ATP profile by train-borne equipment
- Implementation of MA by train-borne system.
• Communication of commands from wayside to external interlocking and status from external interlocking to wayside.
• Communicating data from one wayside controller to other wayside controller.
• Communication between multiple sets of train-borne equipment within a train.

**Benefits of CBTC**

1. CBTC makes effective use of infrastructure in following ways:
   • Allows trains at closer headways.
   • Greater precision and control of trains is possible.
   • Provides continuous safe train separation & over speed protection.
   • Utilizes the track in the most efficient manner while ensuring safety.

2. CBTC requires less maintenance cost due to:
   • Driverless system (or upgradable to driverless) to reduce operating costs;
   • Less wayside equipment
   • Improved reliability
   • Real time diagnostic data

**2.2 CBTC System Design**

As per IEEE 1474.3, CBTC System consists of four major sub-systems:

1. ATS equipment
2. Wayside equipment
3. Train-borne equipment
4. Data communication equipment

The block diagram of CBTC System is given on next page

(1) **ATS equipment**

• ATS equipment is installed at central location & wayside.
• It shall perform the functions of identifying, tracking & displaying trains.
• It provides manual & auto route setting capabilities.
• It regulates train movements to maintain operating schedule.
Figure 10: Block diagram of CBTC System Design

(2) Wayside equipment

- It consists of network of processor based wayside controllers installed at central/wayside locations.
- Interfaces with train-borne equipment, external interlockings & ATS equipment.
- It shall perform MA setting based on tracking of CBTC/non-CBTC trains.
- ATP, ATO & ATS functions reside in Wayside equipment.
- It includes track based equipment necessary to provide unique absolute positioning reference to train-borne equipment.

Figure 11: Tag connected to track for location determination

Figure 12: Wayside Zonal Controller

Communications Based Train Control  
February 2021
(3) **Train-borne equipment**
- It consists of one or more processor-based controllers and associated speed measurement & location determination sensors.
- Interfaces to train sub-systems, wayside equipment & ATS equipment.
- It is responsible for CBTC train location determination, enforcement of speed & MA limits, other train-borne ATP & ATO functions.

![Figure 13: Car borne CBTC Equipment](image1)

![Figure 14: Accelerator](image2)

![Figure 15: Tachometer](image3)

(4) **Data communication equipment**
- It is located at central, wayside location & on-board trains.
- It shall perform bi-directional data communication & intra train communication.
- It shall not perform any non vital CBTC functions.
2.3 Control of train movement through CBTC

In the following paragraphs the details about the working of a CBTC system are explained like concept of moving block, means for determination of exact location of train and how communication among various subsystems is established for control of train movement.

2.3.1 Moving Block Principle

The CBTC system uses the moving block principle in which the safe separation behind the preceding train is dynamically calculated based on the maximum operating speeds, braking curves and locations of trains on the alignment. Because of the high resolution of position reporting, a following train may safely close up within a safe braking distance from the last verified position of the rear of a preceding train, based on the present actual speed. The safety distance moves with the train, hence the name moving block. The graph shown below shows braking curves of three different trains when service brakes are applied according to their respective speeds and location of preceding train:

![Figure 16: Service braking curves for trains with different speeds](image)

The reduced train separation, safe braking distance and greater capacity (throughput and inter-station run times) are accomplished in a moving block system by using data communication with an on-board controller (i.e. not using wayside signal protection). The safe braking distance is a distance between the commanded stopping point of the following train and the confirmed position of the rear of the preceding train. This distance is selected to allow for a series of worst case conditions to exist and still ensure that safe separation is maintained.
Vital supervision of safe train separation is implemented by providing information on the maximum allowable train speed and the current stopping point to the on-board subsystem. The communication is updated cyclically to ensure that continuous updates are available to the train. The train therefore can safely within the envelope defined by the maximum commanded velocity, the confirmed stopping point, the braking curve and track grading.

*Figure 17: Fix Block working*

*Moving Block* - Allows trains to run closer together while maintaining Safe braking distance.

*Figure 18: Moving Block working*

*Figure 17* shows the total occupancy of the leading Train 1 in a fix block system by including the whole Block 1 on which the train is located (This is shown by blue line). This is due to the fact that it is impossible for the system to know exactly where the train actually is within Block 1. Therefore, the fixed block system only allows the following Train 2 to move up to the last unoccupied border of Block 2.

In a moving block system as shown in *Figure 18*, the train position and its braking curve is continuously calculated by the trains, and then communicated via radio to the wayside equipment. Thus, the wayside equipment is able to establish protected areas, each one called Movement Authority (MA), up to the nearest obstacle (in the figure the rear of the Train 1).
2.3.2 Determination of train location in CBTC

The main feature which differentiates a CBTC system from conventional signalling is the ability to determine the location of a train independent of track circuits. Typically this is done using transponder tags or beacons installed along the track. The tags/beacons provide the train borne unit with a course position. The tachometers installed on the axles provide the fine position.

![Train location determination through Transponder Tags or Beacons](image)

From Figure 19 above, as the train crosses tag/beacon B, the train borne unit is aware that it is located at the 200 meter mark (coarse position). As the train moves away, the tachometers will count how far the train has moved (fine position). Taking the coarse and fine position together, the train borne unit will be able to determine that the center of the train is located 247.5m away from the zero reference point. This is a simplified description (for illustration purposes) of how a CBTC system determines the location of a train.

2.3.3 Communication arrangements in CBTC

(i) Basic structure of communication

Once the train is able to accurately determine its location, this information must be relayed to the wayside unit in a timely fashion. In CBTC system, access points are installed along the track. As the train comes within range of an access point, the train borne radio will lock onto its signal and disconnect from the previous access point.

The basic structure of the existing CBTC system is shown in Figure 18. It mainly includes Data Communication system (DCS), Automatic Train Supervision (ATS) system, Computer based Interlocking (CI), Zone Controller (ZC), and processor based Vehicle On-Board Controller/Computer (VOBC). CBTC uses a combination of Wireless communication and trackside backbone network (using fibre optic cables) for two way communication among
Way-side, VOBC and ZC. During the train operation, ATS issues train-related driving plans to ZC through the backbone network. Then, the ZC establishes a movement authority (MA) based on the position report of all the travelling trains and the condition of the trackside controller and then transmits the MA to each train. The VOBC on each train controls the operation of the train based on the received MA.

Figure 20: Basic structure of communication in CBTC

(ii) Types of Communication networks in CBTC
CBTC communication network consists of the following three integrated networks:
(a) Train onboard network (Intra-Train)
(b) Train-to-trackside radio network
(c) Trackside backbone network (Way-side to way-side)
The train onboard network and the trackside backbone network use Ethernet, while the train-to-trackside radio network generally uses Wi-Fi.

(iii) Components used in communication
Following are the major components of a CBTC system which take part in two way communication network that connect the train and the way side.

(A) Onboard components
These comprise the following components:
(a) Vehicle On-Board Controller/Computer (VOBC)
The onboard equipment includes Vehicle On-Board Controller/Computer (VOBC), sometimes also called Car-borne Controller or Onboard Control Unit (OBCU). This system is responsible for sending train control information to the wayside on periodic basis. It either includes, or works together with, the onboard ATP and ATO subsystems.

(b) Onboard ATP and ATO
The ATP and ATO subsystems are part of the onboard ATC functionality. ATP controls safety-related functions and ATO controls the actual train.

(c) Radio Communication System (RCS)
Another critical onboard component is RCS, or Data Communication System (DCS). RCS is typically a combination of software and hardware, including radios and antennas, and is responsible for the radio communication between the train and the wayside. RCS can either be a completely independent system or integrated into VOBC. If independent, the computer system running RCS is also frequently referred to as a Train Unit (TU).

(B) Wayside components
Figure 22 illustrates typical wayside components of a CBTC system. The terms wayside and trackside are often used interchangeably. However, trackside generally contains the components located either on or close to the tracks, and is considered a part of the wayside. A Zone Controller (ZC), or Wayside Controller, is responsible for controlling a particular zone in the railway network. Dividing the wayside network into multiple, independent zones, such that each zone comprises its own wayside infrastructure, improves availability even if one or more zones experience failures. The fundamental function of a ZC is to maintain safe train separation in its zone. A ZC also typically includes the wayside ATP and ATO subsystems.
The ATP subsystem of a ZC manages all the communication with the trains in its zone. It is also this subsystem that calculates the movement authority for every train in its zone. A Computer-based Interlocking (CI) system is either included as an independent system or as a part of the ATP subsystem. CI controls the trackside equipment such as point machines and signals, and is responsible for setting routes for trains. The ATO subsystem provides all the trains in its zone with their destination as well as dwell times. Independent from the ZC is the automatic train supervision (ATS) system, which is responsible for monitoring and scheduling the traffic through ATS Control Centre. Trackside is divided into multiple Wi-Fi cells, each served by one Access Point (AP). Figure 22 uses the green and red colours to differentiate the APs’ radio coverage areas.

APs are either deployed on one side of the track or both, in alternating fashion. Trains communicate to the APs through a radio connection. This constitutes a typical CBTC train-to-trackside radio network. APs are in turn connected to the wayside components through the trackside backbone network.

(iv) The role of radio communication in CBTC
Radio communication is generally unreliable. Designing a reliable train control system over an unreliable radio link is a challenging task. In conventional signalling systems, the distance between trains following each other is large, as seen in Figure 17. Thus a certain number of communication errors for communication technologies used in conventional systems can be tolerated. However, in CBTC, headways are very short, which means in the event of a
communication failure, a train may not receive the location of the train in front of it in time. In this situation, a typical approach in CBTC systems is to apply emergency brakes and then drive it in manual mode. In the worst case, this could trigger a chain-reaction with all the following trains stopping. The timeout interval before emergency brakes are applied varies from project to project, depending on multiple factors, including the frequency of CBTC control messages. Compared to the conventional train control systems, in CBTC, the responsibility of determining a train’s location has been moved from the track circuit to the train itself. This train-centric location determination results in lower certainty. Previously, the train location was determined by the wayside (with the help of a track circuit), independent of the train. The fail-safe design of track circuits meant a failure was interpreted as a train presence. However, in CBTC, the wayside depends on the train to get the location information, which in turn depends on the radio communication. The failure of the radio communication link, therefore, is highly critical for a functional CBTC system. Radio communication failures lead to transmission errors and a large handover latency, resulting in packet delays and losses.

For these reasons, CBTC systems normally allocate a fixed "protection margin" in the calculation of their safe braking distance. Additionally, CBTC systems normally employ a conventional train detection method as a fallback, for location determination in the event of a radio communication failure, as well as for non-CBTC trains operating concurrently with CBTC trains. This is also a requirement of the IEEE CBTC standard.

**Alternative radio communication technologies**
As discussed above, the modern CBTC systems use continuous and high capacity radio communication between the train and the wayside infrastructure to transmit train control information. The high resolution and highly accurate train location enables the "moving block" operation. The result is short headways and increased line capacity. A typical headway in CBTC systems is of the order of 90 seconds. Furthermore, it enables advanced features such as driverless and unattended train operations.

LTE has recently been in focus as an alternative technology for CBTC. The high capacity and large coverage it offers, as well as its potentially long life span, makes it a worthwhile alternative to Wi-Fi for CBTC. LTE’s high capacity ensures it can support additional features such as voice communication, passenger Internet, live CCTV video streaming, and Passenger Information Systems.
Figure 23: A Typical CBTC communication arrangement
Figure 24: A typical plan showing train borne and wayside subsystems of CBTC installation
2.4 Train Operating Modes

(i) Modes of operation as per grades of automation

Table 1: Levels of Automation

<table>
<thead>
<tr>
<th>Grades of automation</th>
<th>Train Operation</th>
<th>Starting Train</th>
<th>Stopping Train</th>
<th>Door Closure</th>
<th>Operation in event of Disruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>GoA1</td>
<td>ATP with Driver</td>
<td>Driver</td>
<td>Driver</td>
<td>Driver</td>
<td>Driver</td>
</tr>
<tr>
<td>GoA2</td>
<td>ATP &amp; ATO with Driver</td>
<td>Automatic</td>
<td>Automatic</td>
<td>Driver</td>
<td>Driver</td>
</tr>
<tr>
<td>GoA3</td>
<td>Driver-less</td>
<td>Automatic</td>
<td>Automatic</td>
<td>Train Attendant</td>
<td>Train Attendant</td>
</tr>
<tr>
<td>GoA4</td>
<td>UTO</td>
<td>Automatic</td>
<td>Automatic</td>
<td>Automatic</td>
<td>Automatic</td>
</tr>
</tbody>
</table>

(ii) Normal train operating modes in CBTC territory

For CBTC equipped trains - Normal working with full protection of ATP.

For Non-CBTC-equipped trains - Under protection of auxiliary wayside system or operating procedures.

(iii) Failure mode train operation in CBTC territory

CBTC shall continue to provide ATP in case of failure through

- Functional elements of CBTC or
- An auxiliary wayside system or
- Combination of both

(a) If trains are affected in one area of control

For example, failure of data communication or wayside equipment – trains can be run with train operator, and

- With protection of auxiliary wayside system or
- Through adherence of operating procedure or
- Combination of both.

ATP functions of Train borne CBTC equipment shall continue to function.

(b) If one train is affected in any area of control

For example, Train borne CBTC equipment failure – train can be run with train operator, and

- With protection of auxiliary wayside system or
• With train speed limited by propulsion system or
• Through adherence of operating procedure or
• Combination of all the above

ATP functions of Train borne CBTC & wayside CBTC equipment shall continue to function.

(iv) CBTC train operating modes in non-CBTC territory
• Train borne equipment shall cater for transition into CBTC territory.

• CBTC equipment may perform ATP functions like –limiting train speed and / or providing zero speed detection.

• CBTC of the train borne equipment can be integrated with local system of non CBTC territory –but it shall be indicated separately

(v) Failure mode train operations in non-CBTC territory
• It has minimal impact

• Failure may be indicated to train operator

(vi) Entering / exiting CBTC territory
(a) Entering into CBTC territory
• CBTC system shall have precise knowledge of limits of CBTC. It shall perform verification checks before entering CBTC territory.

• There is no need to stop while entering the territory.

• Failure results are to be displayed to ATS operator & train operator.

(b) Exiting CBTC territory
• CBTC system may provide visual indication to train operator for time and/or distance until train exits CBTC territory.

• There is no need to stop while entering the territory.

If CBTC knows the new control system, it may display the same.

(vii) Train configurations
CBTC is Capable of supporting a variety of train configurations:
• Fixed length unidirectional trains –one or more units
• Fixed length bidirectional trains –one or more units
• Variable length unidirectional trains
• Variable length bidirectional trains

Note: CBTC – Shall support mixed fleet of trains, with different performance characteristics
2.5 Performance requirements of CBTC as per IEEE 1474.1

There are two types of headways

**Un-interfered:** All trains are allowed to move at maximum permitted speed. It provides minimum trip time for given set of station occupation times.

**Interfered:** Train speed profile is affected by train ahead. Headways may be reduced at the cost of increased trip time.

(i) **Design headways outside the control of CBTC**

1. Track alignment & gradients
2. Civil speed limits
3. Train acceleration & braking rates
4. Station dwell times
5. Terminal track configurations
6. Driver reaction times

(ii) **CBTC factors contributing to achievable headways**

**Location**—Accuracy of end of train locations, resolution of movement authority limits & frequency at which location reports and MA are updated.

**Speed**—Accuracy & resolution.

**Communication delays**—between wayside & train.

**CBTC equipment reaction times**
- time taken to decide new MA after receiving location update.
- time taken to get new MA limits.
- time to determine new ATP profile following MA update.

**CBTC system performance limitations**—For example: maximum trains that can be processed by CBTC within a given area of control.

CBTC automatic **speed regulation algorithm**
**Table 2 : Typical parameters of CBTC**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Parameter</th>
<th>Typical range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maximum trains processed by one wayside controller</td>
<td>10 to 40</td>
</tr>
<tr>
<td>2</td>
<td>Resolution of measured train location –for ATP</td>
<td>+/- 0.25 to 6.25m</td>
</tr>
<tr>
<td>3</td>
<td>Accuracy of measured train location – for ATP</td>
<td>+/- 5 to 10m</td>
</tr>
<tr>
<td>4</td>
<td>Accuracy of measured train location for programmed station stop –without platform edge doors –for ATO</td>
<td>+/- 0.25m</td>
</tr>
<tr>
<td>5</td>
<td>Accuracy of measured train location for programmed station stop –with platform edge doors –for ATO</td>
<td>+/- 0.05m</td>
</tr>
<tr>
<td>6</td>
<td>Resolution of train movement authority limits</td>
<td>+/- 0.25 to 6.25m</td>
</tr>
<tr>
<td>7</td>
<td>Resolution of train speed measurement for ATP</td>
<td>+/- 0.5 to 2Km/h</td>
</tr>
<tr>
<td>8</td>
<td>Accuracy of train speed measurement for ATP</td>
<td>+/- 3Km/h</td>
</tr>
<tr>
<td>9</td>
<td>Resolution of train speed commands –for ATP</td>
<td>+/- 0.5 to 5Km/h</td>
</tr>
<tr>
<td>10</td>
<td>Train to way side message communication delays</td>
<td>0.5 to 2sec</td>
</tr>
<tr>
<td>11</td>
<td>Way side to train message communication delays</td>
<td>0.5 to 2sec</td>
</tr>
<tr>
<td>12</td>
<td>Wayside CBTC equipment reaction times</td>
<td>0.07 to 1 sec</td>
</tr>
<tr>
<td>13</td>
<td>Train borne CBTC equipment reaction times</td>
<td>0.07 to 0.75sec</td>
</tr>
<tr>
<td>14</td>
<td>Rollback detection criteria</td>
<td>0.5 to 2 m</td>
</tr>
<tr>
<td>15</td>
<td>Zero speed detection criteria</td>
<td>Less than 1 to 3 km/h for 2 sec</td>
</tr>
</tbody>
</table>
2.6 Functional Requirements of CBTC as per IEEE 1474.1

The functional requirements of CBTC are as given below:

- CBTC shall provide ATP, ATO & ATS functions.
- ATP–failsafe function –overrides ATO & ATS.
- ATO –Operates functions –otherwise operated by train operator.
- ATS –Provides system status information, means to monitor and override automatic control.
- Bidirectional data communication to support ATP, ATO & ATS – in tunnels, tubes, cuts, elevated structures & at gates.
- Speed to support defined performance requirements.
- Data link includes –protocol structure to support safe, timely & secure delivery of train control messages.

2.6.1 ATP functions

ATP functions shall cover following:

(i) Train location & speed determination
- Train location (both front & rear of the train), Speed & Direction of each train.
- Resolution & accuracy parameters
- Automatic CBTC train detection.
- Compensation for measurement inaccuracies like slipping of wheel, sliding of wheel, wheel wear.
- Secondary Train location determination like detection of occupancy by CBTC train, failed / non-CBTC trains.

(ii) Safe train separation
- Safe train separation for all trains –CBTC, failed/ non-CBTC.
- Movement Authority of a CBTC train following a failed / non-CBTC train is limited to the boundary of track occupied by failed / non-CBTC train.
  OR
  To the route entry point of the route occupied by failed / non-CBTC train.

Movement Authority limit is decided up on following restrictions:
- Rear of CBTC equipped train ahead.
- Boundary of track section –occupied by failed / non-CBTC train.
- End of track.
- Entrance to an interlocking –when route not locked.
- Boundary of a track section –with opposite traffic direction established.
• Boundary of blocked track.
• Entrance to a route – detected not safe for train movement.
• Entrance to a highway grade crossing – when warning devices.
• Operation not confirmed.

CBTC safe train separation function shall support abnormal movements like coupling & uncoupling of trains in designated areas, manual operation of train.

(iii) **ATP Profile**

Calculation of ATP profile is derived from:

Fixed ATP data – Permanent Speed Restriction (PSR)

Variable ATP data – Temporary Speed Restriction (TSR) & Movement Authority (MA) limit.

ATP profile calculated as above is enforced or safe train separation.

(a) **Over speed protection & brake assurance**

CBTC system shall

• Support multiple safe braking models to accommodate different train acceleration/braking rates.

• Ensure correct safe braking model is applied for a given train at a given location.

(b) **Safe Speed**

Speed of train is considered safe when:

• PSR is within ATP speed profile

• TSR is within ATP speed profile

• PSR for the class / configuration of the train

• Speed restriction is imposed on the train in case of train-borne failure

• Maximum speed that allows safe stop prior to MA or meet PSR / TSR

(c) **Automatic brake application**

• The type of brake application is specified by the user. In case service brake is applied by CBTC, the achieved brake rate shall be monitored by CBTC. If the brake rate is not achieved within a time frame, CBTC shall apply emergency brake.

• Emergency brake system shall bring the train to stop within assured distance.

• Reset facility to enable resuming operation – as per user requirement.
• If train speed exceeds ATP profile speed after reset – emergency brakes are applied again.

• Local manual by pass can be provided.

• A safe braking model shall include appropriate allowances for reaction times of brake assurance function.

(d) Rollback protection
• CBTC compares Actual train travel direction with travel direction as per MA.

• If the distance travelled against MA direction is more than Rollback tolerance, Emergency brakes are applied.

• Rollback tolerance –0.5 to 2 meters

(e) End of track protection
Applicable where buffer stops are provided or terminals. It is part of over speed protection feature.

(f) Protection of parting trains
• CBTC shall be able to detect and protect parting trains.
CBTC shall support coupling & uncoupling of trains and shall automatically update the length of the new train.

(g) **Zero speed detection**
As per 5.10 of IEEE Std. 1475-1999, Less than 1 to 3 Kmph for 2 sec.

(iv) **Door opening control protection interlocks**
For trains are operated with crews, it is part of ATP (if User requires).
For trains are operated without crews, it is mandatory to be part of ATP.

(a) **Conditions to be satisfied to enable opening of doors**
- Train is properly aligned at stopping point.
- There is platform on the proposed opening side.
- Zero speed is detected.
- The train is constrained against motion.
- Selective door opening – shall be possible if train length is more than PF length.
- Local bypass facility for failure recovery.

(b) **Departure interlocks**
- For trains without crews – Mandatory, For trains with crews - Optional.
- It shall prevent a stationery train from moving unless all doors are closed & locked.
- Local manual bypass – optional

(c) **Route interlocking**
- CBTC system shall provide all route interlocking functions equivalent to conventional interlocking.
- Route locking shall remain in effect until the train is proven clear by CBTC, subsequently or through operating procedure, or through combination of both.
- If there is loss of point indication, CBTC shall pullback the movement authority to the entrance of interlocking and shall initiate an immediate brake if the train is within braking distance.
- Traffic direction reversal within a section of track shall not be possible, unless conditions are safe for all trains in and outside the section.
- CBTC shall not grant MAs to trains to blocked tracks through switches in other than required position and enforcing restricted speeds.
CBTC may interface to an auxiliary wayside system for the purpose of Broken rail detection.

When Approach warning devices of gate are controlled by CBTC & movement is based on their status, appropriate warnings are given depending on the status of train, road signals and road signage.

CBTC system shall prevent MA to a type of train into a route not safe for that type of train – due to electrical, mechanical, civil or other predefined conditions.

2.6.2 ATO functions
(i) Automatic speed regulation
- Train speed shall be within ATP over speed limits.
- Starting, stopping & speed regulation by CBTC shall be within passenger comfort limits as specified by the user for example speed, acceleration, deceleration & jerk rates.
- CBTC shall support multiple ATO speeds, acceleration and service brake rates as per the operator or ATS.

(ii) Platform berthing control
- When the platform length is approximately equal to the train length, CBTC system shall allow a train to enter platform only if there is sufficient room to fully accommodate the train.
- CBTC shall permit Multiple stopping on a lengthier platform even when another train is berthing a portion of platform.
- If platform length is shorter than train, selective door opening control protection as per ATP applies.

(iii) Door control
- CBTC shall be able to automatically control train doors & platform edge doors.
- Train doors and platform edge doors opening shall be matching while closing & opening.
- It shall be possible to manually disable a set of train & Platform edge doors without affecting others.
- Amount of time doors are opened at a station is decided by ATS and implemented by ATO.

2.6.3 ATS functions
(i) General
- CBTC interfacing with ATS is optional.
The ATS features of CBTC shall be integrated with conventional ATS & non-ATS functions to have a single consistent user interface.

(ii) **ATS User Interface**
ATS functions need not be implemented in fail safe manner, but hazard analysis has to be done for the possibility of
- Safety related commands not being executed when initiated by ATS user.
- CBTC system executing safety related commands that were not initiated by ATS.
- Incorrect information being displayed by the CBTC system to the ATS user.

(iii) **CBTC train identification & train tracking**
- For each CBTC-equipped train in CBTC territory a train identification shall be assigned.
- ATS system shall be able to automatically track and maintain records of, display on the ATS interface, train schedule etc.
- Train location is displayed based on front & rear locations of the train.
- Variation in train length to be displayed proportionately.

(iv) **Train routing**
ATS shall be able to manually or automatically route CBTC equipped trains for example proper merging & diverging of trains at junction, turn back of trains, re routing of trains in case of disruptions.

(v) **Automatic Train regulation**
- Schedule regulation is done by Automatic dispatch function based on train identity, location, scheduled and actual headways between trains, service strategies.
- Headway regulation is done by dwell time variance, running time between stations.
- Train regulation to facilitate transfer between local & express trains, merging point between different lines.
- Station stop functions such as Stop train at next station, Hold train at station, Skip station stop, Door control inhibit.

(vi) **Fault reporting**
**CBTC fault reporting**
- ATS user interface display shall indicate failures, out of tolerance conditions.
- Alarms to be categorised & prioritized into critical & non-critical alarms.
- Critical alarms are to be acknowledged.

(vii) **Train fault reporting**
- Train borne CBTC equipment.
- Interfaces to train borne sub-systems.
2.7 User Interface Requirements of CBTC as per IEEE 1474.2

2.7.1 Operations related user interface requirements – train-borne subsystems

(i) **Train-borne subsystems - Mandatory display data**
   - Train operating mode
   - CBTC operational status
   - Current CBTC determined speed
   - Current max authorised CBTC speed
   - Over-speed condition alarm

(ii) **Train-borne subsystems – Optional display data**
    - Fixed territory related information
    - Train type
    - Train run identity / train destination
    - Train location and /or track designation.
    - Train length
    - Reason for MA limit
    - Target speed
    - Speed profile to an approaching MA limit
    - Distance to an approaching MA limit
    - Required brake rate to an approaching MA limit
    - Time to a penalty brake application
    - Penalty over speed alarm
    - Train route through interlockings
    - Train regulation information
    - Unscheduled train stops
    - Train properly aligned at a station designated stopping point
    - Station management related info – train to skip next station, door status
    - Level crossing status
    - Train parting
• Fault report –related information
• Text messages
• Time & date

2.7.2 Train-borne subsystems –inputs

(i) Mandatory user info inputs
• Operating mode selection
• Over-speed alarm condition acknowledgement

(ii) Optional user info inputs
• User login parameters
• Train type
• Train length
• Crew identification

(iii) Mandatory Audible Alarms
Over-speed condition

(iv) Optional Audible Alarms
• Penalty over-speed condition
• Transitions into and out of CBTC territory
• Detected parting
• Approaching work zone
• Train length conflicting –manually entered & detected by CBTC
Figure 27: Details of Analog circular display of TOD

Figure 28: TOD – Train operators Display - Train Stopped at a Station. No Departure Permitted with Train & Platform Doors Open

Figure 26: Target Speed & Target Distance shown on TOD Departure Permitted with Train & Platform Doors Closed
2.7.3 Operations related user interface requirements – non-train-borne subsystems

(i) Mandatory display
- Fixed territory related information like track plan, location of stations, gates
- Train status related info – train attributes, location etc
- Train movement authority / routing info
- Information related to restricted train operations – work zone etc.

(ii) Optional display
- Fixed alignment related info – permanent SRs
- Train status related info – train attributes, location etc
- Train movement authority / routing info
- Information related to restricted train operations – work zone, CBTC failed trains etc.
- CBTC max authorised speed
- Service performance related information
- ATP profile violations
- Failures & out of tolerance conditions
- Status of elements of auxiliary wayside system

(iii) Mandatory user inputs
- Inputs to request & cancel routes, limit MA.
- Inputs to establish & remove work zones, block track sections / switches & establish TSR.

(iv) Optional user inputs
- Inputs to modify schedules / trips of one train, a group of trains.
- Inputs to adjust the train service braking profiles for CBTC equipped trains for example wet rail condition.

2.7.4 Maintenance-related user interface requirements

(i) General
- Failures resulting in punctuality loss of train.
- Failures resulting in no performance loss but affects loss of specific CBTC functionality.
- Failure resulting in no performance loss [may be due to redundancy].
(ii) **Display data**
- Graphical representation of CBTC system configuration.
- Listing the current status of sub-system –component.
- Time stamped failure log.
- Physical location of failed CBTC sub-system.
- Early warning failures –out of tolerance conditions.
Chapter III
Applications of CBTC in Mass Transit

3.1 Metro trains using CBTC technology

Metro trains come under the category of Mass Transit system. Some of the top world's busiest metros in terms of annual passenger rides utilise a CBTC system. CBTC technology has been (and is being) successfully implemented for a variety of applications. They range from some implementations with short track, limited numbers of vehicles and few operating modes, to complex overlays on existing railway networks carrying more than a million passengers each day and with more than 100 trains. Following is a list of few metros of different countries using CBTC technologies provided by various firms:

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Location/Country</th>
<th>Lines/System</th>
<th>Supplier</th>
<th>Solution</th>
<th>Level of Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>London Underground</td>
<td>Jubilee line</td>
<td>Thales</td>
<td>SelTrac</td>
<td>STO</td>
</tr>
<tr>
<td>2</td>
<td>New York City Subway</td>
<td>IRT Flushing Line</td>
<td>Thales</td>
<td>SelTrac</td>
<td>STO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BMT Canarsie Line</td>
<td>Siemens</td>
<td>Trainguard MT CBTC</td>
<td>STO</td>
</tr>
<tr>
<td>3</td>
<td>Singapore MRT</td>
<td>North East Line</td>
<td>Alstom</td>
<td>Urbalis</td>
<td>UTO</td>
</tr>
<tr>
<td>4</td>
<td>Hungary</td>
<td>Budapest Metro M4</td>
<td>Siemens</td>
<td>Trainguard MT CBTC</td>
<td>UTO</td>
</tr>
<tr>
<td>5</td>
<td>Brazil</td>
<td>Sao Paulo Metro</td>
<td>Bombardier</td>
<td>CITYFLO 650</td>
<td>UTO</td>
</tr>
<tr>
<td>6</td>
<td>Beijing Subway</td>
<td>15</td>
<td>Nippon Signal</td>
<td>SPARCS</td>
<td>ATO</td>
</tr>
<tr>
<td>7</td>
<td>Ankara Metro</td>
<td>M1</td>
<td>Ansaldo STS</td>
<td>CBTC</td>
<td>STO</td>
</tr>
<tr>
<td>8</td>
<td>Riyadh Metro</td>
<td>L4, L5 &amp; L6</td>
<td>Alstom</td>
<td>Urbalis</td>
<td>ATO</td>
</tr>
<tr>
<td>9</td>
<td>Delhi Metro</td>
<td>Line 8</td>
<td>Nippon Signal</td>
<td>SPARCS</td>
<td>UTO</td>
</tr>
<tr>
<td>10</td>
<td>Madrid Metro</td>
<td>1, 6</td>
<td>Bombardier</td>
<td>CITYFLO 650</td>
<td>STO</td>
</tr>
<tr>
<td>11</td>
<td>Paris Métro</td>
<td>1</td>
<td>Siemens</td>
<td>Trainguard MT CBTC</td>
<td>DTO</td>
</tr>
</tbody>
</table>
3.2 Metros with CBTC in India
Following is the list of Metros in India using CBTC technology:

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Metro</th>
<th>Technology/Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hyderabad</td>
<td>Thales SelTrac</td>
</tr>
<tr>
<td>2</td>
<td>Lucknow</td>
<td>Alstom Urbalis</td>
</tr>
<tr>
<td>3</td>
<td>Kochi</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Mumbai</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Jaipur</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Ahmedabad</td>
<td>Nippon Signal SPARCS</td>
</tr>
<tr>
<td>7</td>
<td>Delhi</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Mumbai</td>
<td>Ansaldo STS CBTC</td>
</tr>
<tr>
<td>9</td>
<td>Kolkata</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Delhi</td>
<td>Bombardier CITYFLO 650</td>
</tr>
<tr>
<td>11</td>
<td>Nagpur</td>
<td>Westinghouse by Siemens</td>
</tr>
<tr>
<td>12</td>
<td>Pune</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Bangalore 1</td>
<td>Distance to go</td>
</tr>
<tr>
<td>14</td>
<td>Chennai</td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Delhi Metro lines and routes

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Line</th>
<th>Station From</th>
<th>Station To</th>
<th>Distance</th>
<th>Total no. of stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Line 1 (Red line)</td>
<td>Dilshad Garden</td>
<td>Shaheed Sthal</td>
<td>34.7 km</td>
<td>29</td>
</tr>
<tr>
<td>2</td>
<td>Line 2 (Yellow line)</td>
<td>Samaypur Badli</td>
<td>HUDA city centre</td>
<td>48.8 km</td>
<td>37</td>
</tr>
<tr>
<td>3</td>
<td>Line 3 (Blue line)</td>
<td>Dwarka Sector 9</td>
<td>Noida City Centre</td>
<td>49.93 km</td>
<td>44</td>
</tr>
<tr>
<td>4</td>
<td>Line 4 (Blue line)</td>
<td>Yamuna Bank</td>
<td>Anand Vihar</td>
<td>8.74 km</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>Line 5 (Green line)</td>
<td>Inderlok</td>
<td>City Park</td>
<td>29.64 km</td>
<td>23</td>
</tr>
<tr>
<td>6</td>
<td>Line 6 (Violet line)</td>
<td>Kashmere Gate</td>
<td>Raja Nahar Singh</td>
<td>47 km</td>
<td>32</td>
</tr>
<tr>
<td>7</td>
<td>Line 7 (Pink line)</td>
<td>Majlis Park</td>
<td>Mayur Vihar Pocket 1</td>
<td>58.59 km</td>
<td>38</td>
</tr>
<tr>
<td>8</td>
<td>Line 8 (Magenta line)</td>
<td>Botanical Garden</td>
<td>Janakpuri West</td>
<td>38 km</td>
<td>25</td>
</tr>
<tr>
<td>9</td>
<td>Line 9 (Grey line)</td>
<td>Dwarka</td>
<td>Najafgarh</td>
<td>4.29 Km</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>Airport Express line (Orange line)</td>
<td>New Delhi railway station</td>
<td>Dwarka Sector 21</td>
<td>23 Km</td>
<td>6</td>
</tr>
</tbody>
</table>

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Control of drivers over train operations in existing Delhi Metro lines

Even now, trains are mostly remotely controlled from the command rooms of the DMRC known as Operations Control Centre (OCC), from where teams of engineers track and monitor in real time train movement across the DMRC network. The OCCs are akin to air traffic control towers equipped with large display walls and communication technology. DMRC has three OCCs, including two inside the metro headquarters and one at Shastri Park. But the level of control that the drivers or train operators have over trains vary from line to line.

On Line 1 or the Red Line and Line 3/4 or the Blue Line drivers are in complete control of trains, starting from speed, opening and closing of doors. The target speed is however decided by the Automatic Train Protection (ATP) system, which means drivers cannot run trains above a certain limit. The remaining corridors, including Line 8 for now, are covered by the Automatic Train Operation (ATO) mode. Under this mode, drivers only press the departure command after closing doors at every platform. But the ATO mode is occasionally switched off even on these lines and drivers are made to run trains manually so that they remain prepared to intervene in case of emergencies.
3.3 India's first driverless train on Delhi Metro - A new beginning
The country's first-ever fully automated, driverless train operations was flagged off on the 37 km long Delhi Metro Magenta Line connecting Janakpuri West to Botanical Garden on Monday, December 28. Honourable Prime Minister Narendra Modi inaugurated the first such driverless train at Jasola Vihar-Shaheen Bagh Metro station of Delhi Metro Magenta Line via video conference. According to the metro operator Delhi Metro Rail Corporation (DMRC), with the commencement of the fully automated driverless trains operations (DTO), India has now joined the league of seven percent of countries in the world having this facility in their metro networks which are capable of operating without drivers.

![Figure 30: View from inside of Driverless Delhi Metro cab](image1)

![Figure 31: Inside view of Driverless Delhi Metro cab](image2)
Benefits

- The fully automated trains will reduce human intervention in operations and offer more reliability and safety for the commuters. The system also brings more flexibility to train operations.

- As a result, the number of trains in service can be regulated based on the demand dynamically without any dependence on the availability of the crew.

- Since these trains operate on communication-based train control Signalling system, they can be run with a headway as high as 90 seconds to offer more carrying capacity.

- The driverless train operation's higher level of diagnostic features will help move from the conventional time-based maintenance to condition-based maintenance.

- The system will also reduce maintenance downtime of the Delhi Metro trains.

- The driverless trains will be fully automated which will require minimum human intervention and will eliminate the possibilities of human errors.

Changes in operating procedure on Magenta Line after introduction of driverless train

On Magenta line metro have switched from ATP and ATO, to Driverless Train Operation (DTO) mode. In this mode, trains can be controlled entirely from the three command centres of the DMRC, without any human intervention. The Communication Based Train Control (CBTC) signalling technology also makes it possible to monitor and troubleshoot every aspect of train operations remotely. Manual intervention is required only in cases of hardware replacement. At the command centres, posts of information controllers have been created to handle the passenger information system, crowd monitoring. Rolling stock controllers will monitor train equipment in real-time, download faults and other events captured by CCTVs and assist traffic controllers in executing commands remotely. All station controllers will also have access to on board CCTV feed.
3.4 Comparison between parameters of Mainline Railway and Metro Railway

Table 6: Comparative of Main line and Metro Railways

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Parameter</th>
<th>Mainline Railway</th>
<th>Metro Railway</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Average speed</td>
<td>50 to 75 Kmph</td>
<td>30 to 35 Kmph</td>
</tr>
<tr>
<td>2</td>
<td>Headway</td>
<td>5 to 7 Minutes</td>
<td>90 to 180 seconds</td>
</tr>
<tr>
<td>3</td>
<td>Inter station distance</td>
<td>6 to 10 Km</td>
<td>0.8 to 1.5 Kms</td>
</tr>
<tr>
<td>4</td>
<td>Braking distance</td>
<td>800 m to 1.5 Km</td>
<td>About 250 m</td>
</tr>
<tr>
<td>5</td>
<td>Station yard layouts</td>
<td>Generally complex</td>
<td>Simple yard layout</td>
</tr>
<tr>
<td>6</td>
<td>Signal clearance</td>
<td>Typical 30 seconds to 3 minutes</td>
<td>Typical 3 to 5 seconds</td>
</tr>
<tr>
<td>7</td>
<td>Stoppage time at stations</td>
<td>2 to 5 minutes</td>
<td>20 to 30 seconds</td>
</tr>
<tr>
<td>8</td>
<td>Distance between two trains</td>
<td>In Absolute Block - 6 to 10 Km</td>
<td>25 to 30 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In Automatic Block - 1 to 1.5 Km</td>
<td></td>
</tr>
</tbody>
</table>
Chapter IV
Kolkata East-West Metro Line 2 with CBTC Technology – A case study

4.1 Introduction
The proposed Kolkata East West Metro Line 2 is a rapid transit line of the Kolkata Metro in the Indian state of West Bengal. It has a total 16.034 Km stretch from Sector V (SVSA) station to Howrah Maidan (HWMM) Station. From Sector V (SVSA) station to Salt Lake Stadium (SSSA) for a span of 5.94 Km, 6 stations are elevated. From Phoolbagan (PBGB) station to Howrah Maidan (HWMM) station for a span of 10.094 Km, 6 stations are underground. This project will connect Kolkata with Howrah by an underwater Metro line, below the Hooghly river.
Status as on 23.02.2021

- Phase-I A, Sector V (SVSA) to Salt Lake Stadium (SSSA), Length 5.305 Km : Commercial run started on 14.02.2020

- Phase I B, Salt Lake Stadium (SSSA) to Phoolbagan (PBGB), Length 3.708 Km : Commercial run started from 05.10.2020

- Till date 7 Nos. station have been commissioned. 6 Nos. in elevated section and 1 No. underground. Total length 9.013 Km.

- Phase-II yet to be commissioned from Phoolbagan (PBGB) to Howrah Maidan (HWMM), Length 7.021 KM. 5 stations which are underground, yet to be commissioned.

Salient features

- Kolkata East -West Metro Line 2 is a state of art Communication Based Train Control (CBTC) System.

- This system is based on the Moving Block System (Refer Chapter II) of M/S Hitachi make with design headway of 120 sec. and operational headway of 150 sec.

- Currently it is running in Automatic Train Protection (ATP) mode, i.e. GOA1 (Grade of Automation). Testing of Automatic Train Protection (ATO) is in progress. At the end of Phase 2, i.e. when section will be extended up to Howrah Maidan, it will achieve ATO, i.e. GOA2.

- The Automatic Train Control (ATC) System ensures the safe passage of trains and optimises line operation. ATC guarantees signal safety and high reliability at the same time. CBTC System will comprise of:
  - Automatic Train Operation (ATO)
  - Automatic Train Protection (ATP)
  - Automatic Train supervision (ATS)

4.2 Functioning of CBTC

CBTC system determines the location of a train through transponder tags installed along the track. During the train operation, the Zonal Controller (ZC) receives information from the Computer Based Interlocking (CBI) and Carborne Controllers (CC) and determines a train location map. Then, the ZC establishes a Movement Authority (MA) based on the position report of all the travelling trains and the condition of the trackside controller and then transmits the Movement Authority (MA) to each train. The CC on each train controls the operation of the train based on the received MA.
The boarding and detraining of passengers at platform levels is monitored through IP based CCTV cameras installed in all stations.

Vital data from on-board CBTC and non-vital data from Backbone Routers (BBRS) to Operation Control Centre (OCC) will be exchanged through Data Communication System (DCS).

The visual communications to the passengers are provided through Passenger Information Display System (PIDS) which have control equipments in Equipment Rooms of each Station, as well as Operation Control Centre (OCC) and Backup Control Centre (BCC).

Audio communication with passengers at each Station is made through public address system.

4.3 **Signalling assets**

The signalling system provided in EW Metro is a radio based signalling system which will conform to European Standards (CENELAC). It has following features:

- It will ensure prevention of collisions by enforcement of safe train separation.
- The system is being designed to maintain the operation headway of 2.5 minutes.
- Automatic operation of the trains between stations, automatic stopping of trains at platform and automatic opening of train door and platform screen door (PSD) on the appropriate platform.
- Entire train movement can be monitored in real-time and controlled from the operation control centre (OCC) at Central Park Depot & back up control centre at Howrah station. Using the Tetra Train Radio, the train operator can be contacted from the control centre at any time.
- CBTC Based Signalling system will allow Automatic Train Operation with minimal intervention from the train operator.
- On-time arrival and departure of trains with the help of Automatic Train Supervision (ATS) feature. Real time Passenger information support system at the stations is provided.

**CBTC Subsystem Architecture**

The Core CBTC subsystem consists of:

1. Wayside equipment (orange in Figure below), including the following:
   - The FRONTAM, which interfaces with the Automatic Train Supervision (ATS),
   - The Zone Controller (ZC) & Transponder Tags.

2. Onboard equipment (blue in Figure below), including the following:
   - The Train Operator Display (TOD).
The Carborne Controller (CC).

These equipments communicate among themselves through a Data Communication System (DCS) (green in Figure below).

The DCS is separated into fixed installations (Wayside DCS) and mobile installations on board (Carborne DCS):

- The Wayside DCS is an interface with CBTC wayside equipment i.e. the FRONTAM, the Zone Controller (ZC) and the Interlocking (IXL). It supports the potential connection with various other wayside equipment which do not have an active role within the CBTC system such as Axle counter, Platform Screen Door (PSD).

- The Carborne DCS is an interface with CBTC on board equipment i.e. Carborne Controller (CC).

The core CBTC system is interfaced with the following external systems (yellow in Figure below):

(i). The PSC which manages Platform Screen Door (PSD)

(ii). The ATS, for the supervision and the control of the core CBTC system,

(iii). The Tag Reader Systems (TRS)

(iv). Bi BTM, bi antennas configuration: two TRS per CC, each of them made of

(v). one BTM + one Antenna + wires

(vi). The Rolling Stock (RS) including the Train Management System (TMS)

(vii). The onboard Passenger Information System (PIS)
Figure 33: CBTC System Architecture
Zone Controller (ZC)
The Zone Controller receives information from the Computer Based Interlocking (CBI) (all vital information from track side inputs) and Carborne Controllers (CCs) (location of trains), determines a train location map (location of all trains on the line) and sends a Movement Authority Limit (MAL) to each train. The total number of ZCs depends on the configuration of the line and the number of trains subject to their supervision.

FRONTAM (FTM)
FRONTAM includes mainly two functions - interface management with ATS, called FRONTAL, and maintenance management for Core CBTC System. Installed in the central control room, it is a single unit including devices such as servers and workstations.

The zone controller (ZC) is based on 2003 architecture and thus is resistant to a single failure. The ZC also implements automatic reboot at board level in case of board failure. Assuming that the board that has failed is able to reboot, the ZC can recover full operation without human Intervention.
Carborne Controller (CC)

The CC supervises and controls the train movement, through its ATO/TMS interface and triggers an Emergency braking intervention when the safety situation requires it.

The KMRCL project trains have a Bi-CC configuration. The CCs are located at each end of the train in the cabin and each CC manages one cab. Each CC has its own peripheral equipment.

The MR is the carborne radio device for relaying data between carborne equipment (e.g. ATP and ATO) and wayside equipment. Local communications between the Carbone Controllers are transmitted through the onboard wired network.

![Train Operator Display (TOD)](image)

**Figure 35: Train Operator Display (TOD)**

![Operations menu for ATS operations](image)

**Figure 36: Operations menu for ATS operations**
4.4 Telecom Assets

**CCTV**
The system consists of IP based cameras and motorized IP PTZ CCTV cameras, video management units and video recording units placed at different locations to ensure the redundancy, robustness and stability of the system. Its main purpose is to monitor the boarding and detraining of passengers at platform levels in all stations.

CCTV system installed here has the following video analytic features:- Trip wire, Unidentified object detection, falling on the track etc. CCTV camera installed here are Honeywell make, Switches by Alcatel and Servers by HP.

**Backbone Routers (BBRS)**
The BBRS/DCS system will transmit the video streams from the on-board CCTV cameras to the stations & OCC over the FOTS(GE) network. The On-board cameras server at the stations & OCC will receive the video stream which can be accessed through the client application installed in the ground CCTV MMI.

**DCS**
The Data Communications System (DCS) is a broadband communication system that provides bi-directional, reliable and secured exchange of vital data from on-board CBTC and non-vital data which is collected from BBRS to OCC. To ensure high availability level required for CBTC and BBRS, DCS will operate in two parallel networks. At network level, there shall be two networks (Alpha (α) and Beta (β)) which instead of operating in redundant...
manner will operate in parallel to each other. Unlicensed frequency bands 2.4 GHZ and 5.8 GHZ is used.

Figure 38 : DCS as a medium for CBTC & BBRS

DCS system is Hirschman make and the product is Beldan make.

PIDS
The Passenger Information Display System (PIDS) shall be the primary means of visual communications with Passengers at Station Concourses and Platforms for the notification of scheduled Train arrivals / departures and for operational, normal and emergency including evacuation message displays to Passengers. The PIDS shall have Control equipment located in the Equipment Rooms of each Station, the OCC and BCC. The servers are HP make, TFTD monitors are LG make (Industrial Grade), Software is Nusyn make.

PAS
Public Address System is the primary means of audio communication with passengers at each Station, Concourses, Entry / Exits, Up Platform, Down Platform, staff areas including Office Rooms and staff toilets.

ACS
ACCESS CONTROL SYSTEM is installed at the entry/exit doors of SCR Room, signal telecom equipment rooms etc. to generate alarm in case of unauthorised Access. ACS is Honeywell make.
**Telephone Exchange**
Omni PCX enterprise (OXE) Exchange is installed at East-West Metro. It is provided on the FOTS backbone. It is interfaced with PAS, CSS, MCS, PSTN etc. It is Alcatel make.

**FOTS/GE**
(Fibre Optic transmission system/Gigabit ethernet) It is the communication backbone for all the telecom subsystems like PIDS, PAS, CCTV, ACS, MCS, EXCHANGE, TETRA, CSS etc.
STM- Tejas [OCC –STM 16, Station- STM 4], PD Mux -Vertive.

**TETRA**
It is provided for Communication between OCC and loco pilot, maintenance staffs, Station Master, traffic supervisor etc in both elevated and tunnel section.
In the OCC/CER there is MSO, BTS, NMS, MMI etc. and at stations- BTS, leaky cables are used in Tunnel sections.
Motorola make. IBS is Celcom make.

**MCS**
This is the Master clock system integrated with all other sub-systems for timing synchronization. Mobatime make.

**CSS**
Central supervising System is designed to monitor the Telecom Subsystem equipment that include FOTS, Telephone, Radio(Tetra), BBRS/DCS, PAS, PIDS, CCTV, MCS, ACS and UPS system. It is Athenta make.

### 4.5 List of Signalling Assets at E-W Metro Corridor

**A) Signals**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Description</th>
<th>Total Nos.</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Main Signal Mainline (3 aspect)</td>
<td>23</td>
</tr>
<tr>
<td>2</td>
<td>Main Signal Mainline (2 aspect)</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Main Signal Mainline (1 aspect)</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Main Signal Depot (2 aspect)</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Main Signal Depot (1 aspect)</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>Shunt Signal Depot</td>
<td>30</td>
</tr>
</tbody>
</table>
(B) Point Machines (Vossloh make)

<table>
<thead>
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<th>Description</th>
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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Point Machine at Depot (trailable type)</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>Point Machine at Depot (Non-trailable type)</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Point Machine at Mainline (Non-trailable type)</td>
<td>19</td>
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</table>

(C) Axle Counters (Frauscher make)

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Detection Point (Mainline + Depot)</td>
<td>128</td>
</tr>
<tr>
<td>2</td>
<td>Axle counter rack (mainline + depot)</td>
<td>9</td>
</tr>
</tbody>
</table>

(D) UPS (Vertiv make 3 phase online UPS (1+1) with load sharing basis)

<table>
<thead>
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<th>Description</th>
<th>Total Nos.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>For OCC</td>
<td>2X 160KVA</td>
</tr>
<tr>
<td>2</td>
<td>For Depot</td>
<td>2X 120KVA</td>
</tr>
<tr>
<td>3</td>
<td>For Interlocked Stn. (point zone)</td>
<td>2X 80KVA</td>
</tr>
<tr>
<td>4</td>
<td>For Non-interlocked Stn. (non-point zone)</td>
<td>2X 60KVA</td>
</tr>
</tbody>
</table>

(E) Electronic Interlocking (MICROLOK  Hot standby configuration with CC 3.20 executive version)

<table>
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<th>Description</th>
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</tr>
</thead>
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<tr>
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<td>Microlok rack mainline</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>Microlok rack depot</td>
<td>6</td>
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</tbody>
</table>

(F) Platform Screen Door (PSD)

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<th>Description</th>
<th>Total Nos.</th>
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</thead>
<tbody>
<tr>
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<td>Platform Screen Door</td>
<td>24</td>
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<tr>
<td>2</td>
<td>Emergency Exit Door</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>Maintenance Service Door</td>
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### 4.6 List of Telecom Assets at E-W Metro Corridor

<table>
<thead>
<tr>
<th>Station: SVSA</th>
<th>Gear</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCTV</td>
<td>1. Camera-37</td>
<td></td>
</tr>
<tr>
<td>PIDS</td>
<td>1. LCD Monitor-15, 2. DSLD -4, 3. SSLD -6</td>
<td></td>
</tr>
<tr>
<td>PAS</td>
<td>1. Ceiling 6w-184, 2. Projector 20w-95</td>
<td></td>
</tr>
<tr>
<td>ACS</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>MCS</td>
<td>1. 8 Digital, 2. 3 Analog</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Station: KESA</th>
<th>Gear</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCTV</td>
<td>1. Camera-37</td>
<td></td>
</tr>
<tr>
<td>PIDS</td>
<td>1. LCD Monitor-11, 2. DSLD -4, 3. SSLD -6</td>
<td></td>
</tr>
<tr>
<td>PAS</td>
<td>1. Ceiling 6w-55, 2. Projector 20w-59</td>
<td></td>
</tr>
<tr>
<td>ACS</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>MCS</td>
<td>1. 8 Digital, 2. 3 Analog</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Station: CPSA</th>
<th>Gear</th>
<th>Description</th>
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</thead>
<tbody>
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<td>CCTV</td>
<td>1. Camera-33</td>
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</tr>
<tr>
<td>PIDS</td>
<td>1. LCD Monitor-15, 2. DSLD -4, 3. SSLD -5</td>
<td></td>
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<tr>
<td>PAS</td>
<td>1. Ceiling 6w-54, 2. Projector 20w-74</td>
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</tr>
<tr>
<td>ACS</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>MCS</td>
<td>1. 8 Digital, 2. 3 Analog</td>
<td></td>
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<tr>
<th>Station: CCSC</th>
<th>Gear</th>
<th>Description</th>
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</thead>
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<td>CCTV</td>
<td>1. Camera-33</td>
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</tr>
<tr>
<td>PIDS</td>
<td>1. LCD Monitor-11, 2. DSLD -4, 3. SSLD -6</td>
<td></td>
</tr>
<tr>
<td>PAS</td>
<td>1. Ceiling 6w-55, 2. Projector 20w-68</td>
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<tr>
<td>ACS</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Telephone</td>
<td>1. 8 Digital, 2. 3 Analog</td>
<td></td>
</tr>
</tbody>
</table>
Station: BCSD

<table>
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<tr>
<th>Gear</th>
<th>Description</th>
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<tbody>
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<td>CCTV</td>
<td>1. Camera-35</td>
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<tr>
<td>PIDS</td>
<td>1. LCD Monitor-11</td>
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<tr>
<td></td>
<td>2. DSLD -4</td>
</tr>
<tr>
<td></td>
<td>3. SSLD -6</td>
</tr>
<tr>
<td>PAS</td>
<td>1. Ceiling 6w-32</td>
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<tr>
<td></td>
<td>2. Projector 20w-59</td>
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<td>ACS</td>
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<td>Telephone</td>
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<td>MCS</td>
<td>1.8 Digital</td>
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<td></td>
<td>2.3 Analog</td>
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Station: SSSA

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<td>PIDS</td>
<td>1. LCD Monitor-11</td>
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<td></td>
<td>2. DSLD -4</td>
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<td></td>
<td>3. SSLD -6</td>
</tr>
<tr>
<td>PAS</td>
<td>1. Ceiling 6w-72</td>
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<td></td>
<td>2. Projector 20w-57</td>
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<td>ACS</td>
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</tr>
<tr>
<td>MCS</td>
<td>1.8 Digital</td>
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<td></td>
<td>2.3 Analog</td>
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Station: PHOOL BAGAN

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<tbody>
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<td>CCTV</td>
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<td>PIDS</td>
<td>1. LCD Monitor-7</td>
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<tr>
<td></td>
<td>2. DSLD -2</td>
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<tr>
<td></td>
<td>3. SSLD -6</td>
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<td>PAS</td>
<td>1. Ceiling 6w-88</td>
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<td></td>
<td>2. Projector 20w-41</td>
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<td>MCS</td>
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<table>
<thead>
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<th>CCTV</th>
<th>CLOCK</th>
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<tbody>
<tr>
<td>Admin</td>
<td>11</td>
<td>33</td>
</tr>
<tr>
<td>yard</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Work shop</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>
4.7 Building Requirements

At OCC
OCC (Operational Control Centre) Room with Video display and all workstations.

Central Equipment Room
Containing FOTS, DCS, GE, MSO, PIDS, PAS, ATS, ZC, Frontam cabinets and NMS of DCS, Tetra, PIDS, PAS, CCTV, ACS, MCS etc.

Signalling Equipment Room for Depot
Containing Microlok racks, EN racks, VI Racks, PD1, PD2 racks etc.

Power Room
Containing 3 Phase UPS with standby and battery set.

Stations
Signalling Equipment Room, Telecom Equipment Room, UPS Room, Station Control Room etc.
Annexure

Metro Railways General Rules 2013
& Opening of Metro Railways for Public Carriage of Passengers Rules 2013

Link:
MOST IMMEDIATE

No.K-14011/14/2012-Metro/MRTS-II
Government of India
Ministry of Urban Development
(MRTS-Cell)

Room No. 311'B' Wing, Nirman Bhawan,
New Delhi.-110108, the 7th February, 2013

To,

All the Managing Directors / CEO
of Metro Rail Corporation as per list attached.

Subject: Metro Railways General Rules, 2013 and Opening of Metro
Railways for Public Carriage of Passengers Rules, 2013

Sir,

I am directed to refer to the above stated subject and to forward
herewith a copy of the above mentioned Rules, applicable on all Metro
Railways in the country under the Central Metro Acts (except Kolkata Metro
Railway), which have been approved by the Central Government and also
vetted by Ministry of Law and Justice. The said Rules are under Hindi
translation. The Rules will be notified as soon as the Hindi translation is done.

2. You are advised to please take all necessary actions so that
implementation of the Rules can be done in your Metro Railway soon after the
notification of these Rules. It may be noted that the existing Rules will be
denotified within 30 days from the date of publication of the above mentioned
Rules in the Gazette of India.

Yours faithfully,

Encl. As above.

Under Secretary to the Govt. of India
Telefax. 23082935
E-mail: deen.dayal69@nic.in
1. The Managing Director,
   Delhi Metro Rail Corporation Ltd.,
   Metro Bhawan, Fire Brigade Lane,
   Barakhamba Road,
   New Delhi-110001

2. The Managing Director,
   Chennai Metro Rail Ltd.,
   Harini Towers, No. 7,
   Conran Smith Road, Gopalapuram
   Chennai-600086

3. The Managing Director,
   Kolkata Metro Rail Corporation
   Ltd.,
   4th floor, HRBC House,
   Munshi Premchand Sarani,
   Kolkata-700021

4. The Managing Director,
   Bangalore Metro Rail Corporation
   Ltd.,
   3rd Floor, BMTC Complex,
   K.H. Road, Shankinagar,
   Bangalore-560 027.

5. The Managing Director,
   Hyderabad Metro Rail Ltd.,
   Metro Rail Bhawan, Saifabad,
   Hyderabad-500004

6. The Commissioner,
   MMRDA,
   Bandra Kurla Complex, Bandra
   (East),
   Mumbai-400051

7. The Managing Director,
   Jaipur Metro Rail Corporation Ltd.,
   Khanij Bhawan, Udyog Bhawan
   Premises, Tilak Marg C. Scheme,
   Jaipur – 302005

8. The Managing Director,
   Mumbai Metro Rail Corporation
   Ltd.,
   Bandra Kurla Complex, Bandra
   (East).
   Mumbai-400051

9. The Managing Director,
   Kochi Metro Rail Ltd.,
   8th Floor, Revenue Tower, Park
   Avenue, Kochi- 682011
   Kerala.

10. The Managing Director,
    Rapid Metro Rail Gurgaon,
    2nd Floor, Ambiance Corporate
    Tower, Ambiance Mall Complex,
    N.H.6, Gurgaon - 122001.

11. The Managing Director,
    Delhi Airport Metro Express Pvt. Ltd.,
    (Near Dwarka Sector 8 Metro
    Station),
    Sector 21, Dwarka,
    New Delhi

12. The Chief Executive Officer,
    Reliance Infrastructure,
    Mumbai Metro One Pvt. Ltd.
    Mumbai Metro One Depot,
    D.H. Nagar, RSS Building,
    J.P. Road, 4 Bungalow,
    Opp. 4 Bungalow Grudawara,
    Andheri (W),
    Mumbai-400053
Copy for information to:

1. Shri Prashant Kumar, Chief Commissioner of Railway Safety, Ashok Marg, Lucknow (Email: chiefcom@sancharnet.in).

2. Shri K. K. Aggarwal, Executive Director (Works Planning), Ministry of Railways, Railway Board, Rail Bhavan, New Delhi.

Copy also to:

Director, NIC, for hosting on MoUD website under the heading Urban Transport.

(Deen Dayal)
Under Secretary to the Govt. of India
GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS
(Railway Board)

No.2020/Safety(A&R)/19/31 New Delhi, dated 29.10.2020

OFFICE MEMORANDUM

Sub: Metro Railway General Rules, 2020 reg.
Ref: Ministry of Housing & Urban Affairs’ OM No.K-14011/15/2017-MRTS-II dated 03 August 2020

The undersigned is directed to refer to Ministry of Housing and Urban Affairs (MRTS-II Desk) OM referred to above forwarding therewith a copy of draft Metro Railways General Rules, 2020 for comments of Ministry of Railways. The above draft Rules have been examined by concerned directorates and have been approved by Railway Board (Member / Infra, Member / TRS, Member / O&BD and CRB & CEO) subject to following observations/conditions:

(i) Para 30(4) of MRGR, 2020 deal with failure of brakes to apply or release brakes. The para needs to be modified to keep in view the fact that even if brakes do not release in one bogie and the train is moved, it will result in skidding / development of flat places on the wheel.

Following suggestions may be incorporated:

(a) The brakes need to be released in all the bogies before the train is moved. However, in emergent situations when it may not be possible to release the brakes, the rake may be moved at restricted speed to next station where certified person should attend the rake and certify it fit for further operations before it is allowed in service.
(b) In case of complete failure of brake system leading to less than minimum design braking effort, train shall be withdrawn and passengers shall be detrained at the station.

(ii) In para 101(8) spelling of brake to be corrected.

(iii) As per Para 92(1) & (2), Cab Signalling and Automatic Train Protection are two different things, however as per para 22(1) both are same. Required correction may be made.

(iv) Word ‘Train Control System’ is used in CBTC (Communication Based Train Control) system and CATC (Continuous Automatic Train Control) System as part of Signalling system. As such may not be issued in para 100(3), which do not pertain to failure of Signalling system.

(v) Enabling provisions for introduction of Unattended Train Operation (UTO) and Driverless Train Operation (DTO) may be agreed to subject to adequate precautions to ensure the safety while introducing new system. The safety standards of other Metro Railways in the world where such system is in vogue should be followed in order to have safe operation of Metro trains.

Ministry of Housing and Urban Affairs is requested to take further action accordingly.

(K.P. Yadav)
Executive Director/Safety-II
Railway Board

Sh. K.K. Acharya
Under Secretary / MRTS-II Desk
Ministry of Housing and Urban Affairs,
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References

- Presentation slides on "Introduction to IEEE Standard -1474 CBTC" by Mr. B. Samby Reddy, IRSSE 1980, Chief Engineer - Efftronics Systems Pvt. Ltd., Vijayawada (A.P.)

- Presentation slides on "Conventional Vs CABS Vs CBTC Signalling & their impact to capacity" by Mr. Naeem M. Ali - Director & Principal Consultant, CBTC Solutions Inc., Toronto, Canada

- Radio communication for Communications-Based Train Control (CBTC): A tutorial and Survey - by Mr. Jahanzeb Farooq, Member, IEEE, and Mr. José Soler, Member, IEEE published in IEEE Communications Surveys & Tutorials in year 2017. (Downloaded from orbit.dtu.dk).

- Information on Kolkata East-West Metro Line 2 by SSTE/M II, Kolkata Metro.
“We at RDSO Lucknow are committed to maintain and update transparent standards of services to develop safe, modern and cost effective railway technology complying with statutory and regulatory requirements, through excellence in research, designs and standards by setting quality objectives, commitment to satisfy applicable requirements and continual improvements of the quality management system to cater to growing needs, demand and expectations of passenger and freight traffic on the railways through periodic review of quality management systems to achieve continual improvement and customer appreciation. It is communicated and applied within the organization and making it available to all the relevant interested parties.”
Communication Based Train Control

February 2021