

IEEE Standard for Communications- Based Train Control (CBTC) Performance and Functional Requirements

IEEE Vehicular Technology Society

Developed by the
CBTC & SIG Standards Committee

IEEE Std 1474.1™-2025
(Revision of IEEE Std 1474.1-2004)

STANDARDS

IEEE Standard for Communications-Based Train Control (CBTC) Performance and Functional Requirements

Developed by the

CBTC & SIG Standards Committee
of the
IEEE Vehicular Technology Society

Approved 27 March 2025

IEEE SA Standards Board

Abstract: Performance and functional requirements for a communications-based train control (CBTC) system are established in this standard. A CBTC system is a continuous, automatic train control system utilizing high-resolution train location determination, independent of track circuits; continuous, high-capacity, bidirectional train-to-wayside data communications; and train-borne and wayside processors capable of implementing automatic train protection (ATP) functions, as well as optional automatic train operation (ATO) and automatic train supervision (ATS) functions. In addition to CBTC functional requirements, this standard also defines headway criteria, system safety criteria, and system availability criteria for a CBTC system. This standard is applicable to the full range of transit applications including automated people movers. This standard establishes a set of performance and functional requirements necessary for enhancing performance, availability, operations, and train protection using a CBTC System.

Keywords: automation, CBTC, communications, IEEE 1474.1, signaling, train control

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2025 by The Institute of Electrical and Electronics Engineers, Inc. All rights reserved.
Published 13 June 2025. Printed in the United States of America.

IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 979-8-8557-1565-1 STD27822
Print: ISBN 979-8-8557-1566-8 STDPD27822

IEEE prohibits discrimination, harassment, and bullying.

For more information, visit <https://www.ieee.org/about/corporate/governance/p9-26.html>.

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE Standards documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page (<https://standards.ieee.org/ipr/disclaimers.html>), appear in all IEEE standards and may be found under the heading “Important Notices and Disclaimers Concerning IEEE Standards Documents.”

Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents

IEEE Standards documents are developed within IEEE Societies and subcommittees of IEEE Standards Association (IEEE SA) Board of Governors. IEEE develops its standards through an accredited consensus development process, which brings together volunteers representing varied viewpoints and interests to achieve the final product. IEEE standards are documents developed by volunteers with scientific, academic, and industry-based expertise in technical working groups. Volunteers involved in technical working groups are not necessarily members of IEEE or IEEE SA and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE makes no warranties or representations concerning its standards, and expressly disclaims all warranties, express or implied, concerning all standards, including but not limited to the warranties of merchantability, fitness for a particular purpose and non-infringement. IEEE Standards documents do not guarantee safety, security, health, or environmental protection, or compliance with law, or guarantee against interference with or from other devices or networks. In addition, IEEE does not warrant or represent that the use of the material contained in its standards is free from patent infringement. IEEE Standards documents are supplied “AS IS” and “WITH ALL FAULTS.”

Use of an IEEE standard is wholly voluntary. The existence of an IEEE standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity, nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document should rely upon their own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: THE NEED TO PROCURE SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

Translations

The IEEE consensus balloting process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English language version published by IEEE is the approved IEEE standard.

Use by artificial intelligence systems

In no event shall material in any IEEE Standards documents be used for the purpose of creating, training, enhancing, developing, maintaining, or contributing to any artificial intelligence systems without the express, written consent of IEEE SA in advance. “Artificial intelligence” refers to any software, application, or other system that uses artificial intelligence, machine learning, or similar technologies, to analyze, train, process, or generate content. Requests for consent can be submitted using the Contact Us form.

Official statements

A statement, written or oral, that is not processed in accordance with the IEEE SA Standards Board Operations Manual is not, and shall not be considered or inferred to be, the official position of IEEE or any of its committees and shall not be considered to be, or be relied upon as, a formal position of IEEE or IEEE SA. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that the presenter’s views should be considered the personal views of that individual rather than the formal position of IEEE, IEEE SA, the Standards Committee, or the Working Group. Statements made by volunteers may not represent the formal position of their employer(s) or affiliation(s). News releases about IEEE standards issued by entities other than IEEE SA should be considered the view of the entity issuing the release rather than the formal position of IEEE or IEEE SA.

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE or IEEE SA. However, **IEEE does not provide interpretations, consulting information, or advice pertaining to IEEE Standards documents.**

Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its Societies and subcommittees of the IEEE SA Board of Governors are not able to provide an instant response to comments or questions, except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in evaluating comments or revisions to an IEEE standard is welcome to join the relevant IEEE SA working group. You can indicate interest in a working group using the Interests tab in the Manage Profile and Interests area of the [IEEE SA myProject system](#).¹ An IEEE Account is needed to access the application.

Comments on standards should be submitted using the [Contact Us](#) form.²

Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not constitute compliance to any applicable regulatory

¹ Available at: <https://development.standards.ieee.org/myproject-web/public/view.html#landing>.

² Available at: <https://standards.ieee.org/about/contact/>.

requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Data privacy

Users of IEEE Standards documents should evaluate the standards for considerations of data privacy and data ownership in the context of assessing and using the standards in compliance with applicable laws and regulations.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under US and international copyright laws. They are made available by IEEE and are adopted for a wide variety of both public and private uses. These include both use by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making these documents available for use and adoption by public authorities and private users, neither IEEE nor its licensors waive any rights in copyright to the documents.

Photocopies

Subject to payment of the appropriate licensing fees, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400; <https://www.copyright.com/>. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Updating of IEEE Standards documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect.

Every IEEE standard is subjected to review at least every 10 years. When a document is more than 10 years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit [IEEE Xplore](#) or [contact IEEE](#).³ For more information about the IEEE SA or IEEE's standards development process, visit the IEEE SA Website.

Errata

Errata, if any, for all IEEE standards can be accessed on the [IEEE SA Website](#).⁴ Search for standard number and year of approval to access the web page of the published standard. Errata links are located under the Additional Resources Details section. Errata are also available in [IEEE Xplore](#). Users are encouraged to periodically check for errata.

³ Available at: <https://ieeexplore.ieee.org/browse/standards/collection/ieee>.

⁴ Available at: <https://standards.ieee.org/standard/index.html>.

Patents

IEEE standards are developed in compliance with the [IEEE SA Patent Policy](#).⁵

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE SA Website at <https://standards.ieee.org/about/sasb/patcom/patents.html>. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

IMPORTANT NOTICE

Technologies, application of technologies, and recommended procedures in various industries evolve over time. The IEEE standards development process allows participants to review developments in industries, technologies, and practices, and to determine what, if any, updates should be made to the IEEE standard. During this evolution, the technologies and recommendations in IEEE standards may be implemented in ways not foreseen during the standard's development. IEEE standards development activities consider research and information presented to the standards development group in developing any safety recommendations. Other information about safety practices, changes in technology or technology implementation, or impact by peripheral systems also may be pertinent to safety considerations during implementation of the standard. Implementers and users of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, data privacy, and interference protection practices and all applicable laws and regulations.

⁵ Available at: <https://standards.ieee.org/about/sasb/patcom/materials.html>.

Participants

At the time this IEEE standard was completed, the Communications-Based Train Control Working Group had the following membership:

Yousef Kimiagar, *Chair*

Dave Keevill, *Vice Chair*

Rajee Alexander
Kurt Andersen
Ridhuan Awang
Philippe Ayrault
Yarah Ismail Ali
Basyoni
Nicholas Columbare
Muamer Dedovic
Kenneth Diemunsch
David Dimmer
Stephane Dubois
Alireza Edraki
Antonio
Gaite De Las Heras

Neil Glennie
Ivan Grigorchenkov
John Hofbauer
Kenneth Karg
Srinivas Kumar
Katreddi
Benjamin Koers
Robert Major
David Male
Wilson Milian
Venugopal Nair

Ajay Nayyar
Kourosh Noori
Lisaidyn Perez
Lou Sanders
Will Serrano
Ali Siadati
Narayana Sundaram
Dan Testa
Carl Thompson
Michael Thornburg
David Thurston
Mehmet Turan
Söylemez
Lamont Ward

The following members of the individual Standards Association balloting group voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

Rajee Alexander
David Dimmer
Marc Emmelmann
Antonio
Gaite De Las Heras
Marco Hernandez
Werner Hoelzl
Oliver Holland

Andrew Jones
Kenneth Karg
Piotr Karocki
Srinivas Kumar
Katreddi
Yousef Kimiagar
Wilson Milian
Kourosh Noori
Dev Paul

Stephan Sand
Carl Schwellnus
Jhony Sembiring
Carl Thompson
Michael Thornburg
David Thurston
John Vergis
Weiping Wu

When the IEEE SA Standards Board approved this standard on 27 March 2025, it had the following membership:

Lei Wang, *Chair*

Jon Walter Rosdahl, *Vice Chair*

David J. Law, *Past Chair*

Alpesh Shah, *Secretary*

Edward Au
Ted Burse
Xiaofeng (Alfred) Chen
Doug Edwards
Nehad El-Sherif
J. Travis Griffith
Deborah R. Hagar

Guido R. Hiertz
Ronald W. Hotchkiss
Tyler L. Jaynes
Thomas Koshy
Howard Li
Xiaohui Liu
Kevin W. Lu
Hiroshi Mano

Daleep C. Mohla
Annette D. Reilly
Robby Robson
Daniel Sabin
F. Keith Waters
Sha Wei
Luyang (Eric) Zhang

Introduction

This introduction is not part of IEEE Std 1474.1-2025, IEEE Standard for Communications-Based Train Control (CBTC) Performance and Functional Requirements.

This introduction provides some background on the rationale used to develop this standard. This information is meant to aid in the understanding, usage, and applicability of this standard.

Conventional signaling/train control systems rely almost exclusively on track circuits to detect the presence of trains. Information on the status of the track ahead is provided to train operators either through wayside signals or train-borne cab signals. Ensuring compliance with the signals is achieved through operating procedures, wayside automatic train stops, or train-borne supervisory equipment linked to the train's braking system. These conventional systems are effective in providing train protection, but are not particularly efficient in maximizing the utilization of the rail transit infrastructure, as a result of a few fundamental limitations, specifically, the following:

- a) The location of trains can only be determined to the resolution of the track circuits; if any part of a track circuit is occupied by a train, the whole track circuit shall be assumed to be occupied by the train. Track circuits can be made shorter, but each additional track circuit requires additional wayside hardware, so there is an economical and practical limit to the number of track circuits that can be provided.
- b) The information that can be provided to a train is limited to a small number of wayside signal aspects or a small number of speed codes in a cab signal system.
- c) For a wayside signal system with automatic train stops but without continuous cab signaling, enforcement is intermittent.

Communications-based train control (CBTC) systems overcome these fundamental limitations of conventional track circuit-based systems, and therefore, permit more effective utilization of the transit infrastructure. This is accomplished, for example, by allowing trains to operate safely at much closer headways, by permitting greater flexibility and greater precision in train control, and by providing continuous safe train separation assurance and overspeed protection. Additional benefits of CBTC technology include the economical support of automatic train operations (both on the mainline and in maintenance yards), improved reliability, and reductions in maintenance costs through a reduction in wayside equipment and real-time diagnostic information. The basic characteristics of a CBTC system include the following:

- Determination of train location, to a high degree of precision, independent of track circuits.
- A geographically continuous train-to-wayside and wayside-to-train data communications network to permit the transfer of significantly more control and status information than is possible with conventional systems.
- Wayside and train-borne vital processors to process the train status and control data and provide continuous automatic train protection (ATP). Automatic train operation (ATO) and automatic train supervision (ATS) functions can also be provided, as required by the particular application.

There are currently no independent standards defining the performance and functional requirements to be satisfied by CBTC systems. This standard enhances performance, availability, operations, and train protection, and facilitates design, development, deployment and commissioning of new CBTC applications.

This standard provides standards for Communications Based Train Control functionality. It provides a consistent approach for design and development of these transit control systems. This revision allows for driverless train operation, including automatic people movers.

As technology changes and evolves the architecture and functionality, and subsequently the standards, of Communications-Based Train Control require modification. This revision provides the vehicle to modify CBTC standards to comply with changing needs in function and safety.

Contents

1. Overview	11
1.1 Scope	11
1.2 Purpose	11
1.3 Range of Applications	11
1.4 Existing Applications	11
1.5 Word usage	12
2. Normative references	12
3. Definitions, acronyms, and abbreviations	13
3.1 Definitions	13
3.2 Acronyms and abbreviations	16
4. General requirements	17
4.1 Characteristics of CBTC systems	17
4.2 Categorization of CBTC systems	17
4.3 Train Configurations	17
4.4 Train operating modes	17
4.5 Entering/exiting CBTC territory	20
4.6 Train operating speeds	20
5. Performance requirements	21
5.1 CBTC factors contributing to achievable headways	21
5.2 CBTC factors contributing to achievable trip times	21
5.3 System safety requirements	22
5.4 System assurance requirements	25
5.5 Environmental requirements	27
6. Functional requirements	27
6.1 ATP functions	27
6.2 ATO functions	35
6.3 ATS functions	37
6.4 Interoperability interface requirements	41
Annex A (informative) Bibliography	42
Annex B (informative) Example functional block diagram for a typical CBTC system	43
Annex C (informative) Typical CBTC parameters	44
Annex D (informative) Typical safe braking model	45
Annex E (normative) System Safety and Security Program requirements	48
Annex F (informative) Typical approaches to specifying CBTC system availability	58

List of Figures

Figure B.1—Example functional block diagram for a typical CBTC system 43

Figure D.1—Typical safe braking model 47

List of Tables

Table C.1—Typical CBTC parameters..... 44

Table E.1—Risk assessment..... 56

IEEE Standard for Communications-Based Train Control (CBTC) Performance and Functional Requirements

1. Overview

This standard establishes performance and functional requirements for a communications-based train control (CBTC) system. It is divided into six clauses. [Clause 1](#) describes the scope and purpose of this standard. [Clause 2](#) lists references that are useful in applying this standard. [Clause 3](#) provides definitions that are either not found in other standards or have been modified for use with this standard. [Clause 4](#) defines the general operating requirements for CBTC systems, including train operating modes to be supported. [Clause 5](#) defines the performance requirements for CBTC systems, including headway criteria, system safety criteria, and system availability criteria. [Clause 6](#) defines the functional requirements for CBTC systems, including automatic train protection (ATP) functions, automatic train operation (ATO) functions, and automatic train supervision (ATS) functions.

1.1 Scope

This standard establishes a set of performance and functional requirements necessary for enhancing performance, availability, operations, and train protection using a CBTC system.

1.2 Purpose

There are currently no independent standards defining the performance and functional requirements to be satisfied by CBTC systems. This standard enhances performance, availability, operations, and train protection, and facilitates new CBTC applications.

1.3 Range of Applications

The CBTC performance and functional requirements defined in this standard are intended to be applicable to the full range of transit applications, including commuter rail, heavy rail, light rail, and monorail transit systems, and shall be applicable to other transit applications, such as automated people movers (APMs) if CBTC is used for automated train control (ATC).

1.4 Existing Applications

Existing CBTC installations and projects in progress prior to the publication of this standard need not comply with the new or revised requirements of this standard, IEEE Std 1474.1–20xx, except where specifically required by the authority having jurisdiction.

1.5 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{6,7}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 1474.2™-2025, IEEE Standard for User Interface Requirements in Communications-Based Train Control (CBTC) Systems.,^{8,9}

IEEE Std 1475™-2012, IEEE Standard for the Functioning of and Interfaces Among Propulsion, Friction Brake and Train-borne Master Control on Rail Rapid Transit Vehicles.

IEEE Std 1477™-1998, IEEE Standard for Passenger Information System for Rail Transit Vehicles.

IEEE Std 1478™-2013, IEEE Standard for Environmental Conditions for Transit Rail Car Electronic Equipment.

IEEE Std 1483™-2000, IEEE Standard for Verification of Vital Functions in Processor-Based Systems Used in Rail Transit Control.

IEEE Std 1570™-2002, IEEE Standard for the Interface Between the Rail Subsystem and the Highway Subsystem at a Highway Rail Intersection.

⁶ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁷ The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

⁸ The IEEE standards or products referred to in this clause are trademarks of The Institute of Electrical and Electronics Engineers, Inc.

⁹ IEEE publications are available from The Institute of Electrical and Electronics Engineers, Inc., <http://standards.ieee.org/>.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.¹⁰

authority having jurisdiction (AHJ): An entity that has the power to make decisions relating to the direct or delegated responsibilities assumed in conjunction with the application of a standard or recommended practice.

automated people movers (APMs): A guided transit mode with fully automated operations, featuring vehicles that operate on guideways with exclusive right-of-way.

automatic train control (ATC): The system for automatically controlling train movement, enforcing train safety, and directing train operations. ATC includes automatic train protection (ATP) and may include automatic train operation (ATO) and/or automatic train supervision (ATS).

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

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

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

NOTE—The ATS subsystem also typically includes manual and automatic routing functions.¹¹

basic operating unit: **(A)** A single vehicle designed for independent operation. **(B)** A permanent or semi-permanent combination, designed for independent operation, consisting of two or more vehicles of one or more types.

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

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

car: *See: vehicle.*

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

communications-based train control (CBTC): A continuous ATC system utilizing high-resolution train location determination, independent of track circuits; continuous, high capacity, bidirectional train-to-wayside low-latency data communications; and train-borne and wayside processors capable of implementing vital functions.

¹⁰*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

¹¹ Notes in text, tables and figures are given for information only and do not contain requirements needed to implement the standard.

communications-based train control (CBTC) territory: the geographical area(s) of a rail network equipped for CBTC operation.

communications-based train control (CBTC) user: Any authority-authorized personnel who receive information from, provide information to, or perform repairs or maintenance on, a CBTC system.

communications-based train control (CBTC) user interface: That portion of the human machine interface in which the CBTC user interacts with the CBTC system to observe and/or perform functions implemented by the CBTC system. Includes, but is not limited to, displays, audible indicators, tactile entries, cursor positioning device implementations, and voice input devices.

communications-based train control (CBTC) user profiles: A definition of the vision, hearing, language and physical characteristics of the CBTC user.

commuter rail: A passenger railroad service that operates within metropolitan areas on trackage that usually is part of the general railroad system. The operations, primarily for commuters, are generally run as part of a regional system that is publicly owned or by a railroad company as part of its overall service.

consist: The makeup or composition (number and specific identity) of a basic operating unit or combination of basic operating units of a train.

control action: A request by a communications-based train control (CBTC) user for the CBTC system to perform an operation. A control action may require a single user input, or a sequence of user inputs, and a user requested control action may be subject to verification checks prior to the CBTC system performing the requested operation.

coupling: the function of combining two consists into a new communications-based train control (CBTC) functional consist.

display screen: The surface of a display device on which the visual representation of data is presented.

driving mode: characterization of the manner in which human train operators interact with the train control system for operating a train ranging from manual operation without reliance on the train control system to fully automatic operation without reliance on human train operators.

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

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

function key: Assignable special purpose keys (e.g., on a computer keyboard, keypad or touchscreen) which the communications-based train control (CBTC) user employs to interact with the CBTC system.

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

heavy rail transit: A mode of rail rapid transit generally characterized by fully grade-separated construction, operating on exclusive rights-of-way and station platforms at the floor level of the vehicles.

human machine interface: an interface employing audible, visual and/or tactile devices, provide users with access to the CBTC system to receive information and/or to enter commands.

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

light rail transit: A mode of rail transit characterized by its ability to operate on exclusive rights-of-way, street running, center reservation running, and grade crossings, and to board and discharge passengers at track or vehicle floor level.

location reference: a unique and unambiguous identifier of a geospatial location within a reference location system.

mandatory: The referenced item is required to claim compliance with this standard.

master control: The train-borne device or system directly providing the control signals (propulsion, coast, and brake) to the train.

monorail: a railroad in which the track consists of a single rail, typically elevated, with the trains suspended from it or balancing on it.

movement authority: The permission for a train to enter and travel through a specific section of track, in a given travel direction. Movement authorities are assigned, supervised, and enforced by a CBTC system to maintain safe train separation and to provide protection of the train as it travels along the track.

movement authority limit: The boundaries within which the movement authority is permitted.

optional: The referenced item is not required to claim compliance with this standard. Implementation of an optional item shall be as defined in this standard.

page: A visual representation of data, graphics or text, that is presented on a display screen.

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

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

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

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

NOTE—Vital functions are a subset of safety-critical functions.

safety-related: Carries responsibility for safety.

self-revealing failure: Failures whose effects on system operation are immediately and clearly apparent.

service, revenue: **(A)** Transit service excluding deadheading or layovers. **(B)** Any service scheduled for passenger trips.

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

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

train: A consist of one or more basic operating units.

traffic locking: Electric locking which prevents the manipulation of levers or other devices for changing the direction of traffic into a section of track on which a route is lined, occupied, or locked.

un-coupling: the function of splitting a consist into two new and separate CBTC functional consists.

unit: *See: basic operating unit.*

vehicle: A land conveyance assembly for carrying or transporting people and objects capable of traversing a guideway, having structural integrity and general mechanical completeness, but not necessarily designed for independent operation.

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

window: In graphical user interfaces, a defined portion of the display screen that is separated by a frame from the rest of the screen and which may be opened, closed, resized and moved by the user.

3.2 Acronyms and abbreviations

APM	automated people mover
ATC	automatic train control
ATO	automatic train operation
ATP	automatic train protection
ATS	automatic train supervision
CBTC	communications-based train control
GEBR	guaranteed emergency brake rate
MTBF	mean time between failure
MTBFF	mean time between functional failure
MTBHE	mean time between hazardous event
MTTR	mean time to repair
MTTRS	mean time to restore service
O&SHA	operating and support hazard analysis
PHA	preliminary hazard analysis
SHA	system hazard analysis
SSHA	subsystem hazard analysis
SSPP	System Safety Program Plan

4. General requirements

4.1 Characteristics of CBTC systems

The primary characteristics of a CBTC system include the following:

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

4.2 Categorization of CBTC systems

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

- a) Automatic train protection (ATP) functions only, with no automatic train operation (ATO) or automatic train supervision (ATS) functions
- b) ATP functions, as well as certain ATO and/or ATS functions, as required to satisfy the operational needs of the specific application

A typical functional block diagram for a CBTC system is given in [Annex B](#).

4.3 Train Configurations

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

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

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

4.4 Train operating modes

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

For operation of trains with crews, the train operator will typically be stationed in the lead car of the train and will be responsible for moving the train from station to station. With a multi-person crew, the conductor(s) will normally operate from conductor position(s) within the train to operate the train's doors. A CBTC system shall support single-person train operation by combining the conductor and train operator display information on the train operator's display. For multi-person crews, conductor display information shall also be provided on separate conductor displays.

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

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

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

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

4.4.1 Normal train operating modes in CBTC territory

4.4.1.1 CBTC-equipped trains

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

4.4.1.2 Non-CBTC-equipped trains

Trains not equipped with train-borne CBTC equipment and/or trains with inoperative train-borne CBTC equipment that are operating in CBTC territory shall operate under the protection of the CBTC system using secondary train detection, or a supplementary systems and/or operating procedures, as specified by the authority having jurisdiction.

4.4.2 Failure mode train operations in CBTC territory

For light rail, heavy rail, monorail and commuter rail applications operating with crews, it is an operational requirement to continue to move trains safely in the event of CBTC equipment and/or data communication failures, possibly at reduced operating speeds and/or increased operating headways when compared to normal train operations. Consequently, a CBTC system shall be designed to support degraded modes of operation in the event of failure and to continue to provide ATP with minimum reliance on adherence to operating procedures as specified by authority having jurisdiction.

For fully automated applications operating without crews, the extent to which the CBTC system shall be designed to support degraded modes of operation in the event of failure shall be as defined by the authority having jurisdiction, and may include an ability to remotely reset train-borne equipment and the ability to support automatic push/pull train recovery, as well as the ability to support manual train operations and alternative routing strategies.

For all applications, a fallback plan, based on failure analysis and operating procedures, shall identify train operating modes that will take advantage of the degraded modes of operation and recovery capabilities of the CBTC system. The goal of the plan shall be to eliminate hazards to passengers and staff in accordance with 5.3, while continuing to provide passenger service.