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

IEEE Vehicular Technology Society

Sponsored by the
Rail Transit Vehicle Interface Standards Committee



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

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**Rail Transit Vehicle Interface Standards Committee
of the
IEEE Vehicular Technology Society**

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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.

Keywords: automation, communications, signaling, train control

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

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Introduction

[This introduction is not part of IEEE Std 1474.1-2004, 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 number of 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 must 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.

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:

- 1) Determination of train location, to a high degree of precision, independent of track circuits.
- 2) 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.
- 3) 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.

Although the benefits of CBTC technology are recognized, there are currently no independent standards defining the performance and functional requirements that need to be satisfied by CBTC systems in order to realize enhanced performance, availability, train operational flexibility, and train protection. This standard has been developed to address this.

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Participants

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

Alan F. Rumsey, *Chair*

George Achakji
Stephane Bois
Corinne Braban
Frederick Childs
Michael Crispo
Nicolas Estivals
Harold Gillen
Harvey Glickenstein
Vic Graponne

James Hoelsher
Geoff Hubbs
Kenneth A. Karg
John LaForce
Martin Lukes
Dave Male
Charles Martin
Norman. May
Bob Miller

William Petit
Venkat Pindiprolu
Carl Schwellnus
Mickey Senase
Errol Taylor
John Vogler
Ken Vought
Robert E. Walsh
David Zahorsky

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

Corinne Braban
Frederick Childs
Michael Crispo
David Dimmer
Jeff Eilenberg
Nicolas Estivals
Harvey Glickenstein

James Hoelsher
Geoff Hubbs
Kenneth A. Karg
John LaForce
Martin Lukes
Charles Martin
Norman May
Tom McGean

William Petit
Venkat Pindiprolu
Alan F. Rumsey
Louis Sanders
Jeffrey Smith
John Vogler
Robert E. Walsh

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Steve M. Mills, *Vice Chair*
Judith Gorman, *Secretary*

Chuck Adams
Stephen Berger
Mark D. Bowman
Joseph A. Bruder
Bob Davis
Roberto de Marca Boisson
Julian Forster*
Arnold M. Greenspan

Mark S. Halpin
Raymond Hapeman
Richard J. Holleman
Richard H. Hulett
Lowell G. Johnson
Joseph L. Koepfinger*
Hermann Koch
Thomas J. McGean
Daleep C. Mohla

Paul Nikolich
T. W. Olsen
Ronald C. Petersen
Gary S. Robinson
Frank Stone
Malcolm V. Thaden
Doug Topping
Joe D. Watson

*Member Emeritus

Also included are the following nonvoting IEEE-SA Standards Board liaisons:

Satish K. Aggarwal, *NRC Representative*
Richard DeBlasio, *DOE Representative*
Alan Cookson, *NIST Representative*

Don Messina
IEEE Standards Project Editor

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

1. Overview

This standard establishes performance and functional requirements for a 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 will enhance performance, availability, operations, and train protection and will facilitate new CBTC applications.

1.3 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 1474.1-2004, except where specifically required by the authority having jurisdiction.

2. Normative references

This standard shall be used in conjunction with the following publications. In case of a conflict between this standard and the referenced document, this standard shall take precedence. Those provisions of the referenced documents that are not in conflict with this standard shall apply as referenced.

IEEE Std 1474.2™-2003, IEEE Standard for User Interface Requirements in Communications-Based Train Control (CBTC) Systems.^{1,2}

IEEE Std 1475™-1999, 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 (Reaff 2003), IEEE Standard for Passenger Information System for Rail Transit Vehicles.

IEEE Std 1478™-2001, 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.

IEEE P1582™ (Draft 1.0, February 2002), Draft Standard for Environmental Requirements for Rail Transit Automatic Train Control Systems Wayside Equipment.³

3. Abbreviations, acronyms, and definitions

3.1 Definitions

For the purposes of this standard, the following terms and definitions apply. IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition [B4]⁴, should be referenced for terms not defined in this clause.

3.1.1 authority having jurisdiction: The entity that defines the contractual (including specification) requirements for the procurement.

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

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

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³This IEEE standards project was not approved by the IEEE-SA Standards Board at the time this publication went to press. For information about obtaining a draft, contact the IEEE.

⁴The numbers in brackets correspond to those of the bibliography in Annex A.

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

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

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

NOTE—The ATS subsystem also typically includes manual and automatic routing functions.⁵

3.1.7 auxiliary wayside system: A back-up or secondary train control system, capable of providing full or partial ATP for trains not equipped with train-borne CBTC equipment and/or trains with partially or totally inoperative train-borne CBTC equipment. The auxiliary wayside system may include train-borne equipment and may also provide broken rail detection.

3.1.8 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.

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

3.1.10 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.

3.1.11 car: *See: vehicle.*

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

3.1.13 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 data communications; and train-borne and wayside processors capable of implementing vital functions.

3.1.14 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.

3.1.15 consist: The makeup or composition (number and specific identity) of individual units of a train.

3.1.16 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.

3.1.17 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.

⁵Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

3.1.18 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.

3.1.19 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.

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

3.1.21 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.

3.1.22 master control: The train-borne device or system directly providing the control signals to the train.

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

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

3.1.25 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.

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

3.1.27 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.

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

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

3.1.30 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.

3.1.31 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.

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

3.1.33 unit: *See:* basic operating unit.

3.1.34 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.

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

3.2 Abbreviations and acronyms

APM	automated people mover
APTA	American Public Transportation Association
AREMA	American Railway Engineering and Maintenance-of-Way Association
ASCE	American Society of Civil Engineers
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 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

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

A typical functional block diagram for a CBTC system is given in Annex B.

4.3 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 light rail, heavy rail, and commuter rail transit systems, and shall be applicable to other transit applications, such as automated people movers (APMs) if CBTC is used for ATC.

NOTE—ASCE 21-96 [B3] establishes additional requirements related to operating environment, safety requirements, system dependability, and audio/visual communications for APM systems.

It is the intent of this standard that tiered levels of functionality, and interoperability between equipment provided by multiple vendors, are facilitated to the extent required by the authority having jurisdiction. All CBTC systems shall include ATP functions.

4.4 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.

4.5 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

4.5.1 Normal train operating modes in CBTC territory

4.5.1.1 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.

4.5.1.2 Non-CBTC-equipped trains

Trains not equipped with train-borne CBTC equipment and/or trains with inoperative train-borne CBTC equipment that are operating in CBTC territory shall operate under the protection of an auxiliary wayside system and/or operating procedures, as specified by the authority having jurisdiction.

4.5.2 Failure mode train operations in CBTC territory

For light rail, heavy rail, 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,