US 20220185350A1

(19) United States
(12) Patent Application Publication
Kindt et al.
(10) Pub. No.: US 2022/0185350 A1
(43) Pub. Date: Jun. 16, 2022

(54) **QUASI-MOVING BLOCK SYSTEM OF TRAIN CONTROL**

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(21) Appl. No.: **17/552,218**

(22) Filed: **Dec. 15, 2021**

Related U.S. Application Data

(60) Provisional application No. 63/125,518, filed on Dec. 15, 2020.

Publication Classification

(51) **Int. Cl.**

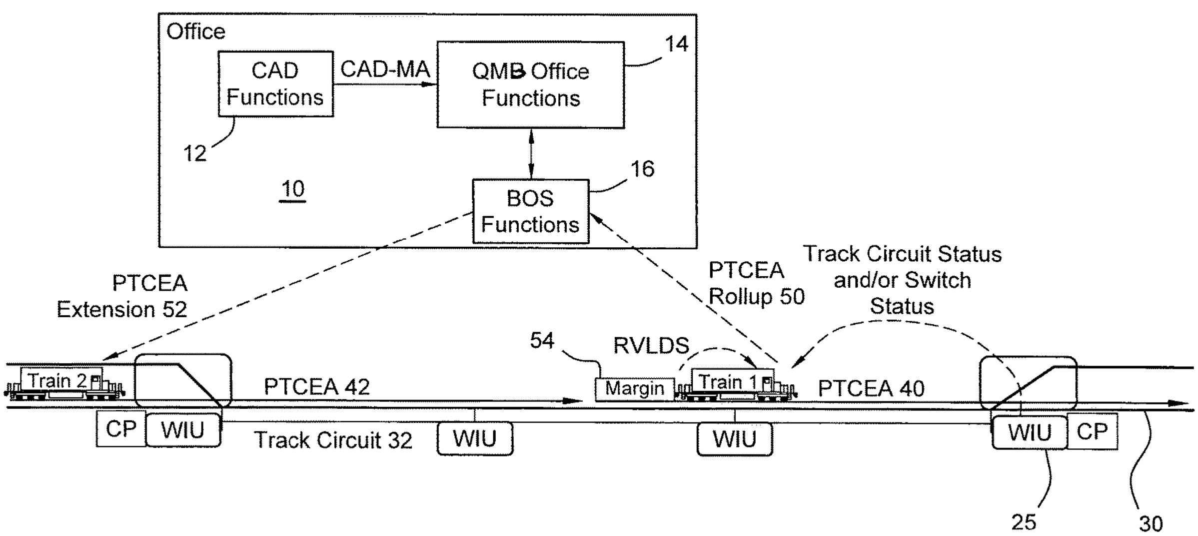
B61L 27/20	(2006.01)
B61L 25/02	(2006.01)
B61L 23/34	(2006.01)
B61L 1/18	(2006.01)
B61L 23/04	(2006.01)

(52) **U.S. Cl.**

CPC ***B61L 27/20*** (2022.01); ***B61L 25/021*** (2013.01); *B61L 27/70* (2022.01); ***B61L 1/18*** (2013.01); ***B61L 23/044*** (2013.01); ***B61L 23/34*** (2013.01)

(57) **ABSTRACT**

A system of train control uses a quasi-moving block methodology for controlling operation of a plurality of trains from a remote office. The office parses the route information for each train into non-overlapping movement authorities that are issued via a communications network. As each train proceeds, it communicates with the office to automatically roll up its movement authority and release the portion of the movement authority behind the train. The office then extends the movement authority of the subsequent train to reflect the released portion of the movement authority of the leading train. The track can be divided into a series of track circuits to enable detection of broken rail or unexpected occupancy. The office segment can then control operation of trains accordingly if broken rail or unexpected occupancy is detected in the train's movement authority.



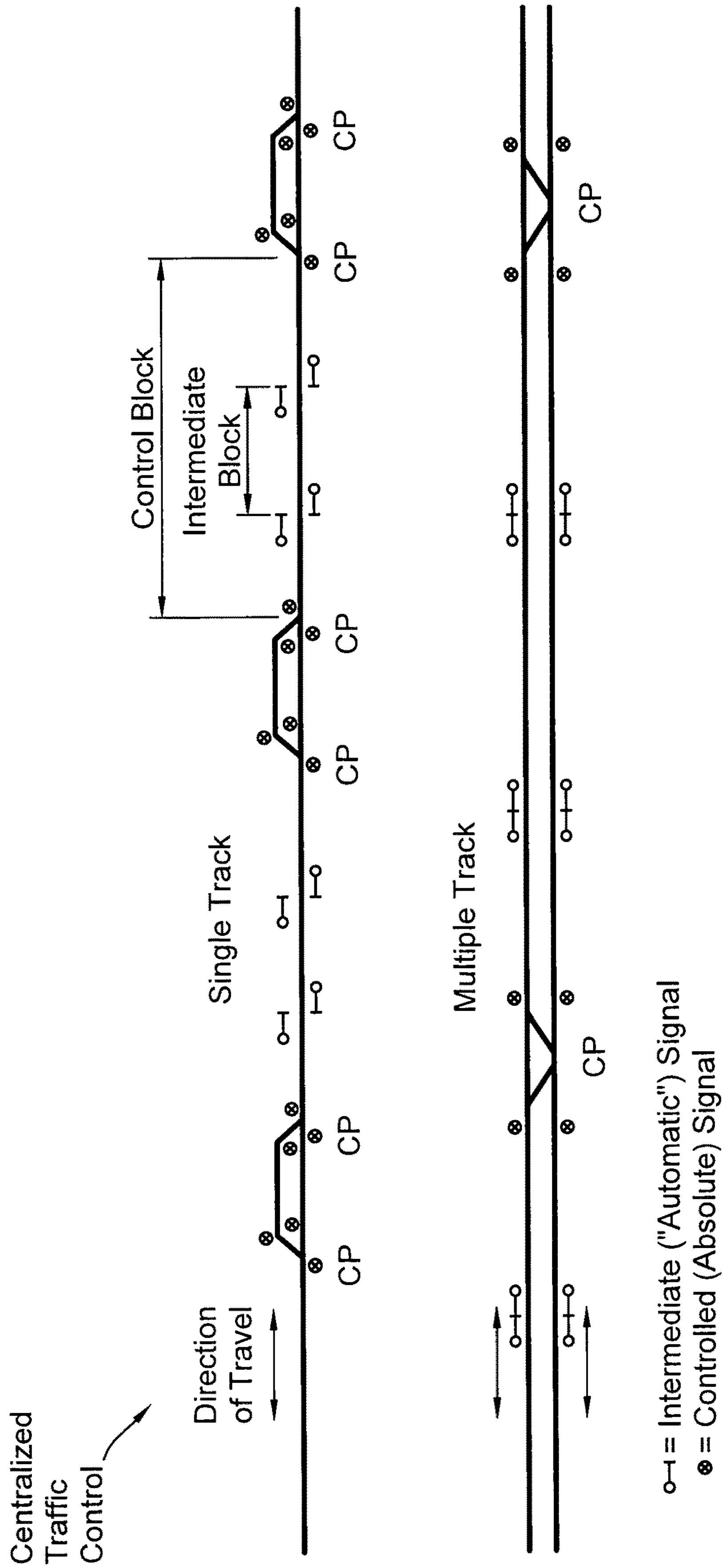


FIG. 1
(PRIOR ART)

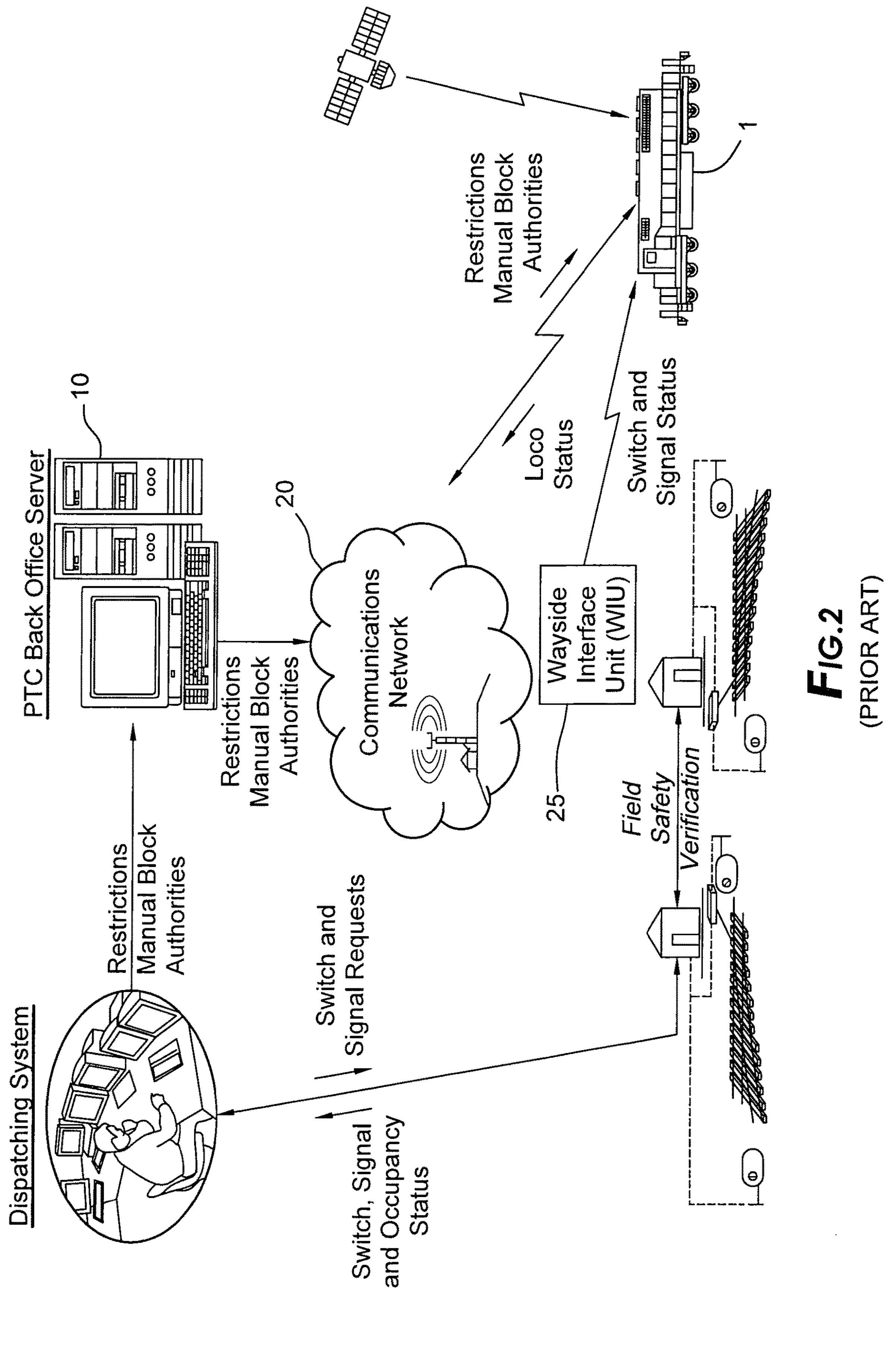


FIG.2
(PRIOR ART)

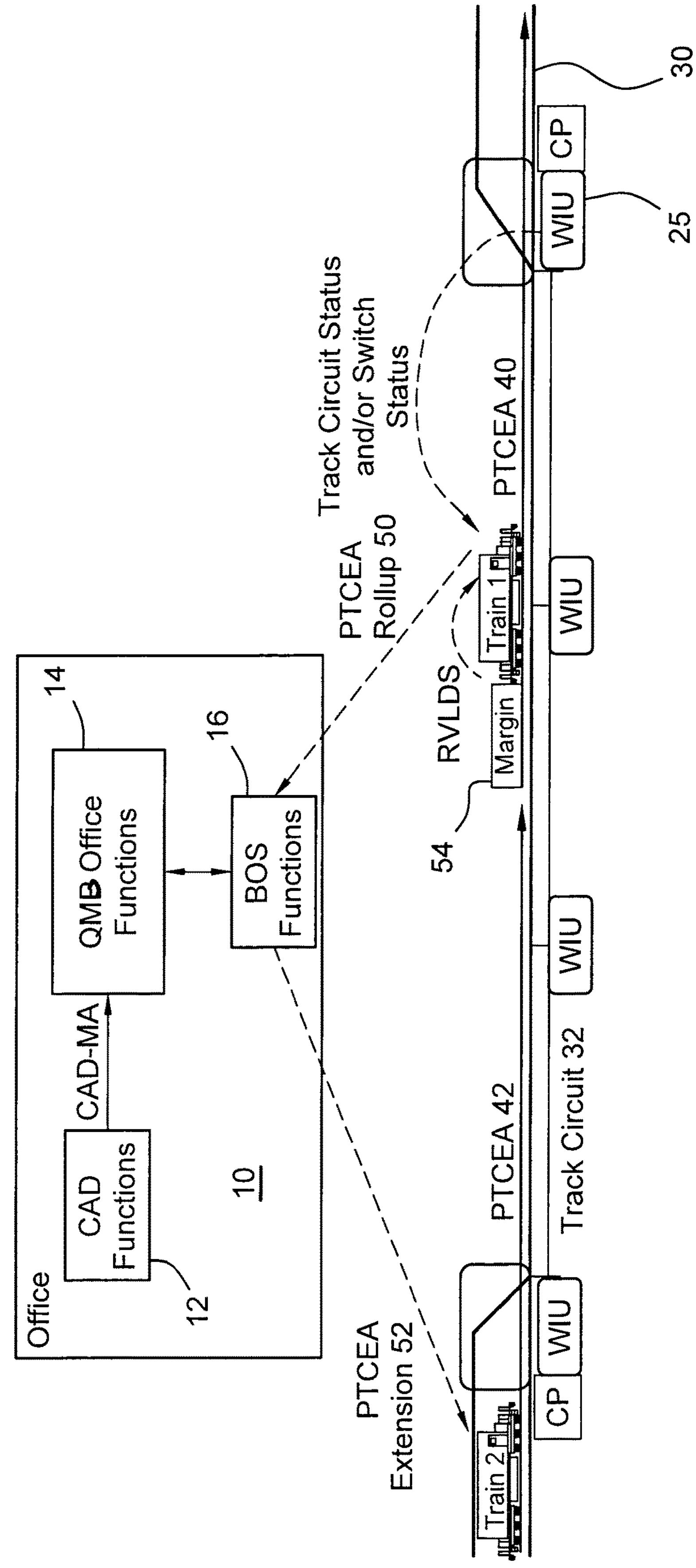

Office
CAD Functions
12
CAD-MA
QMB Office Functions
14
BOS Functions
16
10
PTCEA Extension 52
PTCEA Rollup 50
Track Circuit Status and/or Switch Status
RVLDS
Margin
54
Train 1
Train 2
PTCEA 40
PTCEA 42
Track Circuit 32
WIU
WIU
WIU
WIU
CP
CP
25
30

FIG.3

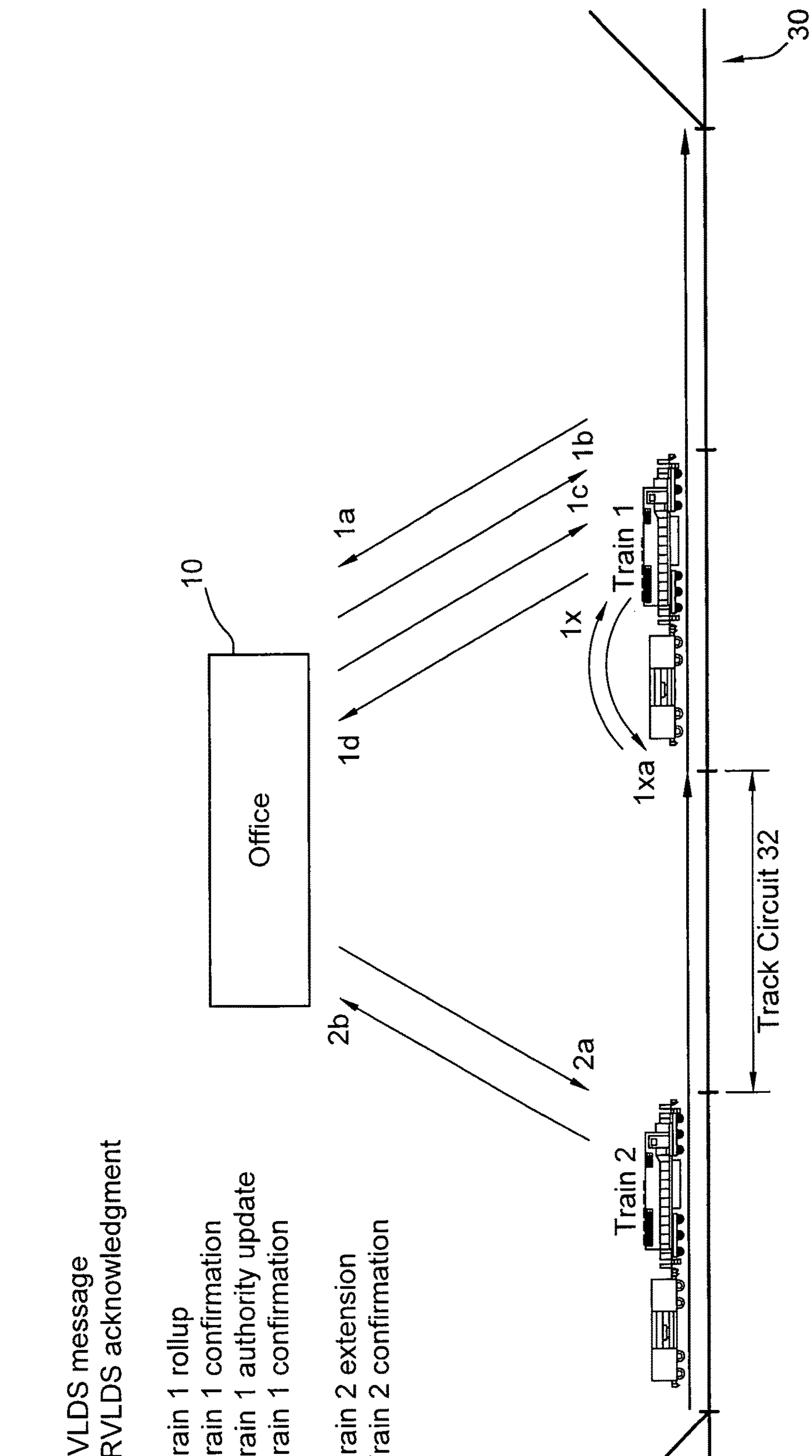

1x) RVLDS message
1xa) RVLDS acknowledgment
1a) Train 1 rollup
1b) Train 1 confirmation
1c) Train 1 authority update
1d) Train 1 confirmation
2a) Train 2 extension
2b) Train 2 confirmation
Office
10
1a
1b
1c
1d
1x
1xa
2a
2b
Train 1
Train 2
Track Circuit 32
30

FIG. 4

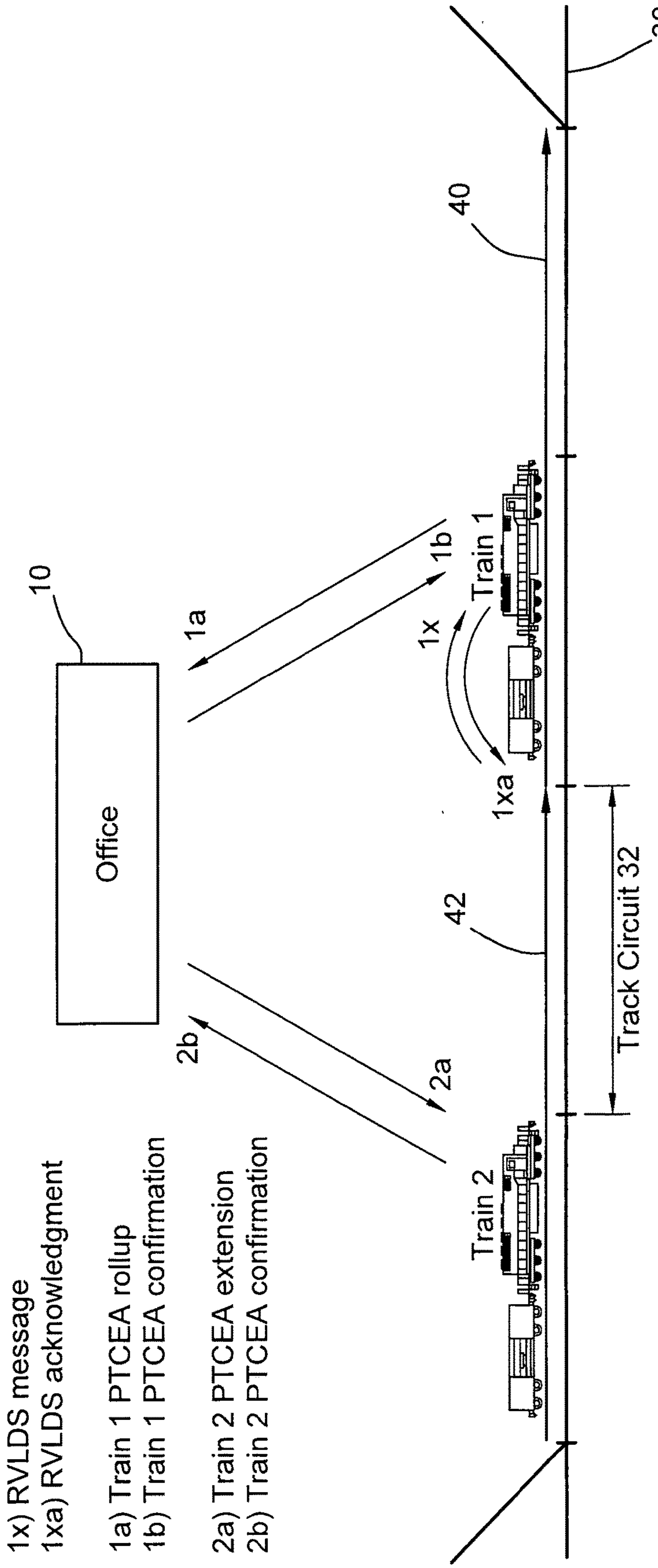

1x) RVLDS message
1xa) RVLDS acknowledgment
1a) Train 1 PTCEA rollup
1b) Train 1 PTCEA confirmation
2a) Train 2 PTCEA extension
2b) Train 2 PTCEA confirmation
Office
10
1a
1b
2a
2b
1x
1xa
Train 1
Train 2
40
42
30
Track Circuit 32

FIG.5

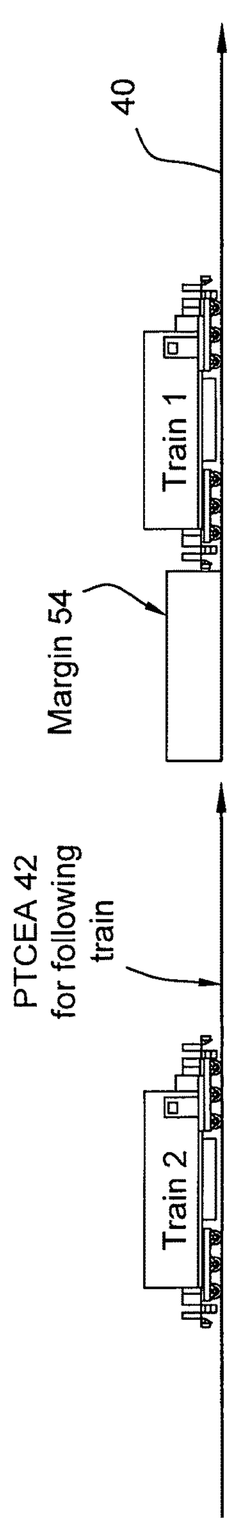

Train 1
Train 2
40
Margin 54
PTCEA 42
for following
train

FIG.6

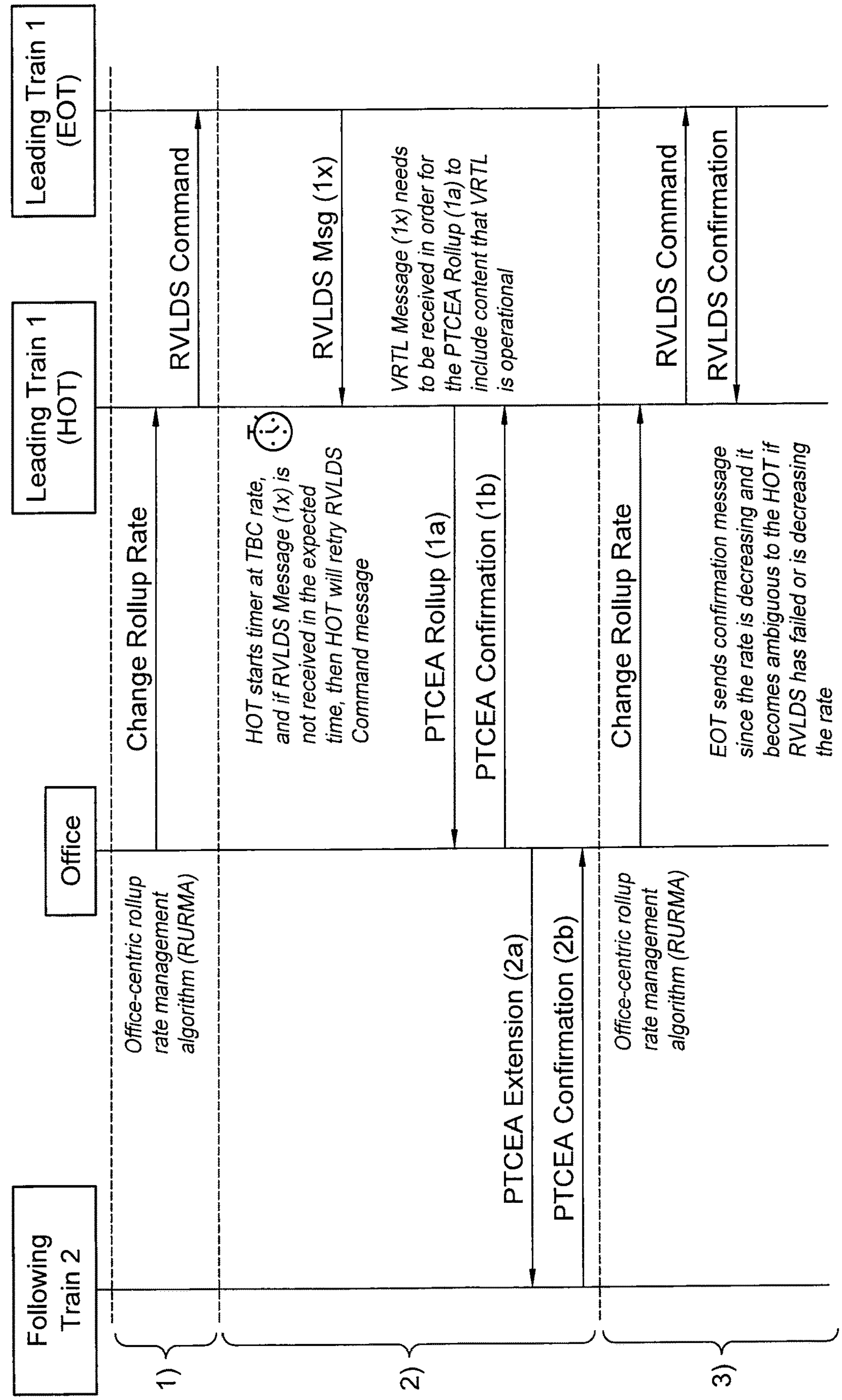

Following Train 2
Office
Leading Train 1 (HOT)
Leading Train 1 (EOT)
1)
2)
3)
Office-centric rollup rate management algorithm (RURMA)
Change Rollup Rate
RVLDS Command
HOT starts timer at TBC rate, and if RVLDS Message (1x) is not received in the expected time, then HOT will retry RVLDS Command message
RVLDS Msg (1x)
VRTL Message (1x) needs to be received in order for the PTCEA Rollup (1a) to include content that VRTL is operational
PTCEA Rollup (1a)
PTCEA Confirmation (1b)
PTCEA Extension (2a)
PTCEA Confirmation (2b)
Office-centric rollup rate management algorithm (RURMA)
Change Rollup Rate
RVLDS Command
RVLDS Confirmation
EOT sends confirmation message since the rate is decreasing and it becomes ambiguous to the HOT if RVLDS has failed or is decreasing the rate

FIG. 7

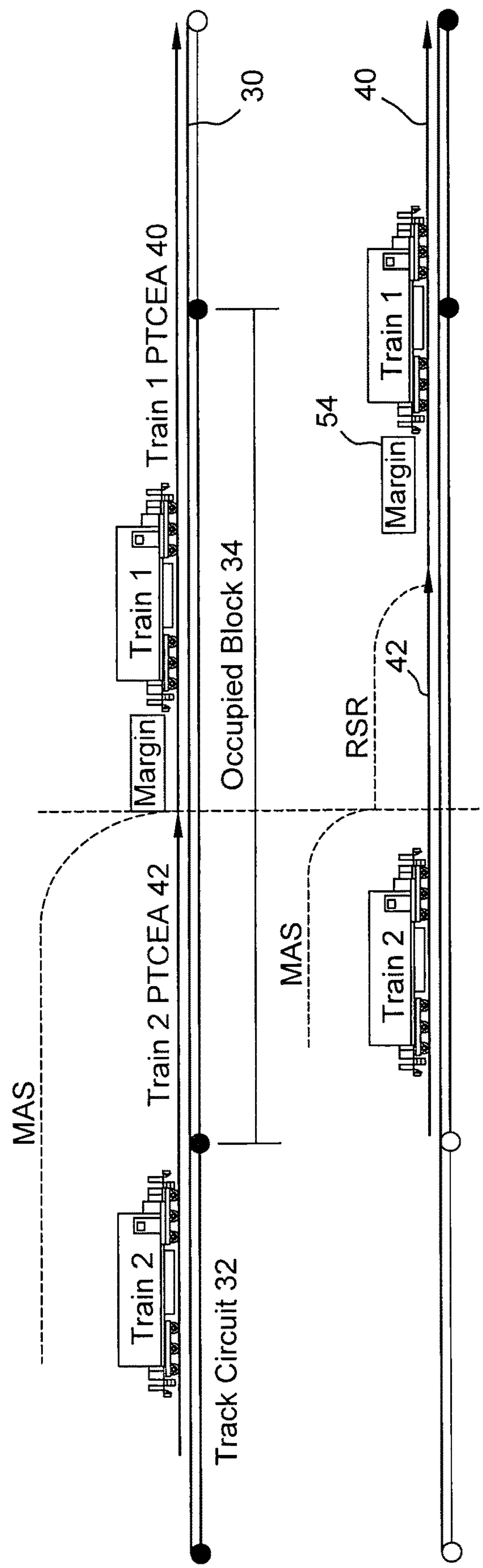

30
Train 1 PTCEA 40
Train 1
Margin
Occupied Block 34
Train 2 PTCEA 42
MAS
Train 2
Track Circuit 32
40
Train 1
54
Margin
42
RSR
MAS
Train 2

FIG.8

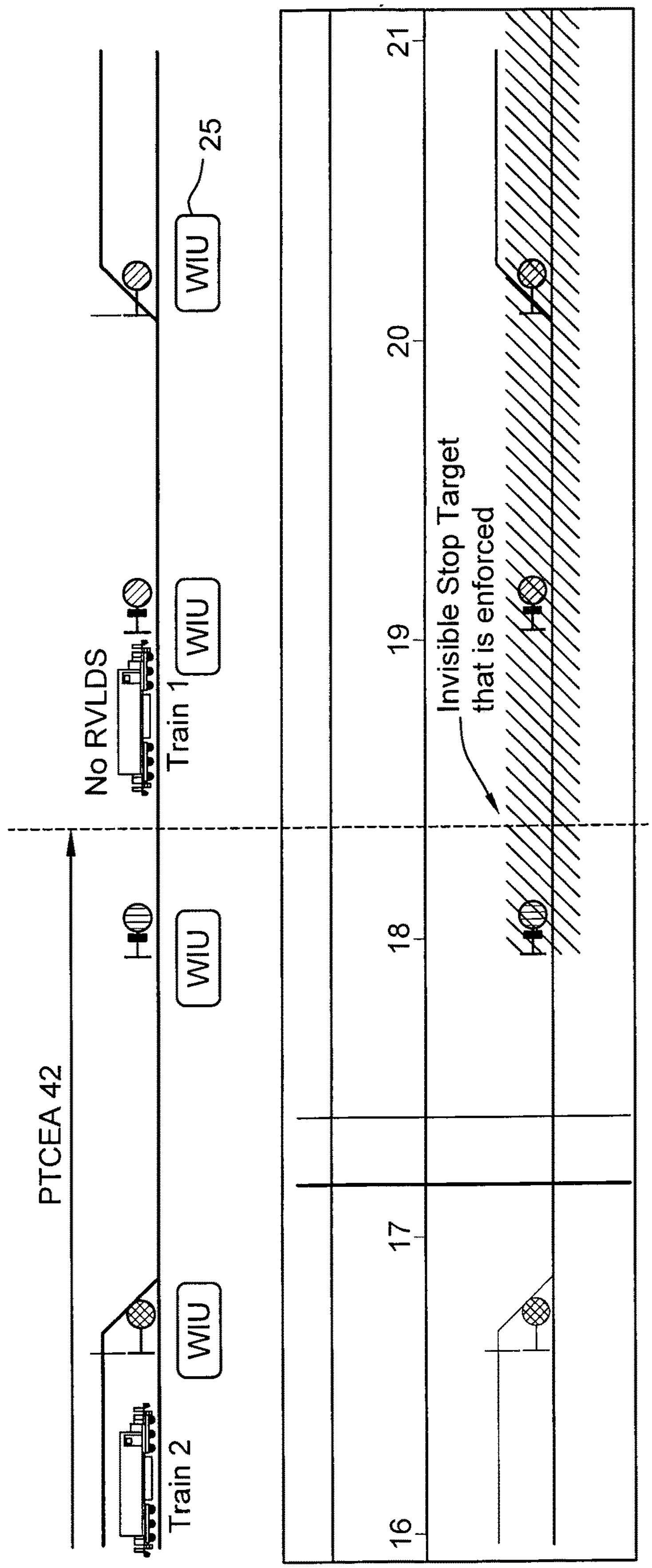

PTCEA 42
No RVLDS
Train 1
Train 2
WIU
WIU
WIU
WIU
25
16
17
18
19
20
21
Invisible Stop Target
that is enforced

FIG. 9

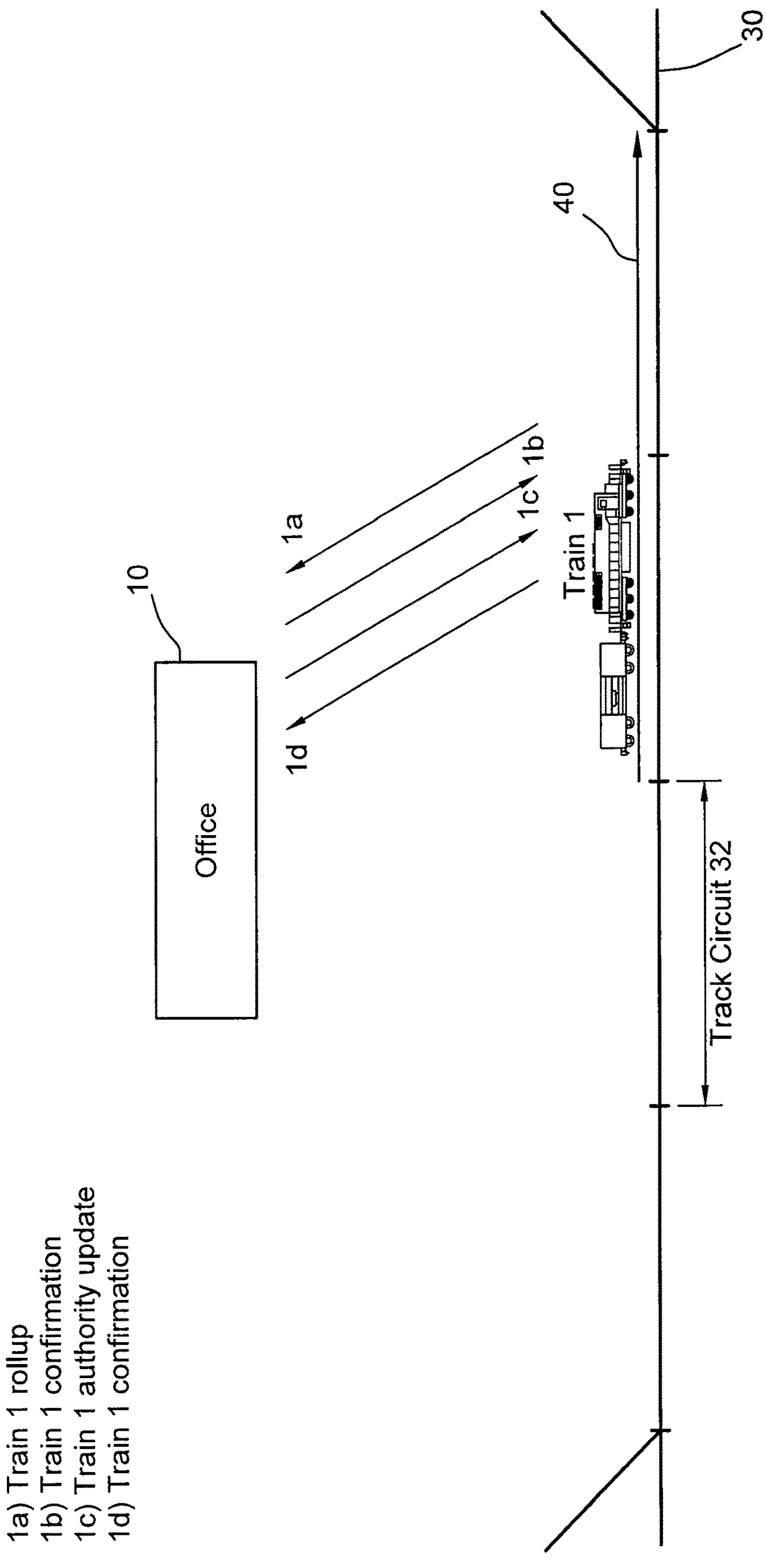

30
40
10
Office
1a
1b
1c
1d
Train 1
Track Circuit 32
1a) Train 1 rollup
1b) Train 1 confirmation
1c) Train 1 authority update
1d) Train 1 confirmation

FIG. 10

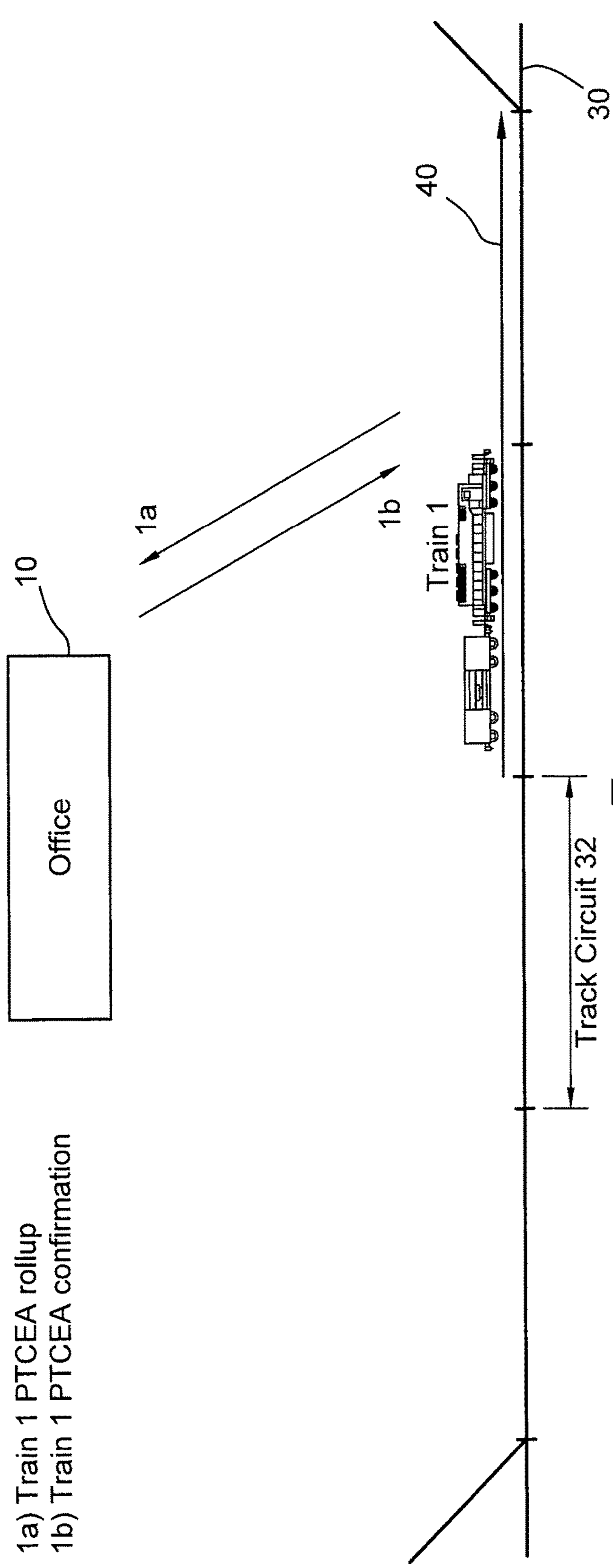

1a) Train 1 PTCEA rollup
1b) Train 1 PTCEA confirmation
Office
10
1a
1b
Train 1
40
30
Track Circuit 32

FIG. 11

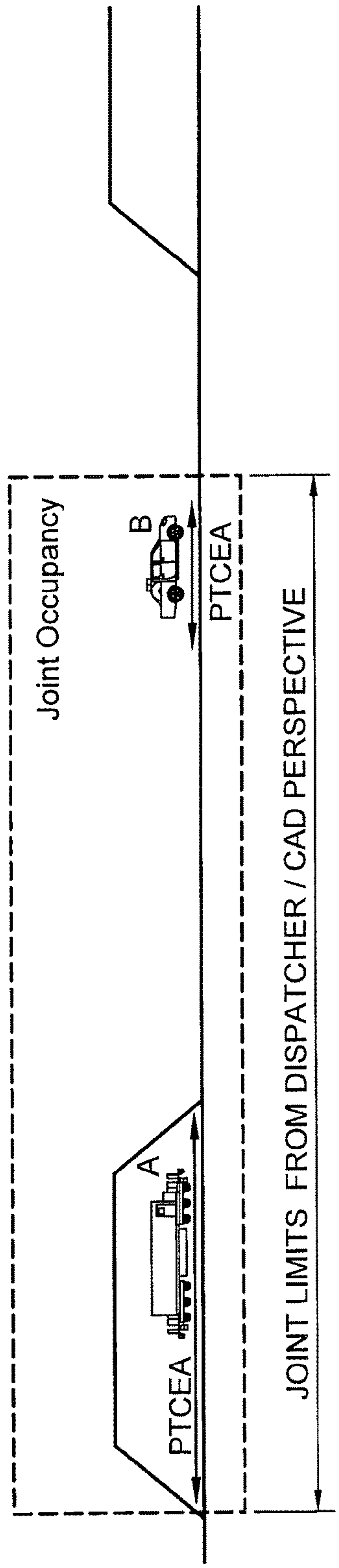

Joint Occupancy
A
PTCEA
B
PTCEA
JOINT LIMITS FROM DISPATCHER / CAD PERSPECTIVE

FIG. 12

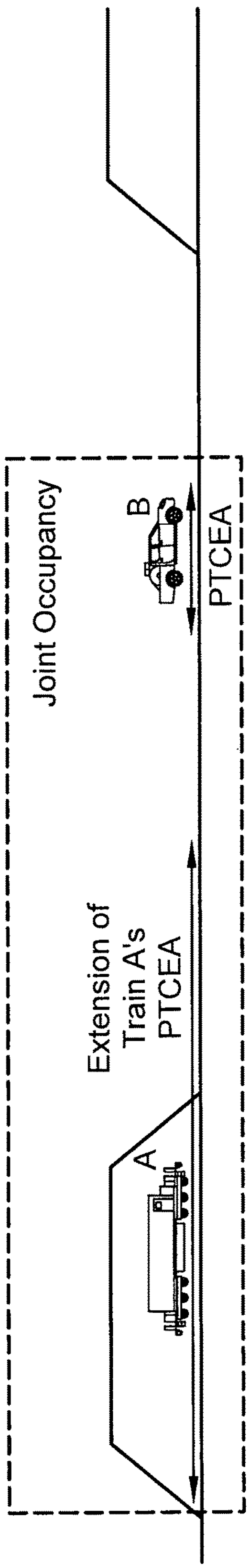


FIG. 13

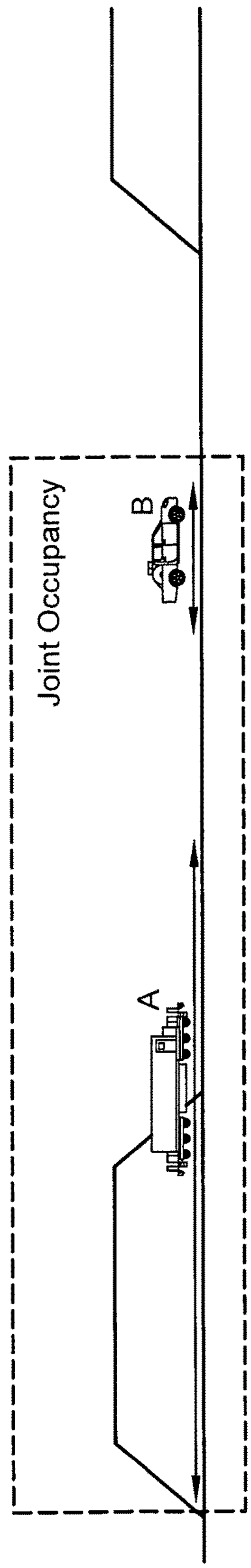


FIG. 14

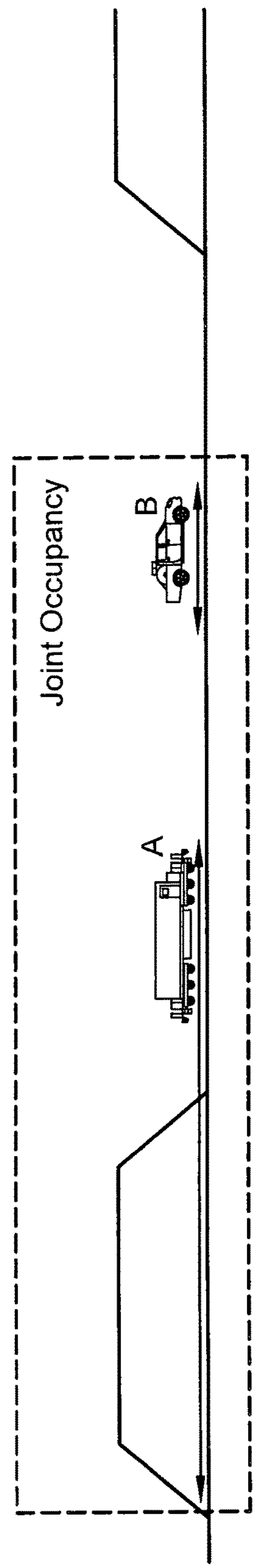


FIG. 15

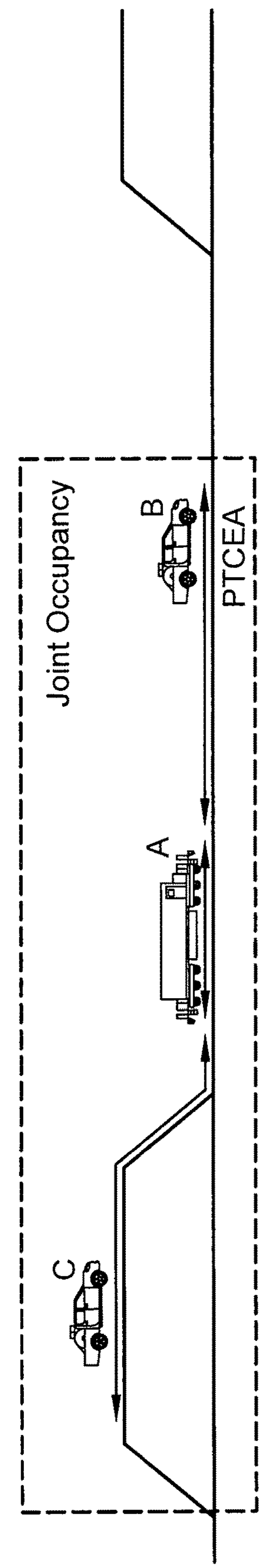

Joint Occupancy
A
B
C
PTCEA

FIG. 16

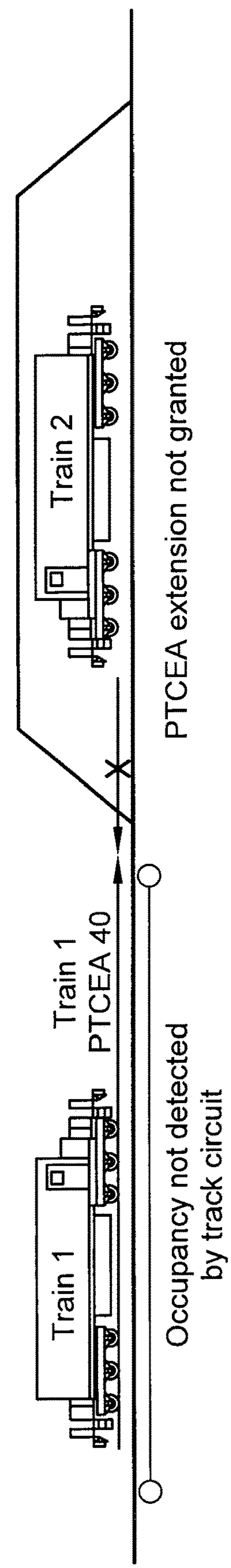

Train 1
Train 2
Train 1
PTCEA 40
PTCEA extension not granted
Occupancy not detected
by track circuit

FIG. 17

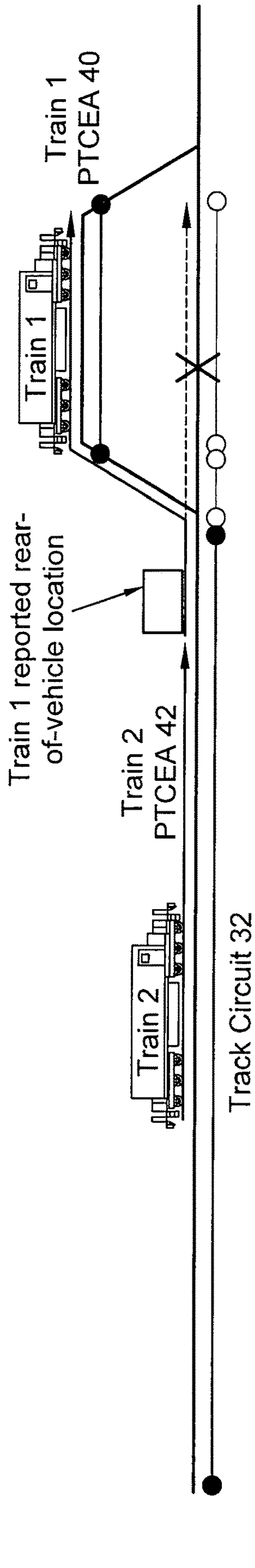

Train 1
PTCEA 40
Train 1
Train 1 reported rear-of-vehicle location
Train 2
PTCEA 42
Train 2
Track Circuit 32

FIG. 18

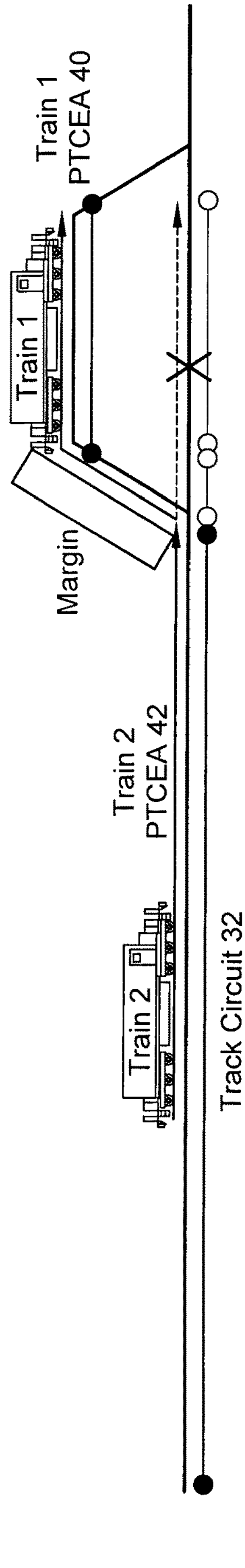

Train 1
PTCEA 40
Train 1
Margin
Train 2
PTCEA 42
Train 2
Track Circuit 32

FIG. 19

QUASI-MOVING BLOCK SYSTEM OF TRAIN CONTROL

RELATED APPLICATION

[0001] The present application is based on and claims priority to the Applicant's U.S. Provisional Patent Application 63/125,518, entitled "Quasi-Moving Block System of Train Control," filed on Dec. 15, 2020.

GOVERNMENT LICENSE RIGHTS

[0002] This invention was made with government support under work sponsored by the Federal Railroad Administration of the U.S. Department of Transportation under contract DTFR5311-D00008L. The government has certain rights in the invention.

BACKGROUND OF THE INVENTION

Field of the Invention

[0003] The present invention relates generally to the field of control systems for trains and other rail vehicles. Throughout this document, the term "train" is used to mean either train or rail vehicle. More specifically, the present invention discloses a system for controlling operation of trains using a hybrid approach of fixed block and moving block train control, referred to as quasi-moving block (QMB) train control while leveraging conventional train control infrastructure and Positive Train Control (PTC), also known as Communications-Based Train Control (CBTC) movement authority architecture.

Statement of the Problem

[0004] The most widely deployed CBTC systems in the United States are fixed-block systems, meaning that they operate based on detection of an occupancy or rail break anywhere within their fixed block limits. Due to their fixed-block nature, they cannot tell where within a block that a rail break or occupancy has occurred. Because of this uncertainty, fixed-block CBTC systems cannot provide collision protection between trains operating within the same block; they only limit speed in that case. A fundamental objective of the present invention is to add collision protection within the same block.

[0005] One of the conventional modern types of signaled territory for higher density lines is Centralized Traffic Control (CTC, also known as Traffic Control or TC). A typical CTC installation allows a dispatcher to manage traffic remotely via field interlocking systems and wayside signals. Signals in CTC territory are generally one of two types (with the exception of signals associated with automatic interlockings at diamonds): (1) a control point (CP), which is an absolute signal that is remotely controlled by a train dispatcher in conjunction with fail-safe field logic; or (2) an intermediate (or automatic) signal that is controlled automatically by the conditions of the track in that signal's block and by the status of the signal or track circuits ahead. CPs designate the boundaries of control blocks and are usually located at the extremities of sidings, junctions, crossovers between adjacent tracks, and manual diamond crossings. Code line systems are used to link the computer-aided dispatch (CAD) system with field interlockings. The dispatcher requests a route, the request is sent to field interlocking logic at CPs along the route via the code line system, and safety is verified in a fail-safe manner by the field interlocking before execution and providing indication back to the CAD system.

[0006] FIG. **1** provides an illustration of CTC with single and multiple tracks. As shown, a control block spans between two CPs. Typically, multiple intermediate blocks are typically within a control block and use Automatic Block Signaling (ABS). The ABS system typically relies on track circuits for track occupancy and broken rail detection. Information about the status of each block is typically transmitted to adjacent blocks through the use of coded track circuits. With coded track circuits, the electrical signal that is transmitted through the rails is coded using different pulse rates to indicate the signal aspect that block is currently displaying. This information is interpreted by the equipment at the adjacent block limit and used in determining the proper aspect to display for the signal governing movement over that block.

[0007] In non-signaled territory, the dispatcher issues authority for a specific train to occupy a given section of track. Track Warrant Control (TWC) is the General Code of Operating Rules (GCOR) method of train control most commonly used in non-signaled territory. Other operating rules use methods similar to TWC in non-signaled territory. While this application gives examples in terms of GCOR, QMB is equally applicable where other rulebooks are in effect. QMB typically requires track circuits, and so is not fully applicable to non-signaled territory unless track circuits are installed throughout. However, a QMB train control system can operate as a full moving block (FMB) system where no track circuits exist. It is possible to have a combination of TWC and ABS (TWC-ABS), where the track warrant grants the movement authority, and the ABS system provides train separation as well as broken rail and rollout (unauthorized occupancy) protection. TWC-ABS territory is amenable to conversion to QMB operation since track circuits are already present.

[0008] The Rail Safety Improvement Act of 2008 (RSIA '08) mandates implementation of interoperable PTC on a significant portion of rail lines in the United States. PTC, as defined in the RSIA '08, is a system designed to prevent train-to-train collisions, overspeed derailments, unauthorized incursions into established roadway work zones, and movement of a train through a mainline switch in the wrong position. There are several systems that satisfy the PTC requirements. The most predominant of these systems is defined by the Interoperable Train Control (ITC) standards, which were developed by the largest U.S. Class I freight railroads. Consequently, QMB is described herein in the context of the ITC PTC system, but the concept is equally applicable to most other forms of PTC or CBTC. The example conventional PTC system (ITC PTC) described herein is referred to as "Overlay PTC (O-PTC)".

[0009] FIG. **2** illustrates the high-level architecture of the ITC PTC system. The locomotive onboard segment determines the location of the train relative to the track and relative to critical assets along the track using a GPS-based location determination system and an onboard track database. Consist (train makeup) and route information, among other data, are provided to the locomotive onboard segment from the PTC back office during initialization. Wayside Interface Units (WIUs) **25**, installed at switch and signal locations along the track, periodically broadcast over a wireless communications network the status of the switch (es) and/or signal(s) they are monitoring. As the train approaches these locations, the status messages are received by the locomotive onboard segment. Work zones, temporary speed restrictions, and other bulletin data are provided in digital form to the locomotive onboard segment by the PTC back office **10** over the wireless communications network **20**.

[0010] The operational data provided to the locomotive onboard segment is processed to determine the operational limits (movement authority and speed restrictions) for that train. The locomotive onboard segment regularly updates the predicted braking distance of the train, and if the train is predicted to be within a specified time of violating an authority or speed limit, warns the train crew. Additionally, the system can invoke a penalty brake application (should the crew fail to take appropriate action) to prevent the violation.

Solution to the Problem

[0011] In contrast to conventional fixed-block methods of train control, the present invention employs a quasi-moving block (QMB) methodology. The office segment receives route information from the computer-aided dispatch (CAD) system and automatically parses it into smaller, non-overlapping movement authority segments when necessary to avoid overlap with other active movement authority segments, each segment herein referred to as a PTC exclusive authority (PTCEA). Each PTCEA is checked to be safe (i.e., exclusive of other PTCEAs and consistent with other conditions) and then is electronically issued to a train. One of the new functions introduced by QMB for the onboard segment is to automatically roll up the PTCEA, so that a portion of its authority that is no longer needed behind the train is released. This allows a PTCEA for a subsequent train to be extended.

[0012] The key objective of QMB is to provide as many benefits of FMB train control as possible while still utilizing fixed-block track circuits for rail integrity and occupancy detection and establishing a foundation that can easily migrate to FMB operation when integrated with a suitable alternative to track circuits for broken rail and rollout detection. The utilization of fixed-block track circuits prevents the need to overhaul existing track circuits. In select circumstances and when integrated with certain advanced technologies, QMB can perform the same as FMB, particularly when the braking distance is greater than one track circuit block length.

[0013] In contrast to conventional train control systems, the QMB approach provides benefits in reliability, safety, and capacity as seen in Table 1. These benefits come at the cost of modifying office functions, additional functions for the onboard segment, and optional wayside modifications. Basic QMB does not require any modifications to the wayside, although it supports the elimination of physical signals. Optional advanced QMB technologies and functionality, including rear-of-vehicle location determination, centralized interlocking, and advanced broken rail detection, enable further benefits.

TABLE 1

QMB Expected Benefits

Category	Expected Benefit
Safety	Collision protection at all speeds (including restricted speed); with higher safety integrity when using real-time rear-of-vehicle location determination. Increases pull-apart (train separation) protection when the real-time rear-of-vehicle location determination system reports greater train length than estimated, in which case the pulled-apart cars are protected by a PTC Exclusive Authority (PTCEA) and alerts. Improved loss-of-shunt protection (using PTCEAs, train location reports, and train length data as additional sources of occupancy determination). Uniform method of train control using PTCEAs. Train drivers (engineers) experience a moving-block style onboard user interface in any type of underlying train control territory.
Capacity & Efficiency	Increased capacity beyond that of O-PTC if track circuits are shortened, which is more feasible with QMB, due to no additional aspects, elimination of wayside signals, reduced wayside logic, possible use of jointless track circuits, and/or possible use of ≥1,000 MGT insulated joints. Further increased capacity beyond that of O-PTC when using advanced broken rail detection (e.g., track circuits with the ability to detect a rail break within an occupied block), along with rear-of-vehicle location determination system (RVLDS). A following train may enter an occupied intermediate track circuit at MAS and maintain MAS per the braking curve and PTCEA MAS limit under certain conditions. The combination of QMB, a Next Generation Track Circuit (NGTC), and RVLDS provides the same minimum train separation as full moving block when the braking distance is greater than one block length. QMB can reduce delays caused by approach and time locking. When a dispatcher needs to change a route already assigned to a train and the train's braking curve indicates the train can safely stop before the CP or interlocking, then the route can be changed without time penalty.
Reliability-Maintain-ability	Supports removal of signal heads and some vital field logic, such ascoded track circuits. QMB with centralized interlocking simplifies field logic and facilitates diagnostics and maintenance. It can also improve overall reliability when optional functionality that allows trains to directly command switches, e.g., based on their PTCEAs, is implemented.

SUMMARY OF THE INVENTION

[0014] This invention provides a system of train control using a quasi-moving block (QMB) methodology. The office segment receives route information for a train from a computer-aided dispatch (CAD) system and automatically parses it into smaller, non-overlapping movement authorities when necessary to avoid overlap with other movement authorities. Each movement authority is referred to as a PTC exclusive authority (PTCEA). A PTCEA is checked to be safe (i.e., exclusive of other PTCEAs currently in effect) and then is issued to the train over a communications network. The onboard segment allows the train to operate as authorized by its PTCEA, and also automatically rolls up the PTCEA, so that a portion of its authority is released behind the train when no longer needed. This allows a PTCEA for a subsequent train to be extended. In addition, the track can be divided into a series of track circuits to enable detection of broken rail or unexpected occupancy. The office segment can then control operation of trains accordingly if broken rail or unexpected occupancy is detected in the train's movement authority.

[0015] These and other advantages, features, and objects of the present invention will be more readily understood in view of the following detailed description and the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The present invention can be more readily understood in conjunction with the accompanying drawings, in which:

[0017] FIG. **1** is a simplified diagram illustrating Centralized Traffic Control (CTC) with single and multiple tracks.

[0018] FIG. **2** is a diagram of the high-level architecture of the ITC PTC system.

[0019] FIG. **3** is a simplified diagram of the QMB functional architecture.

[0020] FIG. **4** is a simplified diagram illustrating the four messages exchanged with a leading train.

[0021] FIG. **5** is a simplified diagram illustrating the two messages exchanged with a leading train for more efficient use of communications bandwidth in QMB operation.

[0022] FIG. **6** illustrates the safety margin **54** and the PTCEA **42** for a following train.

[0023] FIG. **7** is a bounce diagram illustrating the message flow for increasing and decreasing rollup rates with RVLDS.

[0024] FIG. **8** is a diagram showing a following train **42** entering an occupied block **34** at the maximum authorized speed (MAS).

[0025] FIG. **9** is a simplified diagram illustrating the display of a PTCEA when the leading train **40** does not have RVLDS.

[0026] FIG. **10** is a simplified diagram showing the message flow for rolling up a track warrant in the current ITC PTC system.

[0027] FIG. **11** is a simplified diagram showing the two messages exchanged for rollup with the present invention.

[0028] FIGS. **12**-**16** are diagrams of the steps involved in providing additional protection for joint occupancy operation by issuing and enforcing an exclusive PTCEA to each individual QMB-equipped train, workers or equipment (TWE) within work limits.

[0029] FIG. **17** is a simplified diagram illustrating a potential loss-of-shunt scenario, where Train**1** maintains an active PTCEA but fails to shunt, and the office prevents a PTCEA extension from being granted to Train**2**.

[0030] FIG. **18** is a simplified diagram showing an example case for pull-apart protection.

[0031] FIG. **19** is a simplified diagram illustrating a possible margin overlap conflict.

DETAILED DESCRIPTION OF THE INVENTION

[0032] Terminology. The following words and phrases have the following meanings as used in the present disclosure:

Bidirectional authority	An authorization given to a train or other rail vehicle to occupy and move in both directions on a section of track. A bidirectional authority may be issued exclusively to one train or may allow joint occupancy. These authorities require additional considerations beyond routine QMB operation with unidirectional authorities.
Braking curve	A train's braking distance vs. train speed, as calculated continuously by its onboard segment.

-continued

Enforcing train	A train with fully functioning PTC onboard segment (that may or may not be QMB capable), that communicates with the PTC network and can invoke a penalty brake application when required.
Field interlocking logic	Refers to vital logic at control points and automatic interlockings.
Office	The railroad-specific back-office segment associated with train control and traffic control, including the dispatching system, conventional PTC BOS and other servers.
PTC Exclusive Authority (PTCEA)	An authorization given to a train or other rail vehicle to occupy a section of track. A PTCEA may span the entire extent of track requested by the dispatcher or may only span an increment if the QMB office functions cannot assure there are no conflicts beyond that increment. In QMB, all PTCEAs are exclusive (non-overlapping), except for the basic case of joint bidirectional authorities.
PTCEA extension	A process in which authority is added to the current PTCEA, allowing the train to proceed farther.
PTCEA rollup	A process in which a train clears a portion of authorized track, which is then released from the current PTCEA.
Wayside logic	Refers to all vital signaling logic in the field (e.g., at intermediate signals, control points and interlockings).

[0033] The following acronyms and abbreviations have the following meanings as used in the present disclosure:

Acronym	Definition
ABS	Automatic block signaling
ATP	Authority to pass signal at Stop
BOS	Back office server
BPP	Brake pipe pressure
CAD	Computer-aided dispatch
CAD-MA	CAD movement authority
CBTC	Communications-Based Train Control
CIXL	Centralized interlocking
CP	Control point
CRC	Cyclic redundancy check
CTC	Centralized traffic control
EMT	Enter main track
EOT	End-of-train
FMB	Full moving block
GCOR	General Code of Operating Rules
GPS	Global Positioning System
HMAC	Hash message authentication code
HOT	Head-of-train
ITC	Interoperable Train Control
MAS	Maximum authorized speed
MD	Mandatory directive
NENC	Non-enforcing or non-communicating
NGTC	Next generation track circuit
O-PTC	Overlay PTC
PTC	Positive Train Control
PTCEA	PTC Exclusive Authority
QMB	Quasi-moving block
RSIA '08	Rail Safety Improvement Act of 2008
RSR	Restricted speed restriction
RURMA	Rollup rate management algorithm
RVLDS	Rear-of-vehicle location determination system
TBC	To be configured
TWE	Train, workers, or equipment
TWC	Track warrant control
VBTC	Virtual block track circuit
WIU	Wayside Interface Unit
WSM	Wayside Status Message
WSRS	Wayside Status Relay Service

[0034] The present QMB system of train control is based on the following core principles. First, train authority is granted by exclusive PTCEAs (i.e., non-overlapping and electronically-delivered movement authorities). Every train or other rail vehicle on controlled mainline track must have a PTCEA, with the possible exception of work gangs and equipment operating under GCOR Track Bulletin Form B. Control of PTCEAs is centralized in the office, which includes responsibility for issuing and extending PTCEAs. Onboard systems in each train are responsible for automatically initiating rollup **50** of their own PTCEAs. (Note: In failure scenarios, the crew will verbally communicate with the dispatcher.) Wayside signals are not necessary and can be removed (at least at intermediate locations) as part of a migration/implementation plan, if not previously done. Many vital functions currently implemented in a distributed manner with field equipment may be centralized, allowing for life-cycle cost savings.

[0035] The QMB system of train control inherits principles from Overlay PTC, including: (a) WIU-to-locomotive peer-to-peer communication of wayside status (whether relayed by WSRS or not); (b) O-PTC onboard segments states and failure processes; (c) enforcement of authority limits (e.g., from mandatory directives); and (d) Onboard segment determines and enforces speed limit, based on the most restrictive of CAD-MA (PTCEA) speed limit, train-specific speed restriction (where applicable), and track speed restrictions (permanent and temporary). The QMB system also includes communications features, such as providing: (a) message-based communications with a retransmission protocol; (b) data integrity (e.g., 32-bit CRC or HMAC) for safety-critical messages; and (c) failed communications handling: (for Wayside communications, an unknown status results in enforcement of most restrictive state; and for office communications, a non-communicating indication or non-sync results in crew acknowledgment and onboard segment to disengage); and (d) protocols for discarding redundant messages. Finally, the QMB system includes: (a) a process for providing/updating consist length data to the train control system, occurring at initialization and during set-out/pick-up according to the railroad; (b) head-of-train (HOT) location determination, utilizing today's PTC onboard location determination system or more advanced solutions (e.g., including inertial sensors and advanced algorithms); and (c) security features such as message authentication.

[0036] QMB inherits most of the existing overlay ITC PTC architecture. However, the same basic concept and principles can be implemented without any relationship to ITC PTC. FIG. **3** illustrates an example of the overall QMB architecture. The onboard segment retains all the existing core functionality of the Overlay PTC system. The onboard segment also continues to obtain the status of field devices from Wayside Status Messages (WSMs) generated by WIUs **25**. The BOS **16** continues to be the interface between the office **10** and the field. Minimal changes are expected to existing CAD systems and functions.

[0037] Train movement authorities typically originate in the CAD system **12** and can overlap. The QMB office functionality **14** parses overlapping CAD movement authorities (CAD-MAs) into exclusive PTCEAs **40**, **42**. PTCEAs provide the authority for track occupancy and train movements. The onboard segment determines speed and authority limit targets, based on the most restrictive of PTCEAs, WSMs, train-specific speed restriction (where applicable), and permanent and temporary track speed restrictions. CAD-MAs and PTCEAs can be issued without waiting for response from the interlocking system to confirm alignment of the route. This is possible because trains are also enforced by WIU indications in the field which prevent train movement through a misaligned route.

[0038] The onboard segment includes new functions for QMB operation. One of the new functions is for a QMB train to automatically roll up its own unidirectional PTCEA **40**, **42**. This function involves determining the end-of-train (EOT) location, along with sufficient safety margin **54**, either with or without a functioning rear-of-vehicle location determination system (RVLDS).

[0039] QMB introduces a new set of functions for the office **14** as well, which are responsible for the management of all PTCEAs in the system. It tracks which PTCEAs have been issued, which PTCEA rollups/extensions have occurred, which segments of track **30** are reserved for trains, and which segments of track **30** are available for use. Some interlocking functions that are currently implemented in the field can optionally migrate to the office in a concept referred to as centralized interlocking (CIXL). QMB interfaces with either the field interlocking or CIXL if deployed. It should be understood that the office **14** can be implemented either a remote central office or a distribute plurality of sites.

[0040] To the extent that is practicable, QMB can use the messages that are exchanged among existing systems (PTC, CAD, and field interlocking) to implement the communications required for the QMB interfaces with the existing systems. If and when an interlocking becomes centralized (CIXL), a "vital" protocol will be used to assure the integrity of messages that remotely control the switches, similar to the protocol use to communicate safety-critical messages among PTC segments today. As the CAD system and field interlocking interfaces may not be standardized and may depend on each railroad's implementation, the details of associated message types, formats, and protocols will be defined on a case-by-case basis.

[0041] For the interface between the QMB office functions and the onboard segment, existing ITC messages already defined for overlay ITC PTC can be used to the extent practicable. Messages as currently defined for Overlay PTC address most of the movement authority needs. Other messages may be added or modification to existing messages may be required to support QMB as the design progresses.

[0042] The core QMB functionality relies on the issuance of exclusive movement authorities known as PTCEAs **40**, **42**. PTC manages movement authorities (e.g., track warrants) today using a sequence of four messages exchanged. FIG. **4** depicts the message sequence for the issuance of PTCEAs for the four-message exchange model and is described by the following general steps.

[0043] 1. (With RVLDS): Message **1***x* is triggered and is sent from the EOT to the HOT of Train**1**.

[0044] 2. (With RVLDS): Message **1***xa* is sent in response from the HOT to the EOT of Train**1**.

[0045] 3. Message **1***a* is sent to the office and initiates the PTCEA rollup **50** of Train**1**.

[0046] 4. Message **1***b* is sent to Train**1** confirming the PTCEA rollup **50**.

[0047] 5. Message **1***c* is sent to Train**1** and provides the new rolled-up PTCEA.

[0048] 6. Message **1***d* is sent to the office confirming the new rolled-up PTCEA.

[0049] 7. Message **2***a* is sent to Train**2** with a PTCEA extension **52**.

[0050] 8. Message **2***b* is sent to the office confirming the PTCEA extension **52**.

[0051] The following considerations and modifications can be made to the general list of steps.

[0052] RVLDS messages are optional and depend on whether RVLDS is available on a train.

[0053] The frequency of the above sequence may depend on the distance between and the speeds of the two trains.

[0054] Steps 5 and 6, above, could be removed to establish the two-message exchange model. This is recommended for QMB-equipped trains in order to reduce unnecessary communications loading. Messages **1***c* and **1***d* need to be kept for non-QMB trains.

[0055] Steps 7 and 8 depend on the proximity of a following train.

[0056] FIG. **5** depicts the message sequence for the issuance of PTCEAs for the two-message exchange model that is preferred for QMB. This model reduces message loading, especially for close-following moves. The two-message exchange shifts the paradigm of train control in that the onboard segment makes a change to its authority and then informs the remote office about this change. One further consideration is that QMB is different than the existing mandatory directive (MD) architecture. Also, Message **1***a* can update the MD dataset in both the office and locomotive. A train can only reduce its own PTCEA limits, but not increase them, thus making it more restrictive.

[0057] Locomotive Onboard Segment. If the present system is implemented with the original overlay version of ITC-PTC (also known as "O-TTC"), the onboard software is modified to implement functions related to the PTCEA concepts such as automatic PTCEA rollup **50**. Another fundamental modification for QMB trains is the ability for PTCEA concepts (e.g., every train requiring authority conveyed in a movement authority message in addition to WSMs) to be active in all conventional signaled territories (e.g., CTC and current of traffic). An example of how this would affect the implementation of a PTC system, such as ITC-PTC, is that the form-based authority required parameter in the track database is changed to allow for the acceptance and enforcement of unidirectional movement authority data set messages in CTC and GCOR 9.14/9.15 (current of traffic) territory.

[0058] At least the following three classifications of train types are accommodated where QMB is in operation: QMB, non-QMB train with functioning Overlay-PTC (O-PTC), and non-enforcing or non-communicating. Table 2 presents each train type and the corresponding description.

TABLE 2

Train Classifications for QMB Operation

QMB train	Train with fully operational PTC on board at least its lead locomotive, running QMB onboard software. Backwards compatible and could return to O-PTC operation (especially as a part of migration path or to accommodate different types of territory).
Non-QMB train with functioning Overlay-PTC	Train with PTC onboard segment fully operational, running onboard software of a version prior to QMB (e.g., during migration). Crew must manually roll up PTCEAs, e.g., via existing ITC-PTC messages with a request type to roll up an existing authority.
Non-enforcing or non-communicating (NENC) train	Train with onboard segment that has failed en route, or that is not equipped. Burden is on dispatcher and train crew to communicate PTCEAs verbally. There is potential for automated (e.g., synthesized) voice dispatching to reduce the probability of human error and workload.

[0059] It should be noted that one method of handling non-QMB trains more efficiently is to add a QMB-equipped locomotive to the lead of any consist entering QMB territory. For non-QMB trains, a burden is added to the train crew to manually roll up the PTCEAs. There is an option to have the office automatically roll up PTCEAs based on WSMs, but this requires always having an unoccupied block behind the non-QMB train. When trains need to follow each other closer than that, manual rollup is required.

[0060] A rear-of-vehicle location determination system (RVLDS) is an optional technology that can complement QMB operations. The onboard segment requires certain software functionality in order to use RVLDS in support of QMB, including message flow for reporting location (or information from which location can be derived) from the rear of the train to the front of the train, train pull-apart detection (which can be derived from comparing rear-of-train location to the front-of-train location), and for crew interactions during switching operations when RVLDS can be on a portion of the train that is intentionally separated from the front portion of the train.

[0061] As an alternative to having RVLDS report absolute rear-of-train location in every report, a portion of the messages sent by RVLDS can report distance from the last RVLDS rear-of-train location or distance report or average rear-of-train speed since last RVLDS report. These alternative forms of RVLDS report messages can allow the messages to be smaller in order to consume less radio communications resources (e.g., throughput or bandwidth). In that case, an application at the front of the train converts each alternative RVLDS report in relation to an occasional absolute location report from RVLDS into reports of rear-of-train location for use by the QMB onboard.

[0062] Wayside Interface Units (WIUs) **25** are used as the single interface with field devices (track circuits **32** and switches or their associated field logic) under QMB. No modifications to existing WSMs are required while field interlocking is retained with conventional signal indication. Instead, the QMB onboard software interprets the WSMs in accordance with Table 3. Note that the onboard interpretation with three circuit states (Clear, Restricting, Stop) provides a capacity benefit that is possible to achieve without QMB.

TABLE 3

Optional Onboard Interpretation of WSMs While Wayside Logic is Active

	Onboard Interpretations	
WSM Signal Indication	Non- QMB: Overlay PTC	QMB
Advance Approach	Advance Approach	Clear
Approach	Approach	Clear
Restricting (e.g., at an intermediate)	Restricting	Restricting
Stop (e.g., at a CP)	Stop	Stop

[0063] Once wayside logic is removed, QMB trains will only experience an Absolute Stop at locations where absolute signals previously existed, i.e., at OS track circuits **32**, and at any other monitored switch locations. All other track circuits, including those adjacent to an OS, will report Restricting as their most restrictive aspect. The concept of "Approach" and "Advance Approach" signals will no longer be needed.

[0064] Optional onboard functionality can be implemented to take advantage of the direct locomotive-to-WIU communication path, combined with the PTCEA issued to a train. PTCEAs contain the outcome of the QMB interlocking functionality, which CIXL (if implemented) uses to generate commands to the wayside. CIXL uses the same PTCEA sent to the approaching train by the QMB office **10**. This design allows for an additional switch control option, where a train can directly command the field based on its PTCEA **40**, **42** since it contains the same interlocking information that CIXL uses to command the wayside. This functionality can increase the overall system reliability, for the exceptional cases when the wayside does not receive a switch command from the office. The locomotive to WIU communication could also be used to allow trains to command switches during switching operation. Even where CIXL is not implemented, this same method can be implemented and applied (when authorized by a dispatcher) at any powered switch.

[0065] Office Segment. While QMB uses the functional architecture described herein, the physical office architecture is assumed to be railroad specific. Various physical architectures are possible with the office segment and can be determined by the deploying railroad. Therefore, the office segment **10** is described in terms of functional architecture, not physical architecture. In general, the main components of the office segment include the CAD system **12**, QMB office functions **14**, and the existing back-office server (BOS) **16**.

[0066] No changes are expected to be required to the way in which the CAD system manages authorities for trains. The CAD system **12** continues to plan movements, issue route requests to field interlockings, handle responses from the interlockings, and when necessary, issue mandatory directive authorities to trains (e.g., Track and Time, Enter Main Track (EMT) between signals in CTC territories, Track Warrants (or equivalent) in non-signaled and TWC-ABS territories, Track Permits in current of traffic (GCOR 9.15) territory, and Authority To Pass signal at Stop (ATP) anywhere absolute signals exist). Similar to how CAD provides electronic Track Warrants and bidirectional authorities in the form of CAD-MAs to PTC, it must be modified to also provide CAD-MAs for unidirectional authority in CTC and current of traffic (GCOR 9.14 or 9.15) territory. Changes are required for the CAD system **12** to interface with the QMB office functions **14** (e.g., for CAD to provide CAD-MAs to the QMB office). CAD must also be modified to enhance its interface with dispatchers, such as to support the creation and updating of PTCEAs for non-enforcing or non-communicating (NENC) trains. Track bulletins are generally handled independently from QMB-specific functions.

[0067] A route that is cancelled or modified by the dispatcher can be accepted or rejected by the interlocking system. CAD then updates the CAD-MA accordingly for the affected train. The QMB office **14** then updates the train's PTCEA based on any updates to the CAD-MA. For a CAD-MA cancellation, the train's PTCEA will not be totally eliminated if the train still occupies any track identified within that PTCEA, since every train on main track in QMB territory must have a PTCEA permitting it to be there. Possible options for CAD-MA cancellation include no further PTCEA extensions to the train (if the portion of the route canceled was not yet included in the existing PTCEA), truncating its existing PTCEA, or issuing a replacement PTCEA that is shorter.

[0068] Functionality may be optionally included for emergency situations, such as a train entering main track without authorization or when a train overrides its authority. In addition to verbal communication, the CAD system **12** or dispatcher can send out an electronic emergency notification to all affected trains. The QMB office also provides prevents the issuance of PTCEAs in tracks where trains have overridden their authority. The train's onboard segment may immediately warn the crew and then optionally apply braking and send a response back to the office indicating that it has truncated its PTCEA to its predicted stopping location or short of the hazard.

[0069] The QMB office functions **14** are additional functions necessary for QMB operations, beyond those implemented by existing office systems. These functions include and are not limited to:

[0070] Process movement authorities from the CAD system **12** (CAD-MAs) to parse them (reduce their limits) when necessary to eliminate overlap with any other existing PTCEA for another train and convey the authorities to trains as PTCEAs. Mandatory Directives (MDs) that don't require parsing just pass through the QMB office without changes to their contents (payload).

[0071] Identify and maintain record of each train's type: QMB; non-QMB (e.g., Overlay PTC); non-enforcing or non-communicating.

[0072] Perform PTCEA extensions **52** for any train type, based upon PTCEA rollups **50** for any train type.

[0073] In a leading-following train pair, relay information to the following train regarding whether the leading train has functioning RVLDS.

[0074] Perform safety-critical functionality to verify that all PTCEAs are safe and non-overlapping.

[0075] The baseline QMB office functionality **14** issues a PTCEA to a train for the entire length of its CAD-MA when no other train's PTCEA conflicts. However, the QMB office functions **14** can optionally be configured to not necessarily convey an entire train's dispatcher movement authority to the train's onboard segment, but rather limit it to a certain distance and update it as the train moves. For example, if a long route is created in the CAD system that extends through several control points, the QMB office functions may send a PTCEA to the train including just the first five control points. If the chances for modifying a train's route are high, this configuration could save unnecessary message traffic between the QMB office functions and the onboard segment when the dispatcher changes train routes. Conversely, if the chances for modifying a train's route are low, such configuration would cause unnecessary message traffic between the QMB office functions and the onboard segment. A railroad might configure different limits on PTCEA length on a territory-by-territory basis or may choose not to limit PTCEA length at all.

[0076] On its validation by the office, a PTCEA is electronically issued to an enforcing train. A PTCEA may be the original issuance, an extension, or a truncation (e.g., modification). The PTCEA can extend up to the limit of the CAD-MA route if no conflicting moves or PTCEAs are involved. Further, speed restrictions are applied to the train, when necessary, by the same means already existing in O-PTC. Authorized speed is also limited by track database (civil) restrictions, track bulletin data, and WIU status messages for restricting signals. Some types of operation may require a speed restriction in the PTCEA, such as joint authorities.

[0077] During a PTCEA rollup **50**, a train releases a part of its authority for track that it has cleared and sends a report to the office **10**. The train then recognizes its new rolled-up "From" limit. After the office **10** has received a rollup report and updated the PTCEA database, it can then extend the PTCEA for another train to operate on the released track. The rollup rate is configurable and may be automatically changed in real time by the QMB system as conditions change.

[0078] The onboard segment includes a safety margin **54** in its PTCEA rollup **50** limit calculation, or "From" limit. The safety margin **54** accounts for uncertainties in determining the potential rear-of-train location. For trains that do not have functioning rear-of-vehicle location determination, the rear location used by QMB is based on the train length calculation and front-of-train location. FIG. **6** illustrates the rear-of-train safety margin **54** and the PTCEA **42** for a following train. When QMB uses the estimated consist length because RVLDS is not available, the margin **54** added to the train's rear location for QMB purposes is at least equal to the uncertainty in the train length (accounting for factors including train stretching and erroneous consist data) plus the uncertainty in determining the location of the front of the train. For the case of a train with functioning RVLDS, the margin **54** added to the train's rear location for QMB purposes is at least equal to the RVLDS location uncertainty, plus an allowance for train stretching. The system also allows for the possible need to back up to bunch a heavy train or similar operation and other considerations which might require additional margin at the end of PTCEAs.

[0079] When trains on the same route (track) are many miles apart, their PTCEAs can be rolled up infrequently, e.g., once a minute or less often. However, when a train is following another train at a closer spacing, there is a need for the leading train to roll up its PTCEA at a faster rate so that capacity is not wasted spatially between the leading train's PTCEA "From" limit and its current rear position. A faster rollup rate does, however, cause additional message traffic loading in the communication system due to more frequent PTCEA rollups. Consequently, as conditions change, a train's automatic rollup rate or triggering is adjusted in real time by the QMB system to achieve a balance between avoiding excessive communications loading versus impacting traffic capacity. The objective is to rollup only as often as necessary to avoid increasing train separation.

[0080] At least three potential methods of triggering rollups **50** are possible: (a) roll up every XX seconds (temporal rollup); (b) roll up every XX feet (distance-based rollup); or (c) Roll up at designated track features such as track circuit boundaries and/or track points of interest that can be detected by the train and/or identified within the track data. If more than one of the above rollup-triggering methods is selected, the onboard segment will roll up at both or all three, whichever comes first, and potentially reset the time or distance counter at each rollup.

[0081] The baseline approach is to implement only a temporal rate of rollups that is commanded by the office to each train's onboard segment. The first rollup rate command message from office to onboard segment would be sent during or just after PTC initialization of the locomotive, unless the default rollup rate is to be used initially for that train. The office would send another message to the onboard segment whenever the rollup rate needs to change. Other options for determining each train's rollup rate or triggers are available, however, that may or may not involve the office sending a command to a train's onboard segment.

[0082] Each railroad can devise its own office-centric algorithm for setting/changing each train's rollup rate, because there is no need for every railroad to use the same algorithm—it will not impact interoperability. They must all use the same message format, however, to command a train to roll up at the desired rate if they wish to be interoperable with one another and choose an office-centric algorithm for controlling rollup (temporal) rate.

[0083] Rear-of-train rollup locations ("From" limits) received at the office in rollup messages alone provide sufficient information to support an office-centric rollup rate management algorithm (RURMA). However, additional or alternative information can be used by the algorithm, at the preference of the host railroad.

[0084] A potential enhancement to this approach, as an example, is for the onboard segment to include its speed in each PTCEA rollup message for the office to use to improve its prediction of how often rollups will be needed. Another potential alternative or enhancement is for the onboard segment to inform the office of when it gets within a specified distance or time from having to apply braking enforcement with respect to its PTCEA "To" limit. This would provide indication that the rollup rate may need to be increased.

[0085] FIG. **7** is a bounce diagram that illustrates the message flow and includes the following processes: (1) increase PTCEA rollup rate, (2) a repeating message flow, and (3) decrease PTCEA rollup rate. The message flow diagram is one approach, and others can be considered.

[0086] QMB does provide a capacity benefit, which should first be considered with respect to common operational practices as well as the capacity gains that can be obtained with conventional track circuits **32**. The common operational preference of crews to separate trains by sufficient distance such that a following train can maintain a fairly constant speed (rather than having to oscillate between reducing speed for a more restrictive signal and then increasing speed when the signal clears) can still be applied under QMB operation. A QMB train following another train knows approximately when/how often and where the train ahead rolls up its PTCEA, since each rollup **50** by the leading train will result in extension **52** of the following train's PTCEA **42**. The following train also sees when each track circuit **32** ahead is cleared by the leading train, based on WSMs received. Consequently, the QMB onboard segment can optionally provide a pacing cue the crew of a closely following train to keep sufficient distance from and maintain a steady state speed approximately equal to that of the train ahead.

[0087] QMB obtains a capacity benefit with conventional track circuits **32** and interpretation of three track circuit states (Clear, Restricted, Stop). However, this capacity benefit is available without QMB. Potential track circuit enhancements can facilitate increased capacity beyond that achievable with conventional track circuits and the three track circuit states. Two possible track circuit enhancements include a virtual block track circuit (VBTC) and a Next Generation Track Circuit (NGTC).

[0088] VBTC refers to a track circuit that can detect and locate an occupancy or rail break to a subsection of the track circuit known as a virtual block. VBTC can detect a rail break in an occupied block **34** (with some limitations when more than one train occupies the track circuit). VBTC interfaces with the onboard segment and the office basically in the manner same as conventional track circuits, using WSMs, without necessarily requiring modifications to the onboard segment or office.

[0089] NGTC is a type of track circuit that detects a broken rail within an occupied block **34** by measuring electrical current on the transmission end in addition to measuring voltage. The voltages and currents are converted to Boolean states (e.g., true/false, high/low, one/zero) by using predetermined threshold values. If the transmission current ("Tx Current") in the loop is substantial and is converted to a Boolean state of one, then the track circuit is clear of broken rails within that current loop. If the Tx Current is being transmitted and the current loop is near zero and is converted to a Boolean state of zero, then there is a broken rail. By combining the information from the transmission current and the received signal ("Rx Signal") based on transmission from the opposite end, the following states and outcomes are possible as seen in Table 4. This technology was previously disclosed in U.S. Patent App. Publ. No. 2018/0327008 (Kindt et al.)

TABLE 4

NGTC WIU Indications

Tx Current	Rx Signal	Meaning	NGTC WIU Indication
0	0	Broken rail between transmission side and shunting axle or in an unoccupied block	Restricted
0	1	Not normally possible so this indicates an NGTC failure	NGTC is inoperable (Restricted)
1	0	Occupancy somewhere in block No broken rail between transmission side and shunting axle Train can enter at MAS Note: In the case that a PTCEA extends through the entire block, but the authorized train has not yet entered the block, this state indicates a rollout or another anomaly.	Clear to proceed at MAS, but other conditions need to be met including the leading train having RVLDS.
1	1	Clear	Clear to proceed at MAS

[0090] To provide a following train with the most up-to-date information required to achieve minimal headway, the following steps occur:

[0091] During a PTCEA roll up, the (leading) train indicates that it has operational RVLDS within its rollup message to the office.

[0092] The office issues a PTCEA extension **52** to the following train indicating that it can continue at MAS into an occupied block **34** (based on the office's knowledge of operational RVLDS on the train ahead) and is contingent on the train receiving a valid WSM that confirms that NGTC is operational in the block.

[0093] The following train receives the PTCEA from the office and valid NGTC-based WSM confirming that it can proceed at MAS.

[0094] Once the above recommended steps occur, then the following train can enter the occupied block **34** at MAS and maintain MAS within the constraints of the braking curve and PTCEA limit, as shown in FIG. **8**. Once a following train enters the block, it is limited to restricted speed (shown by the dashed vertical line) beyond the last reported rear-of-train location reported by the leading train until the leading train clears the same block and no broken rails are detected.

[0095] QMB will leverage the display and enforcement of existing mandatory directives. In most cases, a QMB train's PTCEA "To" limit is displayed as a Stop target (red fence) on board. This will be enforced as an absolute stop target as done today.

[0096] When there is a pair of trains in a following move, the leading train's "From" limit is the basis for extending the following train's "To" limit. A safety margin **54** is added onto the train's "From" limit to account for uncertainties as previously described. Despite the safety margins **54**, there is still a potential hazard when the leading train does not have RVLDS. The following train will incur detrimental reliance because it assumes its PTCEA "To" limit, based on the leading train's "From" limit, is without error. Below are the potential onboard display solutions for the following train's PTCEA target:

[0097] Invisible target (default): The PTCEA Stop target is not displayed. First, the track circuit boundary preceding the PTCEA limit is determined. Then, an RSR from this preceding track circuit boundary is displayed to the right horizon of the screen (FIG. **9**). Both the RSR and the PTCEA Stop target are enforced. In the case the PTCEA limit aligns with a track circuit boundary exactly, then an RSR does not need to be displayed and the "To" end of the PTCEA limit can be displayed. Furthermore, all Stop targets (e.g., PTCEA "To" limit, O/S, etc.) at or beyond the nearest block reporting Not Clear are suppressed. This is done because if other stop targets are displayed, it could lead the following train's crew to think that their PTCEA extends up to the O/S, even though the leading train may be closer.

[0098] Visible target: If RVLDS is verified to be operational on the leading train, then the PTCEA Stop target is displayed and enforced at the "To" end of the PTCEA limit. The PTCEA Stop target relates to the last reported EOT location of leading train (with margin) that was used to roll up its PTCEA.

[0099] Polling and synchronization are existing ITC-PTC processes that ensure the critical datasets are the same between the office and each onboard segment. In QMB, movement authority datasets change frequently during the PTCEA rollup and issuance processes. Office segment polling is expected to remain independent of QMB PTCEA updates in the sense that PTCEA rollups/extensions and polling messages may occur at any given time relative to one another.

[0100] PTCEAs are similar to track warrants in several aspects and therefore can use similar PTC messaging. The process for rolling up a track warrant in the current ITC PTC system involves the exchange of four messages between the office and the train whose track warrant is being rolled up, as shown in FIG. **10**. The current polling and synchronization process accommodates that protocol. Although there are a few situations in which it is unavoidable, use of this 4-message protocol for rolling up all PTCEAs in QMB would create an unnecessarily excessive load on the PTC radio network, due to the much greater rate of PTCEA rollups than track warrant rollups, on average. Consequently, a streamlined, 2-message rollup process is used for QMB trains, as shown in FIG. **11**.

[0101] For QMB trains operating with the 2-message rollup protocol, the onboard segment automatically initiates the PTCEA rollup process and on doing so will temporarily have a more recent (rolled up) PTCEA "From" limit than the office until the office processes the PTCEA rollup sent by the onboard segment. If the office happens to send an office segment poll message to the locomotive during this brief time when it is has a different PTCEA "From" limit than the train, QMB must have a way to resolve the difference. There are potentially two differences that QMB must resolve during polling and synchronization. First, the onboard segment may have a more recent "From" limit than the office. This can be resolved by the onboard segment such that the onboard segment calculates the aggregate CRC (or HMAC) for both the old and new PTCEAs. Consequently, there should not be a CRC mismatch in one of the instances and this avoids the need for invoking a problematic synchronization process to update the train with the office's older "From" limit. The onboard segment enforces the PTCEA with the more restrictive "From" limit (i.e., the newer PTCEA). Second, the office may have a more recent "To" limit than the onboard segment. This is expected occasionally because message **2***a* may have been lost or delayed when first sent. When this happens, there is a CRC mismatch on board and the synchronization process is triggered, resulting in the PTCEA being re-sent. This is already handled by the current O-PTC polling and synchronization process. Some degree of optimization may be needed to adjust the amount of delay that is acceptable before the onboard segment displays out-of-sync and requires reduced speed and possible disengagement.

[0102] In addition to unidirectional authorities, QMB is also able to handle special authority situations, including bidirectional authorities, joint occupancies, and switching operations. For example, QMB handles bidirectional authorities that are issued by the dispatcher. Similar to how PTC handles bidirectional authorities today, the PTCEA for an exclusive bidirectional authority is not rolled up while the train, workers or equipment (TWE) are within bidirectional authority limits. The work authority can be rolled-up or voided once the TWE clears that authority segment or is manually rolled up by the crew/gang or dispatcher as needed. For bidirectional operation, where an entire control block (between CPs) can be allotted, "Track and Time" is the type of bidirectional work authority granted to TWE in CTC territory. "Track Permit" is the type of bidirectional work authority granted under GCOR to TWE in GCOR 9.14/9.15 territory. Currently, when bidirectional authority is granted in CTC or 9.15 territory, the CPs at either end of the territory are "blocked" (set to absolute stop) to prevent other (unauthorized) TWE from entering the work area. In TWC-ABS territory (not 9.14/9.15 territory), a track warrant is generally used to issue bidirectional authority, using line 4.

[0103] A joint authority is a type of bidirectional authority that can be shared among multiple TWE. Under QMB operations for the basic case, joint occupancies are authorized by a dispatcher in a similar manner as done today. That is, all TWE sharing the joint authority are given the entire bidirectional authority limits in their PTCEA along with a Restricted Speed Restriction. A few examples include: (a) joint track and time in CTC territory; (b) joint track permit in 9.14/9.15 territory; and (c) track warrant (lines 4 and 11 or 12) in ABS-TWC territory.

[0104] At minimum, QMB/PTC keeps all authorized trains within dispatcher-defined bidirectional limits, keeps unauthorized trains out, and enforces (upper) speed limit of restricted speed in a joint bidirectional authority. The crews are responsible for avoiding collisions within the joint authority, per Restricted Speed rules. This is referred to as the "basic case" of QMB joint bidirectional authorities.

[0105] In the optional advanced case, QMB provides additional protection for joint occupancy operation by issuing and enforcing an exclusive PTCEA to each individual TWE within the bidirectional limits. This requires monitoring the locations of individual QMB trains (as well as workers and equipment if they are equipped with QMB) and their PTCEAs inside dispatcher-defined bidirectional limits. The concept is described in the example steps below.

[0106] Step 1: Joint Occupancy Issuance. The dispatcher initiates a dispatcher-defined joint occupancy for multiple instances of TWE to work within the same track limits. Note that in some cases, an exclusive bidirectional authority is issued to the first train and is later changed to a joint authority later when another train is ready to enter the limits. The QMB office then issues exclusive PTCEAs and Authorization to Pass Signal at Stop (ATP) equivalent to one train at a time, to allow TWE within limits, as shown in FIG. **12**.

[0107] Step 2: PTC Exclusive Authority Issuance. TWE (person) requests (via the onboard segment) an authorization to move to a destination further inside the dispatcher-defined jointly-occupied limits, as shown in FIG. **13**. The QMB office extends the PTCEA to the extent safe to do so.

[0108] Step 3: As a rail vehicle moves, the onboard segment enforces movement based on its granted PTCEA, as shown in FIG. **14**.

[0109] Step 4: Other personnel operating TWE in the jointly occupied dispatcher-defined limits request PTCEA extensions and operate simultaneously inside the dispatcher-defined limits, with PTCEAs managed by the office, as shown in FIG. **15**.

[0110] Step 5: TWE may need to roll up its PTCEA to release a portion of track when personnel from another TWE requests a PTCEA extension **52**. This is coordinated by the office or the dispatcher.

[0111] The following is an example of the interaction between the rail vehicles jointly occupying bidirectional limits, as illustrated in FIG. **16**. Vehicle C requests an extension of its PTCEA to MP X. The office then sends a request to Train A (the one currently holding a PTCEA over part or all of the requested extension area) to roll up its PTCEA to the necessary location. Train A can respond indicating: (a) The existing onboard PTCEA has been rolled up; or (b) The existing onboard PTCEA has been rolled up only up to MP Y; or (c) The PTCEA cannot be rolled up at that time. Only after Train A responds with option (a) or (b) can the office roll up Train A's PTCEA in the office database; and lastly, extend Vehicle C's PTCEA. The crews can communicate among themselves to resolve conflicts (e.g., using voice radio). If a conflict cannot be resolved between crews, then the dispatcher can help resolve it.

[0112] It should be noted that TWE are allowed to move bi-directionally within their respective PTCEAs, as needed, under bidirectional authority. Any type of TWE (hi-rail, service units, regular trains, gangs) with authority to do so can operate within bidirectional limits. The choice of bidirectional limit locations is not necessarily restricted (by PTC) to any specific physical constraints, such as a track circuit boundary or CP. Restrictions can be added, however, to only allow definition of limits at human actionable or identifiable locations. Once the dispatcher issues bidirectional authorities for joint occupancy, the entire operation of trains might be completed without burden to the dispatcher if all TWE involved are QMB-capable. If there is mixed traffic with non-QMB vehicles, and the burden for the crew and dispatcher becomes significant, it might be preferred to use the basic case mode of QMB operation. If trains change length, decouple, etc., the crew or the dispatcher must update the PTC consist data. As in current railroad operations, broken rail protection within joint bidirectional limits is limited due to the high instance of track circuits being jointly occupied; this can be improved where NGTC is implemented. The fallback mode of operation for the advanced case (e.g., in case of failure or an incapable onboard segment) is the basic case.

[0113] There is a corner case for helper/rescue locomotives or intentional splitting or combining of trains. Safety margins required on PTCEAs do not allow two trains with exclusive PTCEAs to come close enough together to couple. In this case, both trains should be given basic joint bidirectional authorities for coupling. The joint bidirectional authorities are issued when trains are close and stopped (or below TBD mph) to allow combining/merging of their trains. After physical coupling of the two trains and then taking one train's onboard segment out of the Active state, the two trains' joint bidirectional PTCEAs are replaced by the dispatcher with a single, exclusive PTCEA (typically unidirectional) assigned to the train ID of the train whose onboard segment remains in the Active state. Only that one trains ID remains in use. Similarly, a bidirectional authority is used when a train needs to split into two trains. This stops rollups and allows sufficient limits in the PTCEA for the two parts of the train to become sufficiently separated to allow the margin required for creation of two exclusive PTCEAs. A new ID is required from the dispatcher/office for the new train (the segment that does not include the original QMB controlling locomotive). Alternatively, a special mode could be created for the joining or splitting of trains.

[0114] QMB supports switching operations in which cars need to be picked up or set out. Switching operations are notably different than normal unidirectional QMB operations as the trains can move in both directions without bidirectional authority and with changing consist lengths. The basic approach for switching operations involves QMB providing a method for operators to set limits to keep the PTCEAs of other trains from encroaching upon the planned switching zone. Typically, the dispatcher or train crew enters limits for switching. The QMB office uses these "Switching Limits" for the train that is to perform the switching operations, as follows. The PTCEA of the train performing switching is constrained to not be less than the Switching Limits (i.e., the switching train's PTCEA is not rolled up to any point within the switching limits during the switching operations). The train crew performing the switching operations uses the existing PTC Restricted State (the switching PTCEA's limits are not enforced by the train performing the switching, but it is under a Restricted Speed Restriction). The QMB office creates PTCEAs for other trains as needed that do not conflict with the switching train's PTCEA, as with any other PTCEA. This provides protection such that nearby trains do not enter the limits of the switching train's PTCEA. When switching operation is done, the dispatcher or train crew removes the switching limits and the switching train's PTCEA is now able to be rolled up without switching constraints.

[0115] An optional advanced switching feature is possible in which the train performing switching, or at least its lead locomotive, are enforced to remain within the switching limits. All else would remain the same as described above for the basic switching approach.

[0116] If at the time the dispatcher requests switching limits, the switching train's PTCEA does not include those entire limits, the office attempts to automatically extend the train's PTCEA. This may also require first rolling up the PTCEA of another train if it includes any track within the desired switching limits.

[0117] A centralized location that provides geographic boundaries where QMB operation is enabled or disabled (i.e., defining the limits of QMB territory) is necessary. It is recommended that the CAD system understands the geographic areas to be defined as QMB territory, especially because CAD-MAs will need to be generated for all unidirectional authorities where QMB is operational.

[0118] All trains require a PTCEA, which is a type of form-based authority (particularly from PTC's perspective), in QMB territory. There is a parameter in the ITC PTC track database that is set to require a movement authority message in QMB territory. For QMB trains, another mechanism is used in addition to setting the form-based authority required parameter in the track data. If QMB territory were defined solely by the formed-based authority required parameter, then QMB functionality could unintentionally be enabled in territories that use form-based authority required (e.g., TWC) without any option to disable QMB functionality.

[0119] Thus, QMB functionality is enabled in CTC territory when the form-based authority required parameter is set in the track data, and a QMB-specific authority type is given in the ITC-PTC movement authority (PTCEA) message. The office determines the train type during initialization and then sends the proper authority type to each train each time a new PTCEA is needed. Potential authority types for QMB trains include: (a) PTCEA without RVLDS on leading train/no leading train; and (b) PTCEA with RVLDS on leading train. The above method avoids the need to create and maintain different versions of track data for QMB versus O-PTC trains. However, an acceptable alternative approach is to designate where QMB is enabled in track data.

[0120] Within QMB territory, there are processes for enabling and disabling QMB operations, e.g., for supporting major system maintenance activities. These processes involve multiple steps and are not expected to be done frequently. Table 5 provides a process for enabling QMB operations and Table 6 provides a process for disabling QMB operations. An individual railroad has the discretion to enable or disable QMB operations while noting the potential burden on the dispatcher and/or train crews with mixed mode operations. The percentage of available QMB trains (e.g., 25, 50 or 75 percent) can be a factor in choosing when to enable QMB operations.

TABLE 5

Enabling QMB Operations

Step	Description	Outcome
0	A person with the proper authority determines that QMB mode should be enabled.	Authority is provided to continue with the steps below.
1	Set form-based authority required for intended QMB territories. This will likely be done by the railroad's track data management team.	Track data is changed.
2	Use normal processes for updating track data for all trains,	Track data is synchronized between the office and onboard segments.
3a	Office starts sending PTCEA messages to non-QMB trains with: Crew Action Required = RR-specific Authority Type = "Track warrant/track authority" Note: Crew will need to be informed they need to manually roll up their PTCEA at an appropriate rate.	QMB mode begins for non-QMB trains in the given territory.

TABLE 5-continued

Enabling QMB Operations		
Step	Description	Outcome
3b	Office starts sending PTCEA messages to QMB trains with: Crew Action Required = "No crew action required" (recommended) Authority Type = "PTCEA [. . .]"	QMB mode begins for QMB trains in the given territory.

TABLE 6

Disabling QMB Operations		
Step	Description	Outcome
0	A person with the proper authority determines that QMB mode should be disabled.	Authority is provided to continue with the steps below.
1	Return form-based authority required to its original value based on the original territory.	Track data is changed.
2	Use normal processes for updating track data for all trains,	Track data is synchronized between the office and onboard segments.
3a	Office discontinues sending PTCEA messages to non-QMB trains for unidirectional authorities in CTC and 9.14/9.15 territory. When/where form-based authorities are required in the absence of QMB (e.g., in track warrant territory and for bidirectional authorities, ATP and in the messages. EMT), legacy authority types are used	QMB mode is disabled for non-QMB trains in the given territory.
3b	Office discontinues sending PTCEA messages to QMB trains for unidirectional authorities in CTC and 9.14/9.15 territory. When/where form-based authorities are required in the absence of QMB (e.g., in track warrant territory and for bidirectional authorities, ATP and EMT), legacy authority types are used in the messages.	QMB mode is disabled for QMB trains in the given territory.

[0121] It should be noted that the steps for either process (enabling or disabling QMB) may not happen simultaneously for all trains. Some trains will be in QMB mode while others may not until all have applied the revised track data. The office keeps record of when each train transitions to using the new track data so that it can send the appropriate authority type in any PTCEA message sent to that train. A following train without a PTCEA may encroach upon a leading train's PTCEA, if its crew is not adhering to non-QMB operating rules.

[0122] The deployment of QMB may be gradual. It is possible that at the beginning of operation of QMB in a territory, a significant percentage of trains in operation on that territory will not be upgraded with QMB software on board, either because of the gradual upgrade of onboard software (particularly if the fleet operating in that territory is not captive), or because of operation of trains from foreign railroads that have not yet migrated to QMB. Retaining wayside signals allows more efficient handling of non-QMB trains during the transition period.

[0123] It is assumed that QMB train control will be deployed in select areas already established as Overlay PTC territory. Consequently, there will be operational scenarios in which trains will transition into and out of QMB territory. Transitions will utilize existing processes, such as transitioning into and out of TWC territory.

[0124] While in QMB territory, a QMB train may at any time become a non-enforcing or non-communicating (NENC). A NENC train may have a failed onboard segment, an onboard segment that is communicating but is not in an active state, an onboard that is not communicating, or may be unequipped with any form of PTC.

[0125] There are existing processes today for handling trains that are NENC. Generally, these are onboard-centric processes, and the office segment does not act upon that information. For QMB operation, there needs to be an indication of a NENC train in the office segment. This helps to direct how the PTCEA is provided to the train. If enforcing (i.e., active) and communicating, then the PTCEA is electronically issued to the QMB train. If non-enforcing or non-communicating, then the PTCEA is sent to the CAD system and the dispatcher verbally issues the PTCEA to the train crew.

[0126] A train is determined to be non-enforcing by the office upon receiving a message that is different than the active state. A train is once again enforcing upon receiving a message that it is in an active state.

[0127] A train is determined to be non-communicating by the office if that train does not respond for a specified number of consecutive messages. To restore a non-communicating train back to communicating, the office should listen for (or subscribe to) any message that the onboard of such train sends. Note that it is unknown to the office whether the train is enforcing or non-enforcing while it is non-communicating.

[0128] QMB has features that can provide additional protection (as compared to relying on conventional CTC systems) and potentially reduce the burden on the dispatcher to handle loss of shunt scenarios as described below.

[0129] If a train fails to shunt a track circuit, a conventional signaling system may release a route to be issued to another train, which is a concern when operating light trains or on tracks where conditions facilitate loss of shunt. In QMB, the office retains a train's PTCEA until it has received a rollup message from the train even when the track circuit where the train is located reports unoccupied. FIG. **17** illustrates a potential loss-of-shunt scenario, where Train**1** that is operating and maintains an active PTCEA but fails to shunt, and the office prevents a PTCEA from being granted to Train**2**.

[0130] When train cars pull apart, the momentum of the separating cars might be in the same direction or in the opposite direction of the original consist (e.g., a slow train on a steep uphill grade). Either way, the separation of the air hoses between cars should trigger the air brakes to go into an emergency application (as long as the air hose [brake pipe] contains no blockages or closed angle cocks) in order to slow down and ultimately stop the separated cars (for as long as sufficient reservoir air pressure remains). The degree of QMB protection then depends on whether there is rear-of-vehicle location available. In any case, there is no less protection in QMB territory than exists today without QMB. But additional protection exists under QMB operation when the train pulling apart has rear-of-vehicle location determination functionality.

[0131] If there is rear-of-vehicle location determination, there are three protective measures with regard to a train separation (pull apart). First, the onboard segment will detect the train has pulled apart when the reported or derived rear-of-train location falls behind front-of-train location plus the estimated train length plus margin **54**. The onboard segment alerts the crew and other trains in the area that the train has pulled apart. This is beneficial because: (a) information is quickly provided regarding the cause of the emergency application; or (b) there could be cases in which an emergency brake application does not occur (e.g., brake pipe is blocked). Once detected, the onboard segment and/or head-of-train device immediately warns the crew, and a command can be sent over the head-of-train to end-of-train radio link to automatically apply emergency braking at the end of the train.

[0132] Second, any subsequent rollup reports are based on the rear-of-vehicle location determination system with safety margin such that the rolled up PTCEA includes the track occupied by the separated cars.

[0133] Third, WSMs from the track circuit occupied by the pulled apart cars result in an RSR for the occupied track circuit(s). However, a track circuit does not provide protection if the following train has already entered the track circuit before the separating cars leave the track circuit, or if the separated cars do not shunt the track circuit.

[0134] The following is an example case for pull-apart protection (FIG. **18**) with rear-of-vehicle location determination functionality. OS is reporting clear. The rear-of-vehicle location determination system is reporting its location on the main track (or alternative information [e.g., distance from last reported location] from an application at the front of the train can derive rear-of-train location). The estimated train length plus margin is shorter than what is indicated by rear-of-vehicle location determination system. Pull-apart is detected by Train**1** and a message is sent to the office. Train**1** PTCEA can be rolled up, but not beyond Train**1**'s reported rear-of-vehicle location determination system. Train**2** PTCEA can then be extended, but not beyond Train**1**'s reported rear-of-vehicle location determination system.

[0135] For an undetected pull-apart without rear-of-vehicle location determination functionality, any rollup reports after a pull-apart event indicate an erroneous rear-of-train location since the PTCEA rollup is based on an estimated train length that is assumed to be intact. This error grows in time as there becomes a greater distance between the separating cars and the location cited in the restricted rollup report.

[0136] Protective measures for QMB trains that pull apart and do not have rear-of-vehicle location determination system reporting are similar to today's operation: (a) an emergency brake application should occur (assuming brake pipe is not blocked), but no information is available as to the cause of the emergency application; and (b) WSMs from the track circuit occupied by the pulled apart cars result in an RSR for the occupied track circuit. However, as with legacy (non-QMB) operations, a track circuit does not provide protection if the separated cars do not shunt the track circuit or a following train enters the track circuit before the separated cars enter it.

[0137] It is possible for a train to clear main track onto a siding while its PTCEA continues to overlap the OS. This causes a discrepancy between field indications (OS indicates Clear) and the inability to extend the PTCEA for the following train. FIG. **19** depicts the following situation and becomes increasingly more likely based on the length of the safety margin. The goal of handling margin overlap at the O/S is to avoid dispatcher involvement and to minimize onboard complexity. For example, these goals can be met by the following process. The CAD issues a CAD-MA for Train**2** to pass through the clear O/S. However, the office cannot extend Train**2**'s PTCEA since there is PTCEA overlap due to Train**1** margin overlap. The office sends an electronic prompt to Train**1**, or the dispatcher contacts Train**1**, to roll up its PTCEA if it safe to do so. If Train**1** rolls up its PTCEA, this will clear the issue. If Train**1**'s crew responds with an indication to wait, then the office waits for further crew response. If there is no response after TBC seconds, the office sends another request to Train**1**'s crew. If Train**1**'s crew indicates that they cannot confirm their train is clear of the O/S, then the office sends a message to Train**2** that provides the identity of Train**1** and directs Train**2** to verify that Train**1** is clear. Train**2**'s crew informs Train**1**'s crew (via voice radio) if their train is clear and its PTCEA should be rolled up or if it needs to be moved to clear the route.

[0138] The above disclosure sets forth a number of embodiments of the present invention described in detail with respect to the accompanying drawings. Those skilled in this art will appreciate that various changes, modifications, other structural arrangements, and other embodiments could be practiced under the teachings of the present invention without departing from the scope of this invention as set forth in the following claims.

We claim:

1. A method for increasing the level of protection provided by a communication-based train control system against collisions among a plurality of trains along a track divided into a series of fixed-block track circuits, said method comprising:

parsing the route for each train into exclusive movement authorities;

issuing and subsequently updating a movement authority to each train, thereby granting exclusive authority for each train to move within a movement authority;

constraining the operation of each train to proceed along the track within its movement authority;

automatically rolling up the movement authority to release the portion of the movement authority behind the train with a safety margin to allow for any uncertainty in the rear-of-train location as the train proceeds along the track;

extending the movement authority of a potential subsequent train, allowing it to occupy the released portion of the movement authority of the prior train;

detecting the existence of occupancy by any rail vehicle in each track circuit by applying and detecting an electrical signal to the rails;

communicating the state of existence of occupancy by any rail vehicle in each track circuit to the trains;

further constraining the operation of each train to protect against a detected unexpected occupancy within the movement authority of each train;

detecting the existence of broken rail in each track circuit by applying and detecting an electrical signal to the rails;

communicating the state of existence of broken rail in each track circuit to the trains; and

further constraining the operation of each train to protect against a detected broken rail within the movement authority of each train.

2. The method of claim **1** further comprising enabling a following train to proceed at up to maximum authorized speed into an occupied track circuit block, if the track circuit has the ability to detect a broken rail within an occupied block, upon receiving information that: (a) no broken rails have been detected in the occupied track circuit block between the entry part of the track circuit block in the direction of travel and the rear-of-train location of the leading train; and (b) the leading train that is occupying that track circuit block has a functioning rear-of-train location determination or train integrity determination system.

3. The method of claim **1** wherein the step of rolling up of movement authorities is repeated over time at a frequency based at least in part on at least one of: (a) the distance between the subsequent train and the rear of the leading train; (b) elapsed time; (c) elapsed distance; and (d) the train location relative to predetermined points along the track.

4. The method of claim **1** wherein each movement authority rollup location is based on a rear-of-train location determination system that reports absolute rear-of-train location to the front of the train.

5. The method of claim **4** wherein a movement authority rollup location is determined at least in part from the reported distance traveled by the rear of the train since the rear-of-train location was last reported.

6. The method of claim **4** wherein a movement authority rollup location is determined at least in part from the reported average rear-of-train speed since the rear-of-train location was last reported.

7. The method of claim **2** wherein an onboard system on each train applies a restriction when an occupancy is detected within a block by the track circuit for that block and the occupancy is not expected because the train's exclusive electronic movement authority extends through the entire block.

8. The method of claim **2** wherein a speed restriction is applied in areas with a potential rail vehicle rollout, comprising:

providing the onboard track database having information regarding whether there is a derail or rollout detector installed at each switch;

the onboard system checking the track database in advance of the predicted braking distance ahead of each switch in a block with an occupancy ahead, and if there is not a derail or detector installed at the switch, the onboard displaying and enforcing a speed restriction at that switch rather than allowing operation at maximum authorized speed;

if the train enters the block before the occupancy ahead clears the block, the onboard system continuing to enforce a speed restriction at each hand-throw switch ahead in that block that lacks a derail or rollout detector.

9. The method of claim **2** wherein a broken rail location is estimated by identifying the rear-of-train position at the time when the track circuit detects the rail break.

10. The method of claim **1** wherein the system sets the boundary between parsed movement authorities for joint occupants of a bidirectional movement authority based on location destinations requested by a joint occupant.

11. The method of claim **1** wherein the boundary between parsed movement authorities for joint occupants of a bidirectional movement authority is automatically set based on at least one of: (a) updated reports of location; (b) train speeds; and (c) braking distance from at least one of the joint occupants.

12. The method of claim **1**, wherein movement authorities are provided to each train in a format compatible with the train's level of onboard system functionality and interface protocol as known by the office.

13. The method of claim **1**, where the rate of automatic movement authority rollup by each train is assigned by an off-board system based on changing conditions.

14. A method for increasing the level of protection provided by a communication-based train control system against collisions among of a plurality of trains along a track divided into a series of fixed-block track circuits, including a remote office communicating via a communications network with the trains, each train having an onboard system operating the train in accordance with movement authority limits received from the office via the communications network, said method comprising:

parsing the route for each train into exclusive movement authorities by the office;

issuing and subsequently updating a movement authority from the office to each train, thereby granting exclusive authority for each train to move within a movement authority;

constraining the operation of each train by its onboard system to proceed along the track within its movement authority;

communicating from each train's onboard system to the office via the communications network to automatically roll up the movement authority for each train, releasing the portion of the movement authority behind the train with a safety margin to allow for any uncertainty in the rear-of-train location as the train proceeds along the track;

extending by the office the movement authority of a potential subsequent train, allowing it to occupy the released portion of the movement authority of the prior leading train;

detecting the existence of occupancy by any rail vehicle in each track circuit by applying and detecting an electrical signal to the rails;

communicating the state of the existence of occupancy by any rail vehicle in each track circuit track circuit to the trains;

further constraining the operation of each train by its onboard system to protect against a detected unexpected occupancy within the movement authority of each train;

detecting the existence of broken rail in each track circuit by applying and detecting an electrical signal to the rails;

communicating the state of the existence of broken rail in each track circuit track circuit to the trains; and

further constraining the operation of each train by its onboard system to protect against a detected broken rail within the movement authority of each train.

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