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Principles

ERTMS/ETCS Hybrid Train Detection

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1D	15/10/2020	Additional review comments processed	RD
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1G	16/07/2024	Several corrections plus the use of axle counter info included in detail	RD MBa

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1 Introduction

1.1 Purpose

1.1.1.1 This paper describes the Hybrid Train Detection (HTD) concept. The main characteristic of the concept is that it uses fixed (pre-configured) virtual blocks for the separation of trains which are able to send train integrity confirmation in the position report, while a limited installation of trackside train detection is used for the separation of trains which are not able to send integrity confirmation, as well as for the handling of degraded situations.

1.1.1.2 The concept is defined in a generic way, which makes it applicable for all kinds of lines, from high-density, high-performance lines to low density lines.

1.1.1.3 The concept defines only the principles of the Hybrid Train Detection concept. It is not a detailed system specification.

1.2 Why hybrid?

1.2.1.1 From the start the ETCS specifications contained a trackside implementation concept where the train separation function (collision avoidance) is fully based on train position and train integrity confirmation, both reported by the on-board to the trackside.

1.2.1.2 The advantage of such a concept is mainly a reduction of the trackside implementation cost, an improved performance, or a combination of both. The main cost saving is that in principle there is no need for trackside train detection. Only a reference for the train position remains necessary. Due to the absence of trackside train detection, it is easy to achieve very short fixed virtual block sections just by adapting the configuration of the trackside system, or even moving block sections, without an increase of cost for additional trackside devices, thereby improving the performance at relatively low cost.

1.2.1.3 In absence of trackside train detection, the whole concept relies fully on the condition that the trackside knows at all times the position and integrity status of each train or vehicle that is physically present in the area under its control. The problem is that in practice this condition cannot always be fulfilled. The train is not visible anymore for the trackside when there is no connection, e.g. the on-board enters shunting mode, is switched off intentionally (NP mode) or loses the radio connection. Even if the trackside remembers the last reported position of the train and the area in which the train was authorised to move, there is no guarantee that the train will stay within this area. There could be reasons to move the train under the supervision of operational procedures. The train could also move without any authorisation. Without trackside train detection, there is no way for the trackside to know the location of such a train in a sufficiently reliable way.

1.2.1.4 In case of switching on/off the trackside system (intentional restart or due to crash) it would have no knowledge at all of the trains in its area. Recovering from this situation would be cumbersome (sweeping of the whole trackside system area) and could require a long time.

1.2.1.5 In order to mitigate the problems related to these pre-conditions, while still preserving the cost and performance advantages, the Hybrid Train Detection concept was developed. This concept is presented in the next chapter.

1.3 The Hybrid Train Detection concept

1.3.1.1 The HTD concept described in this document is based on the following features:

1.3.1.1.1 It uses fixed virtual blocks. This is not a fundamental need of the concept. It is just for pragmatic reasons. In comparison to moving blocks, fixed virtual blocks have in several implementations less impact on the existing trackside systems such as the RBC, interlocking and traffic control centre as well as on the operational procedures. By reducing the length of the virtual blocks, the performance can be similar to moving blocks, which means that the performance benefit is not compromised.

1.3.1.1.2 It uses a limited implementation of trackside train detection. Trains which are not reporting confirmed integrity can still be authorised to run on the line, albeit with longer, but still acceptable, headways. Trains which are disconnected from the trackside are no longer lost. They are still visible by means of the trackside train detection, which facilitates operational movements of disconnected trains, protection against unauthorised disconnected trains, and recovery after a crash of the trackside system. In addition, trackside train detection can improve performance by providing a faster release of critical infrastructure (e.g. points) than what can be achieved on the basis of the position reports.

1.3.1.1.3 It uses the status of the virtual blocks for the train separation function. The underlying trackside train detection is only used, together with the position reports, to determine the status of the virtual blocks.

1.3.1.2 If the installation of trackside train detection is implemented by axle counters, which are restricted to the areas where the points are located, and possibly the level crossings, the cost will be only a fraction of the cost to fit the whole line with train detection (axle counter heads). The whole stretch of track between the point areas can be implemented as one large trackside train detection section. This large physical section is then split into as many virtual sections as necessary for the intended performance. In the points area power and cables are present anyway to operate the points. On the relatively long line between the point areas and on areas where (very) short blocks are required for short following, the main cost savings are achieved.

1.3.1.3 It can be used on existing lines, which are already fitted with train detection, to provide a cost-effective way to increase the capacity of the line, specifically in the peak hours. During the off-peak hours, trains which are not able to report confirmed integrity could be scheduled, e.g. freight trains. Therefore, the concept is beneficial when the majority of trains is able to report confirmed integrity.

1.3.1.4 It can also be used on low density lines, where the fitment of a few train detection devices around the points (e.g. axle counters) together with a HTD trackside system would provide a cost-effective way to achieve an ETCS implementation.

1.3.1.5 It should be noted that the HTD concept described in this document is by no means intended to be the only concept which uses information from the train position report for the train separation function on trackside.

1.3.1.6 The HTD concept can deliver the same performance as a moving block concept if the virtual block sections are sufficiently small.

1.3.1.7 Since there are no easy solutions for the problems related to the train separation function without any trackside train detection, the HTD concept is a pragmatic and flexible solution.

1.3.1.8 This HTD concept is further developed in detail in the following chapters.

1.4 Implementation considerations

1.4.1.1 The HTD concept is based on the ETCS specifications as defined in the TSI CCS and the related operational rules as defined in the TSI OPE.

1.4.1.2 In principle the HTD concept can be implemented on any ETCS radio-based trackside implementation, independent of the implemented system version. However, for some system versions the following considerations have to be taken into account.

1.4.1.3 The HTD concept is fully compatible with on-boards which are certified to ETCS system version 2.2 and 3.0.

1.4.1.4 When an on-board of system version 2.0 or 2.1 is intended to run on the HTD infrastructure, the infra manager should require the on-board to implement the CRs 0940 and 1304. These CRs ensure that the integrity confirmation of the train in conjunction with the acquired train length is achieved with the required safety level.

1.4.1.4.1 If it is not immediately feasible to implement CRs 0940 and 1304 in the on-board, the infra manager could implement the proposed mitigations in annex B.

1.4.1.5 Note that the specifications allow for the train integrity to be confirmed by the driver. This is however not considered as an acceptable solution for most lines since it does not provide the required safety level. Only in situations where the risk of mistakes by driver is relatively low, this function could be acceptable.

1.4.1.6 For further information about the engineering of the HTD concept, see the related engineering guidelines [2].

2 Documents & Terminology

2.1 Reference documents

[1] *ERTMS/ETCS Subset-026: System Requirements Specification 3.6.0.*

[2] *21E087-3- HTD engineering.*

[3] *ERTMS/ETCS Subset-023: Glossary of Terms and Abbreviations 3.3.0.*

[4] *COMMISSION REGULATION (EU) No 1302/2014 of 18 November 2014 concerning a technical specification for interoperability relating to the 'rolling stock — locomotives and passenger rolling stock' subsystem of the rail system in the European Union.*

[5] *COMMISSION REGULATION (EU) No 321/2013 of 13 March 2013 concerning the technical specification for interoperability relating to the subsystem 'rolling stock — freight wagons' of the rail system in the European Union.*

[6] *ERTMS/ETCS Subset-093 GSM-R Interfaces Class 1 Requirements 4.0.0.*

[7] *ETCS CR 0940: Minimum safe rear end position and position reporting ambiguities.*

[8] *ETCS CR 1304: Missing Level 3 safety requirements.*

2.2 Abbreviations

Note: Abbreviations already defined in [3] are not repeated in this section.

ATAF	Automatic Track Ahead Free (engineering guideline)
EoM	End of Mission
HTD	Hybrid Train Detection
PTD	Positive Train Detection (based on position reports from trains)
SMB	Stop Marker Board
TIMS	Train Integrity Monitoring System
TTD	Trackside Train Detection (using conventional methods)
VSS	Virtual sub-section

2.3 Definitions

Note: Definitions already defined in [3] are not repeated in this section, except when useful for understanding the HTD concept.

VSS:	A virtual sub-section, corresponding to a sub-division of a TTD section for which the occupation status is determined using both PTD and TTD information. A VSS can have four different states. See Figure 1 for the section conventions. See chapter 3.2 for the definition of the VSS states.

TTD:	A section defined by a conventional trackside train detection system, e.g. track-circuits or axle-counters.
L_TRAIN	Train length reported as valid data train, defined in [3].
L_TRAININT	Confirmed train length included in a Position Report with integrity confirmed, defined in [3].
PTD:	Detection of the train location based on information received from the train in the position report (position, integrity status,L_TRAININT) and, in case of a non-integer train, in the reported train data (L_TRAIN).
FS MA	An MA with no mode profile covering the relevant VSS
Train location:	This represents the trackside view of the track currently occupied by a train. See 3.3 for detailed explanation.
Safe Rear Margin:	This is a distance the trackside is adding to the confirmed train's rear end as an additional safety margin.
Chasing train:	Train that is following another train at a "short" distance. "Short" is relative and depends on the trackside configuration, block length, speed, etc.
Chased train:	This is the train in advance of a chasing train (see also chasing train), running in the same direction.
Ghost train:	A ghost train is either a physical object that is present on the track and detected by TTD, but that is unknown to the trackside system by means of PTD (no radio communication), or it is a virtual object which seems to occupy the track due to a trackside failure.
Shadow train	A ghost train that is following a train operating normally in the HTD area.
Integer train:	A train which reports "integrity confirmed" becomes an integer train.
Trackside integrity status	Trackside view of the integrity status of a train. It may momentarily differ from the integrity status reported by the on-board. The status "train treated as integer" allows the trackside to release infrastructure in rear of the train.
Non-integer train:	A train for which any of the conditions not to be treated as integer (see a)) is fulfilled, becomes a non-integer train.
Connected train	A train with an established safe radio connection to the trackside and valid train data
Disconnected train	A train without an established safe radio connection to the trackside, or a train with an established safe radio connection, but without valid train data, e.g. during SoM

Confirmed rear end	Min safe rear end of the train derived from a position report with integrity confirmed (min safe front end minus L_TRAININT)
Established rear end	Trackside view of the rear end of a train which is treated as integer
Reported rear end	Min safe rear end of the train derived from a position report without integrity confirmation (min safe front end minus L_TRAIN)
Assumed rear end	Trackside view of the rear end of a train which is not treated as integer
Max safe rear end	The max safe front end minus L_TRAIN
Min safe rear end	The min safe front end minus L_TRAIN
Memorised train location	The last train location that was known by the trackside before a train gets disconnected
Jumping train	A train which does not report its position on every block, due to the discrete intervals in which position reports are sent and/or time delays in the trackside train detection

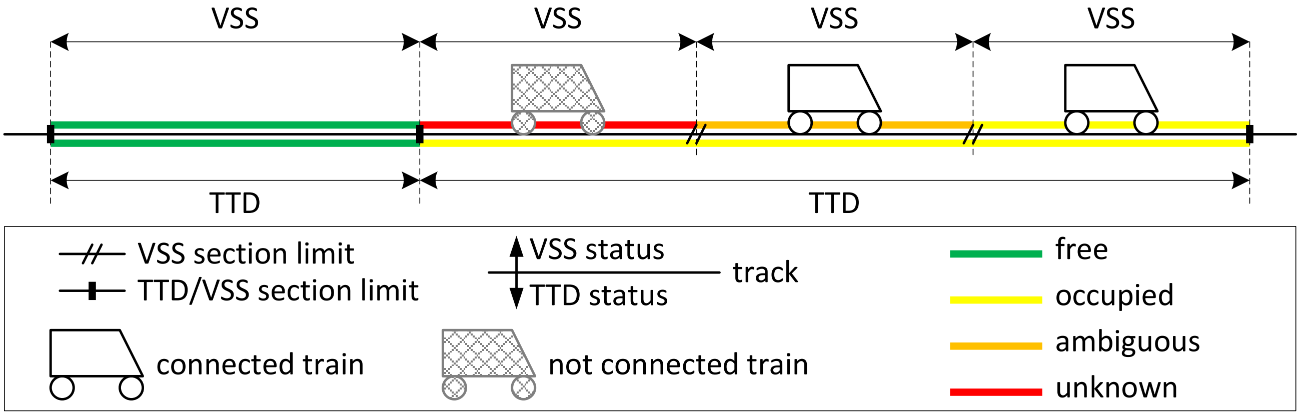


Figure 1: Section conventions

Note: Marker Boards are not foreseen at every section border. They are only installed to protect movable objects in the track.

3 Main principles for Hybrid Train Detection

3.1 General

3.1.1.1 The concept in this document is defined as a HTD only implementation. It means that mixed ETCS level implementations (e.g. with level 1, level NTC) and lineside signals are in principle possible, but are not within the scope of this document.

3.1.1.2 TTD sections (including those containing movable elements) can be divided into several VSS sections.

3.1.1.3 Note: It is an implementation decision whether movable elements can only be moved when the corresponding TTD is free.

3.1.1.4 Note: The introduction of VSS does not change the principles of route setting and handling of MAs since VSS are treated in the same way as sections with TTD. Also, the principles for placing marker boards do not need to change compared to sections with TTD.

3.1.1.5 TTD information is considered as safe, i.e. reporting free only if no train is present on the TTD section. As a result, all VSS on a free TTD can be considered as “free”.

3.1.1.5.1 Note: A malfunctioning TTD is considered as occupied.

3.1.1.6 The calculation of the safe rear end of a train relies on the train length in the train data. The reported L_TRAIN in the train data of an integer train is considered as safe data, i.e. covering the actual train length and updated if the train length changes e.g. because of splitting or joining.

3.1.1.7 In the context of the HTD concept (the trackside view), an MA is understood as to cover the track between the rear end of the train location, as defined in 3.3, and the SvL or LOA. This notion of MA remains valid when the train location is deleted (see 3.3). In that case the MA is based on the memorised train location, but it is still considered to exist.

3.1.1.7.1 Note that this does not mean that the MA will exist forever. The trackside may have its own specific conditions to decide when an MA that was sent to a train, which later lost its connection, is not taken into account anymore.

3.2 Definition of VSS states

3.2.1.1 Besides the two states (free, occupied) which at least exist for a TTD (depending on the implementation there may be other logical states), two additional states are needed for a VSS to cover all operational situations. State "unknown" when there is no certainty if the VSS is “occupied” or not. State "ambiguous" when the VSS is known to be occupied by a (connected) train, but when it is unsure whether another (not connected) vehicle is located in rear of this train on a VSS on which the first train is located.

3.2.1.1.1 Note: The distinction between "ambiguous" and "unknown" provides a convenient way to manage potentially hazardous situations. See the scenarios in annex A for some examples.

3.2.1.1.2 Note: When the words "free", "occupied", "ambiguous" and "unknown" are surrounded by quotes, they refer to the state of a VSS.

3.2.1.2 Each VSS is in one of the states defined in the table below. The transitions are defined in section 4.6.1.2.1.

VSS state	Description
Free	The trackside is certain that no train is located on the VSS.
Occupied	The trackside has information from a position report that a train treated as integer is located on the VSS and the trackside is certain that no other vehicle is located in rear of this train on a VSS on which the first train is located.
Ambiguous	The trackside has information from a position report that a train is located on the VSS and the trackside is NOT certain that no other vehicle is located in rear of this train on a VSS on which the first train is located.
Unknown	The trackside has no information from a position report that a train is located on the VSS, but it is not certain that the VSS is free.

Table 1: VSS states

3.2.1.3 The state of a VSS is derived from TTD occupancy information and train position reports.

3.2.1.4 For the purpose of authorising train movements and the indication to the traffic controller, only the VSS state "free" needs to be individually distinguished. All other states can be treated as if the VSS is “occupied”. This could enable an easy integration of HTD with existing trackside systems as explained in chapter 1.3.

3.3 Definition of train location

3.3.1.1 The term “train location” defines the trackside view of the stretch of track that is currently occupied by a connected train. The granularity of the train location is one VSS. The front end of the train location is not depending on the integrity status whereas the rear end of the train location is different (established for a train treated as integer or assumed for a train which is not treated as integer).

3.3.1.1.1 The train location can only be based on one type of rear end at a time. The established and assumed rear end are mutually exclusive. When the train is not treated as integer anymore (see 3.5), the train location is based on the assumed rear end, not anymore on the established rear end.

3.3.1.2 The front and rear end of the train location are considered independently from each other. If information of the front and rear end is received together, i.e. one position report, they are treated as two independent events, and the front end is processed first.

3.3.1.3 The train location only exists as long as the train is considered as connected to the trackside. As soon as the mute timer expires (see 3.4.1), the train location is deleted, but as memorised train location still valid for use in the state machine.

3.3.2 Front end of the train location

3.3.2.1 When the trackside receives the confirmation that the max safe front end of the train has entered a VSS (through position reports), it considers the train to be located on this VSS and all preceding VSS up to the last VSS currently covered by the train location.

3.3.2.1.1 Exception 1: If the max safe front end is on the VSS in advance of the EOA, but the min safe front end is in rear of the EOA, the train location shall not be considered to extend on the VSS in advance of the EOA. The exception is to avoid treating the next VSS in advance of the MA as “occupied”, which would prevent sending a new FS MA over it. The consequence of this exception is that the train may have physically entered the VSS in advance of the EOA, while the state of this VSS is still "free". This risk can be mitigated with a release speed zero or by forbidding opposing movements on VSS limits. For TTD limits this risk does not exist (train in advance of EOA would be detected by TTD).

3.3.2.1.2 Exception 2: As long as the TTD where the max safe front end is reported is free, or if this TTD becomes free when a preceding train leaves it, the train location shall not be considered to extend on the VSS which are part of this free TTD. This avoids setting a VSS to “occupied” before the train physically entered it and therefore helps when cancelling routes or changing the train orientation.

3.3.2.2 Updating the front end of the train position does not depend on the integrity status in the position report.

3.3.2.3 When the trackside receives information that the max safe front end of the train has moved backwards within the previous confidence interval (this could be due to relocation), a VSS which was previously part of the train location and which is now in advance of the max safe front end, shall still be considered as part of the train location.

3.3.2.3.1 Note: In this way the relevant VSS are only updated if a real movement in backwards direction took place.

3.3.3 Established rear end of the train location

3.3.3.1 For a train treated as integer the established rear end of the train location is derived from the confirmed rear end and from TTD information confirming that the train is not located on a VSS which was left by the train.

3.3.3.1.1 See Figure 2 for an example which shows how the train location is derived from the PTD and TTD information.

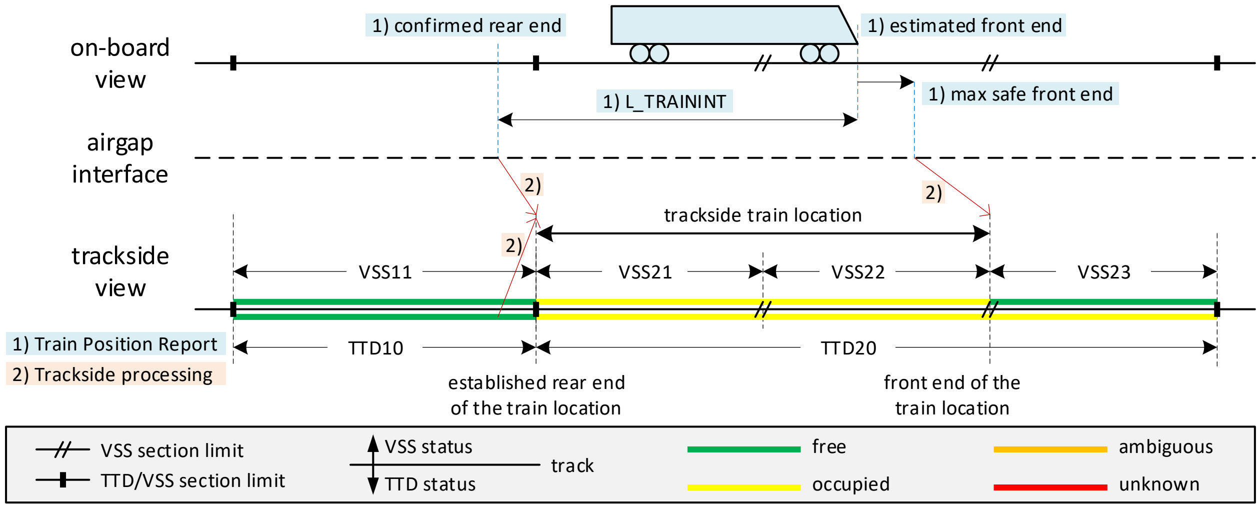


Figure 2: Train location for a train treated as integer

3.3.3.2 Note: The train is not located anymore on a VSS and all preceding VSS (i.e. the established rear end of the train location is moved) when the trackside receives the confirmation that the rear end of the train has left a VSS.

3.3.3.3 Note: It is up to the specific trackside implementation whether an integrity confirmation by driver is taken into account for updating the established rear end of the train location or not. The arguments to take driver confirmation into account or not, are outside the scope of this document.

3.3.3.4 Note: The established rear end of the train location is never updated by position reports with the integrity status “Lost” or “No information available”.

3.3.3.5 The established rear end of the train location is never updated by position reports of on-board in the modes Sleeping or Non-Leading.

3.3.3.6 If an update of the established rear end of the train location by TTD information would lead to a train located on no VSS anymore, the train is considered to be located on the first VSS of the following occupied TTD. This is to avoid losing the train location due to delayed PTD information (“jumping train”).

3.3.3.6.1 An update of the established rear end of the train shall only take place if the resulting rear end will not be in advance of the train front end. This is to avoid an inconsistent location in case the TTD was left by the train, while the next TTD has not yet become occupied (due to delays in the detection).

3.3.3.7 If the established rear end of the train location has moved forward due a TTD becoming free, and if this TTD becomes occupied again (due to a following train), the confirmed rear end might be reported again on a VSS of this TTD. In that case the established rear end shall only be updated if this newly received confirmed rear end is in rear of the confirmed rear end from the last position report when the concerned TTD was still free.

3.3.3.7.1 Note: In this way the relevant VSS are only updated if a real movement in backwards direction took place.

3.3.4 Assumed rear end of the train location

3.3.4.1 For a non-integer train the position of the rear end of the train location can only be assumed since there is no positive confirmation of its location. The assumed rear end is however also used for integer trains which are not treated as integer (see3.5).

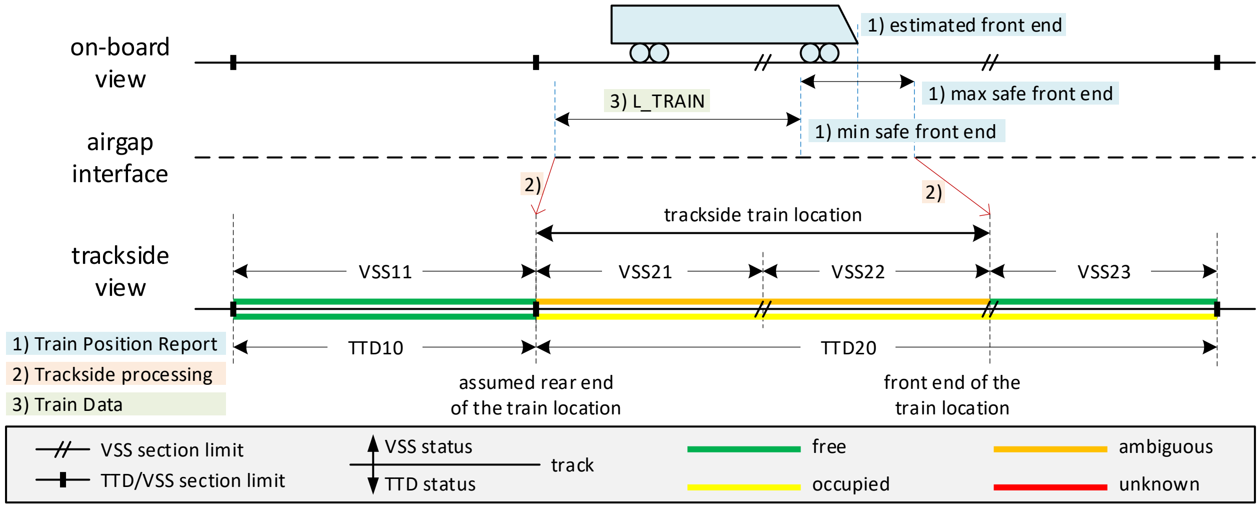


Figure 3: Train location for non-integer train

3.3.4.2 The assumed rear end of the train location is derived from the reported rear end (the min safe front end of the last position report minus L_TRAIN) of a train as well as from TTD information confirming that the train is not located on a VSS.

3.3.4.3 Note: The train is not located anymore on a VSS and all preceding VSS (i.e. the assumed rear end of the train location is moved) when the trackside receives the information that the rear end of the train has left a VSS.

3.3.4.3.1 Since the assumed rear end of the train location is only "assumed" it can never be used to clear a VSS in rear. Therefore, the VSS that was left by the assumed rear end of the train is not set to "free", but to “unknown”.

3.3.4.4 If an update of the assumed rear end of the train location by TTD information would lead to a train located on no VSS anymore, the train is considered to be located on the first VSS of the following occupied TTD. This is to avoid losing the train location due to delayed PTD information (“jumping train”).

3.3.4.4.1 An update of the assumed rear end of the train shall only take place if the resulting rear end will not be in advance of the train front end. This is to avoid an inconsistent location in case the TTD was left by the train, while the next TTD has not yet become occupied (due to delays in the detection).

3.3.4.5 If the assumed rear end of the train location has moved forward due a TTD becoming free, and if this TTD becomes occupied again (due to a following train), the reported rear end might be again on a VSS of this TTD. In that case the assumed rear end shall only be updated if this new reported rear end is in rear of the reported rear end from the last position report when the concerned TTD was still free.

3.3.4.5.1 Note: In this way the relevant VSS are only updated if a real movement in backwards direction took place.

3.3.4.6 On an ambiguous VSS the assumed rear end is used for the train location. This to prevent that for an integer train the L_TRAININT is used for the shadow train timer when leaving the TTD AND to prevent a ‘train length’ change if temporarily reporting “no integrity info”.

3.4 Definition of timers

3.4.1 Waiting timers

3.4.1.1 Waiting timers are implemented in the trackside to avoid unnecessary changes in the state of a VSS due to the asynchronicity of train position, train integrity and TTD information.

3.4.1.1.1 Justification: Such unnecessary VSS state changes would have a negative impact on operation and performance.

3.4.1.1.2 A waiting timer may be configured with or without a stop event. Without a stop event, once started it will always run until it expires and will stay in the "expired" state. It will be reset when the start condition is met again.

3.4.1.1.3 If a start or stop event contains more than one numbered condition (a, b, c), these conditions shall be combined with an OR, i.e. any of these conditions will trigger the start/stop event.

3.4.1.2 A “mute timer” is assigned to each connected train. For usage see 3.9.

3.4.1.2.1 Start event:

a) Information is received from the train.

3.4.1.2.2 Stop event:

a) The train is disconnected and can be assumed to be stopped.

3.4.1.3 A “wait integrity timer” is assigned to each connected train. For usage see 3.8.

3.4.1.3.1 Start event:

a) Integrity confirmation is received from the train.

3.4.1.3.2 Stop events:

a) The train reports "integrity lost"
b) The mute timer of the train expires
c) The train reports a change of L_TRAIN

3.4.1.4 Intentionally deleted

3.4.1.5 A “shadow train timer” is assigned to each TTD for each direction and for each connected train on the TTD. For usage see 4.5.

3.4.1.5.1 Start event:

a) The integer train reports that its max safe rear end is inside the TTD

3.4.1.5.2 Before the “shadow train timer” is started, this timer should be increased with the time to cover the distance from the last reported max-safe-rear to the TTD-limit, with a maximum of the position_report_period time. To be on the safe side an acceleration shall be assumed. This increase of the timer is to avoid that it will expire too early because of the position report interval.

3.4.1.5.3 Stop events:

a) The train becomes not treated as integer (see a)).

b) The mute timer of this train expires.

3.4.1.5.4 Note: The delays due to communication can be mitigated by using the difference of the timestamp and the time when the position report was received. This mitigation requires synchronisation of the on-board and trackside time. An example of such synchronisation can be found in the engineering guideline 64 "Handling of Level Crossings with BL3", see www.ertms.be.

3.4.2 Propagation timers

3.4.2.1 Propagation timers are implemented in the trackside to avoid unnecessary propagation of the state “unknown” to VSS sections for which there is no immediate risk that a rail vehicle could be located on them.

3.4.2.1.1 Justification: An immediate propagation, without timer, would have a negative impact on operation and performance.

3.4.2.1.2 A propagation timer is always configured with at least one stop event, which occurs when the state machine of chapter 4.6.1.2.1 has been fully processed following the expiration of the propagation timer which triggered the state machine.

3.4.2.1.3 A propagation timer which is stopped after it has expired, is not considered as expired anymore. This to make sure that its expiration is processed only once.

3.4.2.1.4 If a start or stop event contains more than one numbered condition (a, b, c), these conditions shall be combined with an OR, i.e. any of these conditions will trigger the start/stop event. When a propagation timer is started, it is not restarted if another start condition occurs before it is expired.

3.4.2.1.5 The propagation timers can be configured to be location and direction specific. This allows them to take into account the need to deviate in locations where either changing direction, rolling back and/or ghost train movements are less likely within a specific time.

3.4.2.2 A “disconnect propagation timer” is assigned to each VSS. For usage see 4.2.1.

3.4.2.2.1 Start event:

a) The VSS changes to "unknown" because it is part of the MA of a train for which the “mute timer” has expired.

b) A train located on the VSS reports termination of communication session.

c) The mute timer expires for a train, located on the VSS, without an MA.

3.4.2.2.2 Stop event:

a) The connection of all trains for which the timer was started, is restored with the same train orientation.

b) The TTD of the VSS becomes “free”

c) The VSS state machine (see chapter 4.6.1.2.1) is fully processed after the timer expired

3.4.2.3 A “ghost train propagation timer” is assigned to each TTD. For usage see 4.2.2.

3.4.2.3.1 Start events:

a) (TTD becomes “occupied”) AND (no train located on it) AND (in each direction no FS MA exists covering the first VSS of the TTD).

b) (TTD becomes “occupied”) AND (no train located on it) AND (an FS or OS MA exists covering the first VSS of the TTD in one direction) AND (the train to which the MA was sent could not have reached the TTD in the time between the last position report and the moment the TTD becomes occupied).

c) (TTD is occupied) AND (trackside system detects movement into TTD section) AND ((no connected train is located at the TTD border) OR (no connected train could have reached the TTD border in the time between its last position report and the moment movement is detected at the TTD border)).

3.4.2.3.2 Stop event:

a) The VSS state machine (see chapter 4.6.1.2.1) is fully processed after the timer expired

3.4.2.3.3 A started ghost train propagation timer is considered immediately expired when the TTD becomes free again. In that case the train must be on one of the neighbouring TTDs, and therefore propagation should start immediately.

3.4.2.4 An “integrity loss propagation timer” is assigned to each VSS. For usage see 4.2.2.1.

3.4.2.4.1 Start event (only applicable for a train on a VSS in state “occupied” or "ambiguous"):

a) train becomes not treated as integer (see a))

Note that this event also triggers a transition of the VSS to state "ambiguous".

3.4.2.4.2 Stop events:

a) All trains, for which the timer was started, report confirmed integrity again with unchanged L_TRAIN compared to the last position report based on which the train was still treated as integer before the timer started
b) VSS state changes to “occupied” or to “free”
c) The VSS state machine (see chapter 4.6.1.2.1) is fully processed after the timer expired

3.4.2.4.3 Note: The condition "occupied" in the stop events avoids that a sweeping (OS MA) train, which would set the VSS to "occupied", would be disturbed when the timer expires.

3.5 Definition of the trackside integrity status

3.5.1.1 The HTD trackside will decide whether a train has to be treated as integer or not, based on information received from the train.

3.5.1.2 The trackside will treat a train as integer as soon as all the following conditions are fulfilled:

a) train is an integer train
b) train has crossed a TTD border where the last VSS of the TTD in rear was in state “ambiguous” when the train was located on this VSS
c) TTD in rear becomes “free”
d) train reports to have left TTD in rear

e) the “shadow train timer” of the TTD in rear for this train is not expired

3.5.1.2.1 Exception: If axle counter information is used (see section 5.2), the condition c) above can be omitted.

3.5.1.3 The trackside will not treat a train as integer if one of the following events occurs:

a) the train reports "integrity lost"
b) PTD with no integrity information is received after the "wait integrity timer" has expired
c) the train reports changed L_TRAIN
d) the train is located on at least one VSS where there is also another train located
e) the VSS in rear of the train location, or, if applicable, the memorised train location, becomes “unknown”
f) a propagation timer of the VSS, or of the related TTD, in rear of the train location, or, if applicable, the memorised train location, expires
g) (trackside system detects movement into TTD) AND (train is located on the first VSS of this TTD where the incoming movement is detected) AND (the “shadow train timer” of the TTD in rear for this direction and for this train is expired)

3.5.1.3.1 Note: Condition g) is only applicable if axle counter information is used (see section 5.2),

3.5.1.4 The train integrity status transitions are shown in Table 2.

Non-integer train		< 3
1 >	**Integer train**	
	2 >	**Train treated as integer**

Table 2 Train integrity status transitions from trackside perspective

Condition ID	Content of the conditions
1	Train reports confirmed integrity
2	All conditions in 3.5.1.2 are fulfilled
3	One of the events in a) occurs

3.6 Operation of trains treated as integer

3.6.1.1 The trackside will release infrastructure based on position reports from a train reporting confirmed integrity. The VSS that the train leaves will become “free” if there is no shadow train risk (see 4.5).

3.6.1.2 A train that reports “no integrity information available”, after having reported "confirmed integrity", is treated as integer as long as none of the events to change the trackside integrity status occurs. This does not mean that the reported rear end is used to update the train location. See 3.3.3.6.1.

3.6.1.2.1 Note: This to avoid that an intermediate position report without integrity confirmation would lead immediately to substantial operational impact.

3.6.1.2.2 The "wait integrity timer " can be set to a relatively high value, e.g. 1 minute, because there is no direct safety issue.

3.6.1.3 The performance on the line depends on the time delay between the moment when a train treated as integer leaves a VSS and the moment when this VSS changes its state to "free". This delay time depends on the frequency of the position reports and integrity confirmation. To achieve an optimum performance the trackside should request frequent position reports.

3.7 Operation of trains not treated as integer

3.7.1.1 The trackside will not release infrastructure based on position reports from a train that is not treated as integer. The "ambiguous" VSS that the train leaves, i.e. the assumed rear end of the train as defined in 3.3.3.6.1 is in advance of this VSS, will become “unknown”. These sections will be set to “free” when the whole TTD becomes free. Thus, this corresponds to a system without virtual sub-sectioning.

3.8 Operation of trains with lost integrity

3.8.1 Introduction

3.8.1.1 When a train reports “integrity lost” it is not treated as integer, but it can, from the train protection point of view, continue its mission. If a coupling is indeed physically broken (wagons or carriages decoupled from the original train) and not a failure in the TIMS function, both train parts will be braked to standstill according to requirement 4.2.4.2.1. (4) in [4] and requirement 4.2.4.3.1 in [5].

3.8.1.2 The reported integrity loss of Train 1 in Figure 4 will result in an update of the established rear end to the assumed rear end (not releasing infrastructure in rear of the train, see 3.7) and does not impact the mission of Train 1 but the trackside will not be able to extend the FS MA for Train 2.

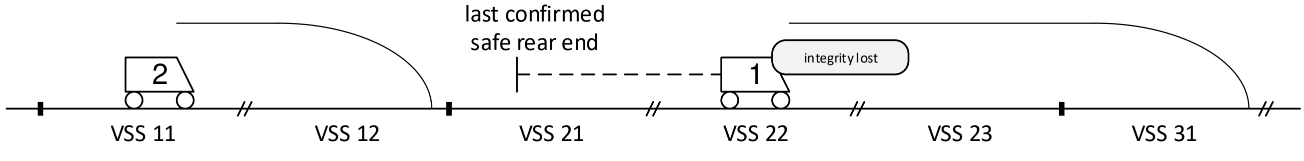


Figure 4: Loss of train integrity

3.8.2 Chasing train has an MA ending before the TTD section with the loss of integrity

3.8.2.1 When the chasing train does not have an MA ending inside the TTD section where the chased train is located when it loses its integrity, the impact is the same as for a train following a train not reporting confirmed integrity.

3.8.3 Chasing train has an MA ending in the TTD section with the loss of integrity

3.8.3.1 When the chasing train does have an MA ending inside the same TTD section where the chased train is located when it loses its integrity, the chasing train can be impacted.

3.8.3.2 At the moment the chased train reports “loss of integrity”, a changed L_TRAIN or "no integrity information" after the “wait integrity timer” expires, the VSS sections, in which the train is located, are considered as “ambiguous”. They will become “unknown” when the train exits them (based on the assumed rear end).

3.8.3.3 Then two scenarios are possible:

a) The chased train (Train 1) frees the whole TTD section before the chasing train enters the TTD section. In that case all the VSS sections in this TTD change to free and the FS MA can be extended until the end of the TTD section. The impact is the same as for a train following a train not reporting confirmed integrity.

b) The chasing train (Train 2) enters the TTD section before the chased train leaves it. In that case, the VSS sections remain “unknown” and the chasing train has to operate in OS or in SR until the end of the TTD section. If Train 2 is integer, this results in sweeping those VSS enabling the sending of FS MAs to a following train on the same TTD.

3.8.3.4 Note: If the Infra Manager wants to avoid this operational impact of sweeping, a FS MA should not be extended onto a TTD when a loss of integrity is detected on this TTD.

3.9 Operation of trains without connection to the trackside

3.9.1 Train disconnection

3.9.1.1 According to [1], the communication session is considered as lost by the trackside (or by the train) 5 minutes after the last received message from the train (or from the trackside). This timer is not adapted to the HTD system needs.

3.9.1.2 The trackside shall consider the communication lost with the train after a smaller timer called “mute timer”. To allow the train to recover from a temporary loss of radio communication this timer could be set to a value of at least 22s (see [6] clause 10.4.2.5). As soon as the “mute timer” expires, the VSS section on which the train is located shall be considered as “unknown”.

3.9.1.3 When the train is disconnected from the trackside because the mute timer expires, the VSS sections part of the MA and on an occupied TTD, up to the first VSS which is “occupied” or "ambiguous" (both states due to another train), are set immediately to “unknown”.

3.9.1.3.1 Because the train can still move after the mute timer expires, the VSS on a TTD section that becomes occupied within the MA are also immediately set to “unknown”.

3.9.1.3.2 This is done because the train can occupy all VSS which are part of its MA.

3.9.1.3.3 Note: If the Infra Manager wants to avoid this operational impact of sweeping, a FS MA should not be extended onto a TTD when a loss of connection is detected on this TTD.

3.9.2 Train reconnecting

3.9.2.1 When a train reconnects with the same train orientation after the “mute timer” has expired, the VSS sections set “unknown” when the “mute timer” expired can be restored based on the following conditions:

- The VSS sections where the train is located will become “occupied” if the train reports “integrity confirmed”, no change of L_TRAIN was reported since the previous position report and there is no shadow train risk. If these conditions are not fulfilled, these VSS sections will become “ambiguous”.
- The VSS sections in advance of the train covered by the original MA will become “free” if the original MA is still valid on-board, or can be re-issued to the train. If this condition is not fulfilled, these VSS sections will remain “unknown”.
- The VSS sections in rear of the train location become “free” if the train reports “integrity confirmed”, no change of L_TRAIN was reported since the previous position report and there is no risk that another train had entered these sections. If these conditions are not fulfilled, these VSS sections will remain “unknown”.

3.9.2.2 Note: VSS sections in state “unknown” in rear of the train would of course also become “free” if the TTD is released.

3.10 Sweeping of sections

3.10.1 Sweeping of VSS sections

3.10.1.1 The sweeping mechanism allows clearing VSS with state “unknown” without waiting until the TTD becomes free. The following procedure would apply:

a) A train treated as integer receives an authorisation (e.g. OS or SR) to move through the “unknown” VSS.
b) When the train treated as integer enters that VSS, the VSS becomes “occupied”.
c) When the train treated as integer exits that VSS in the same direction as when it entered, the VSS becomes “free”.

3.10.1.1.1 Note: Sweeping of a VSS with state "ambiguous" is not possible, because the first train which leaves the VSS would trigger the VSS to become "free" while there is still another train (the sweeping train) on the VSS.

3.10.1.1.2 Note: If a TTD is in state occupied due to broken rail (detected by track circuit), all VSS on this TTD will nevertheless become free after sweeping. The infrastructure manager should take appropriate mitigation measures in this case. The nature of these measures is implementation specific and outside the scope of this document.

3.10.2 Sweeping of TTD sections

3.10.2.1 It could be considered to increase the availability of the infrastructure by using PTD information from “sweeping” trains to recover from TTD failures.

3.10.2.2 It is however not obvious that such a functionality would be feasible for all locations, since TTD is used for safety purpose in the HTD concept (e.g. to detect ghost trains). Further details for this mechanism are not provided in this paper and are up to the specific implementation.

3.11 Entry/exit of a HTD area

3.11.1.1 When a train enters a HTD area, the first VSS will become ambiguous because it cannot immediately be excluded by the HTD trackside that another train is following the entering train. To allow a smooth entry in the HTD area, specific measures should be taken to trigger the transition from ambiguous to occupied when the train is completely inside the HTD area, i.e. it has passed a TTD border at the entry of the HTD area. Since these measures depend on the area that is left by the train, they are not defined in this document

3.11.1.2 As soon as a train has left the HTD area completely, it is not taken into account anymore by the HTD trackside, i.e. location and related timers do not exist anymore

4 Hazard mitigation

4.1 Introduction

4.1.1.1 In addition to the risks which exist in implementations which fully rely on TTD, there are two generic risks which have to be taken into account for any trackside implementation which uses position report information for the train separation function, including HTD:

a) Not connected vehicles could be present on the track. Examples are: trains with cab closed, track-train communication failure, trains not fitted with ETCS, vehicles which perform shunting movements, wagons which are not coupled to a loco.
b) Such a not connected vehicle could move due to e.g. operational procedures, brakes which have lost their brake power (air pressure reduced after a certain amount of time), defective brakes, unauthorised movements.

4.1.1.2 If the trackside is not aware of such a stationary or moving not connected vehicle, another train movement could be authorised over the track where the not connected vehicle is present, resulting in the main related hazard.

4.1.1.3 The following sections in this chapter describe the different situations in which the VSS states "ambiguous" and "unknown", together with the relevant timers, are used to mitigate the risk mentioned above.

4.2 Protection against non-connected trains

4.2.1 Disconnection of a train

4.2.1.1 When there is no communication anymore with a train (due to End of Mission or due to a communication failure, see also 3.9), the train is not known anymore to the trackside.

4.2.1.2 The VSS sections on which the train is located when the disconnection is detected by the trackside are immediately set to “unknown” to indicate that a not-connected vehicle can be present on these VSS.

4.2.1.3 A train with a communication failure could have used its MA completely. Therefore, all the VSS which are

- in advance of the last train location, AND
- on an occupied TTD (also if the TTD becomes occupied after the disconnection), AND
- part of the MA sent to that train,

shall also be set to “unknown” immediately, up to the first VSS which is "occupied" or "ambiguous" (both states due to another train).

4.2.1.4 As the train can move after the disconnection without the trackside being aware of the movement, the state “unknown” shall be propagated as soon as the “disconnect propagation timer” expires onto adjacent VSS, forward and backward, until one of the following sections is reached:

a) Free TTD
b) VSS where a train is connected (i.e. “occupied” or “ambiguous”)
c) VSS which is part of the MA of another train on another TTD

4.2.1.4.1 Note: The value of the “disconnect propagation timer” depends on the risk for these movements to occur in the specific location/operation. A value between 5-15 minutes would seem to be practical. The 5 minutes will allow a reconnection within the session. But a lower value could be selected. If this risk is mitigated by other means the value could be infinite or several hours.

4.2.1.5 If a TTD section, which is fully/partially part of an MA sent to the train before the disconnection occurred, becomes occupied, the VSS inside this TTD shall immediately be set to “unknown”, up to the next free TTD or up to the next VSS “occupied” or “ambiguous”. This is done since the occupation of the formerly free TTD indicates that the disconnected train moved onto the VSS not yet set to “unknown”.

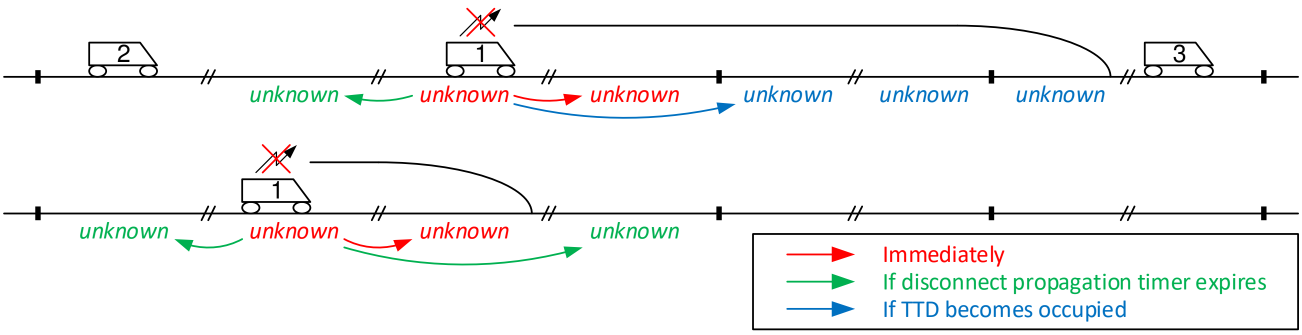


Figure 5: Propagation of "unknown" after disconnection during mission

4.2.1.6 If a chasing train has a FS MA covering a VSS becoming “unknown”, the MA of the chasing train can be impacted, depending on the implementation, in a way that it does not extend anymore over this "unknown" VSS.

4.2.1.7 Note: Including a TTD section with one VSS section at strategic locations is a good mechanism to stop propagation. If the state of this VSS is “free” or “occupied” or "ambiguous" (the normal situation), it will indeed stop propagation (see 4.2.1.4 a and b). If its state is "unknown", it is itself the trigger for propagation.

4.2.1.8 Note: When the TTD section with a point is occupied and the point direction is unknown in a degraded situation, propagation is performed over both legs of the point. If the point direction is known and it changes, the propagation can be performed in the new direction. This is a project specific implementation and can be achieved by restarting the propagation timer.

4.2.2 Additional protection against ghost trains

4.2.2.1 If a TTD section becomes unexpectedly occupied when in each direction no FS MA exists covering the first VSS of the TTD and no train is located on the TTD, the presence of a train not connected to the trackside cannot be excluded. If the TTD becomes occupied while there exists an MA (FS or OS) covering the first VSS of the TTD in one direction and the train to which the MA was sent could not have reached the TTD in the time between the last position report and the moment the TTD becomes occupied, the presence of another train cannot be excluded. In both scenarios all VSS sections inside the TTD section shall be set to “unknown". Because there is no information that the ghost train has not moved to neighbouring VSS sections on other occupied TTD, the state “unknown” shall be propagated as soon as the “ghost train propagation timer” expires onto adjacent VSS, forward and backward, until one of the following sections is reached:

a) Free TTD
b) VSS where a train is connected (i.e. “occupied” or “ambiguous”)

4.2.2.1.1 Note: The ghost train propagation timer could be set to the expected time that the TTD could be passed by a ghost train with the SR/SH speed.

4.2.2.1.2 Note: With an OS MA there remains a risk that there was another train ahead occupying the TTD. If the OS MA will be shortened, this train could be undetected on the TTD. In case OS mode profile is used to cover a not occupied track (this is project specific) the first condition of the ghost train mitigation defined in 4.2.2.1 can be extended to include the OS mode profile covering the first VSS of the TTD. For the OS mode profile used at start of mission the ATAF method can be used to ensure that no other train is ahead. If the ATAF fails (conditions for the FS MA not valid anymore) the same response as in 4.2.2.1 could be triggered.

4.2.2.1.3 Note: The trackside can have another protection mechanism to verify that the occupation of a TTD inside the MA in advance of the train is caused by the train itself. E.g. a CES that is sent on TTD occupation. If the train reports that the CES was accepted, the TTD occupation must have been due to another cause and the same response as in 4.2.2.1 could be triggered.

4.2.2.1.4 Note: The propagation is only necessary if no other confirmation is available, e.g. from axle counter point, that the train has not crossed the TTD border. See section 5.2 for the details how to use such axle counter info.

4.3 Protection for loss of integrity situations

4.3.1.1 When a train that was treated as integer is no longer treated as integer, the VSS sections on which the train is located become “ambiguous” and the VSS sections left by the train afterwards shall become “unknown”. The “unknown” state of the VSS section shall be propagated, as soon as the “integrity loss propagation timer” expires onto the VSS sections in rear of the “unknown” until one of the following sections is reached:

a) Free TTD
b) VSS where a train is connected (i.e. “occupied” or “ambiguous”)
c) VSS which is part of the MA of another train on another TTD

4.3.1.2 Note: The “integrity loss propagation timer” is different from the “disconnect propagation timer” and can be relatively long and location specific, depending on the risk assessment of the moment when the lost part of the train would start rolling or moving backwards.

4.3.1.2.1 Note: The wait integrity timer could take into account the max expected delay in the integrity confirmation reports from the train. Nominally not more than the position report frequency.

4.3.1.2.2 Note: The integrity loss propagation timer could take into account:

a) risk for rolling back after integrity loss (gradient and loss of brake power/pressure) i.e. ±30 min

b) risk for wrong movement after splitting, i.e. 5-15 min
c) short enough to avoid that another train enters the TTD (if not covered by the traffic management system)

4.4 Two reporting trains in one VSS

4.4.1.1 When a train reports that it has entered a VSS already “occupied” by another train, then all VSS under both trains are set to “ambiguous”.

4.4.1.1.1 Note: This is a simplification as it is assumed that at an EoM and joining will occur. The possible negative impact on performance can be mitigated with a TTD section (see also 4.2.1.7)

4.5 Protection against shadow train hazard

4.5.1.1 The HTD concept uses the VSS state "ambiguous" to mitigate the shadow train hazard that could occur if an integer train is followed by a not connected train.

4.5.1.2 To achieve this, the state of the VSS is set to “ambiguous” in those VSS for which the trackside is not able to confirm that no other vehicle is located in rear of a connected train (e.g. after start of mission when a train connects to the trackside or VSS section in rear of the train becomes “unknown”, e.g. when a train on the VSS in rear gets disconnected (change from "occupied" to "unknown"), or due to propagation (change from "free" to "unknown").

4.5.1.3 An example of the shadow train hazard is shown in the scenario depicted in Figure 6 and explained in the following clauses. This explanation is followed by a description of the related mitigation measures for a not connected train following on a short distance.

4.5.1.3.1 When an integer train is located on an "ambiguous" VSS (or entering a HTD area), it means that there may be a train in rear which is not known by PTD to the trackside, see first line in Figure 6 with integer train 1 and ghost train 2.

4.5.1.3.2 When train 1 enters the first VSS of a new TTD, this VSS will become "ambiguous" because this risk remains, see second line in Figure 6.

4.5.1.3.3 When train 1 reported to have left the VSS in the TTD in rear and the TTD in rear becomes free, the VSS on which train 1 is located could go to "occupied". This because it is confirmed that there is no train on the TTD in rear of train 1. However, a short following train 2 could also be present on this VSS, see third line in Figure 6.

4.5.1.3.4 If train 1 leaves the first VSS in the new TTD, the state of this VSS would go to "free" based on the PTD info, see the fourth line in Figure 6. The trackside could authorise another train (3) onto the released infrastructure on which ghost train 2 is still present. This is called the "shadow train" hazard and it is the reason that a mitigation is necessary to avoid that the situation in the third line in Figure 6 can occur.

4.5.1.3.5 Note: it is normal to have some time difference between the report from train 1 that he has left the VSS on the previous TTD and the moment that this previous TTD becomes free, due to delay time in the TTD detection and the position reports, delay of on-board integrity monitoring, confidence interval.

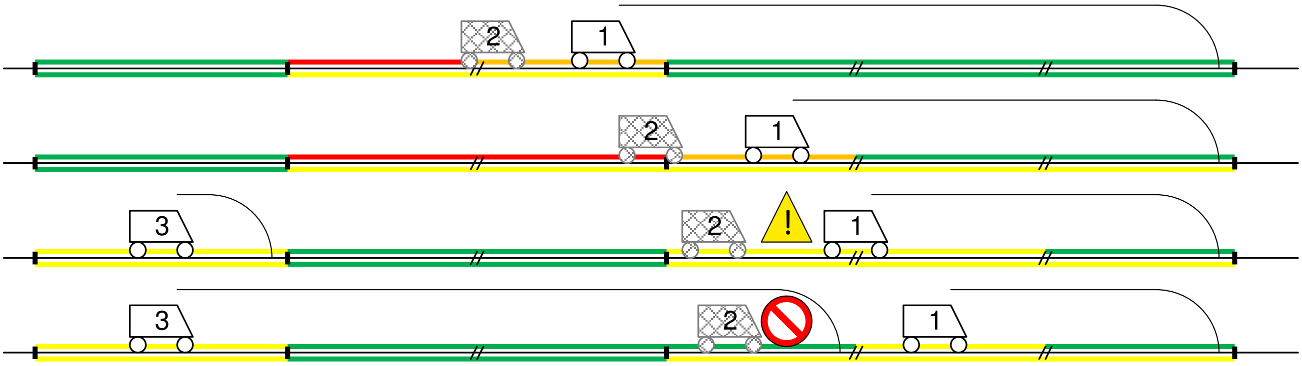


Figure 6: Shadow train hazard

4.5.1.4 To prevent that the shadow train is not detected, as shown in step 3 in Figure 6, the following mechanism is defined. When a train has crossed a TTD border where the last VSS of the TTD in rear was in state “ambiguous” when the train was located on this VSS, and the two events {TTD in rear becomes “free”} and {integer train reports to have left TTD in rear} occur within the “shadow train timer” of the TTD in rear, the train is treated as integer and the VSS in the new TTD are set to “occupied”. If this condition is not fulfilled, the train is not treated as integer and the VSS in the new TTD are set to "ambiguous". See the scenarios in annex A for examples of this mechanism.

4.5.1.4.1 Note: The value of the “shadow train timer” depends on the risk of a shadow train and the expected delays in PTD (integrity and position report interval) and TTD information. A value between 5-10 seconds would seem to be practical. Note that communication delays are mitigated with the use of timestamps of these events.

4.5.1.5 Note: A position report can be requested by the trackside from the on-board when passing the TTD limit and the impact of communication delays on the timer evaluation can be minimised by using T_TRAIN information.

4.5.1.6 Note: The check on shadow trains in rear of a train with train integrity confirmed is only required once. Once this check is performed (see 4.5.1.4) and the train moves on, the following VSS sections have the state “occupied” and not “ambiguous” since it can now be excluded that a shadow train is following.

4.5.1.7 Note: When the shadow train check (see 4.5.1.4) is performed for the integer train that has already passed the first (very short) VSS sections on a TTD, these passed VSS sections will be set to “free” (i.e. immediate transition from “ambiguous” via “occupied” to “free”).

4.5.1.8 Note: Axle counter head information (information from individual axle counting points) on a detected train movement can be used to improve the shadow and ghost train detection, eliminating the need for a free TTD in rear to treat a train as integer (see 4.5.1.4). See section 5.2 for the details how to use such axle counter info.

4.6 Rolling backwards

4.6.1.1 ETCS provides protection against rolling backwards. The roll away distance after which ETCS will apply the brake can be set through D_NVROLL. It is an implementation choice which roll away distance is allowed.

4.6.1.2 If the roll away distance greater than zero is implemented, this distance plus the (worst case) brake distance, as well as multiple roll away, should be taken into account in the safe rear margin.

4.6.1.2.1 Note: This safe rear margin can be speed depended as it would always require some time/distance for a train to stop:

safe_rear_margin = MAX (0,SRM0 - V^2/(2*a_max))

Where:

- SRM0 is the safe rear margin which is applicable at standstill
- a_max is train/project specific between approx. 1 and 3.5 m/(s^2).

E.g. a SRM0 of 5m with an assumed a_max = 2m/(s^2) would have no impact on performance for speeds above V= SQRT (2*2*5) = 4.5 m/s = 16 km/h.

5 State machine for VSS

5.1 Transitions without the use of axle counter info

5.1.1.1 The Figure 7 represents the state machine of each VSS. The Table 3 gives the conditions for the transition from each state to each other. The sub-conditions (e.g. #1A, #1B) are always combined with a logical OR to give the result for the main condition, e.g. #4 = #4A OR #4B.

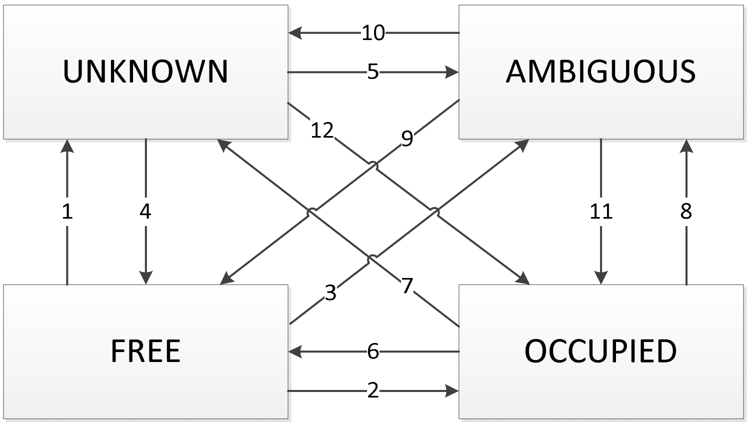


Figure 7: VSS section state diagram

5.1.1.2 The state machine does not run continuously, but is event driven. VSS states are updated by running the state machine according to a sequence of actions based on the following events:

Event	Sequence of actions
PTD information or communication termination order received	1. Reinstate the train location from the memorised train location (if applicable due to reconnection)
	2. Update the front end of the train location and evaluate the timer start/stop conditions
	3. Update the VSS states (run the state machine)
	4. Update the rear end of the train location and evaluate the timer start/stop conditions
	5. Update the VSS states (run the state machine)
TTD information (occupied/free)	1. Update the front end of the train location and evaluate the timer start/stop conditions
	2. Update the VSS states (run the state machine)
	3. Update the rear end of the train location and evaluate the timer start/stop conditions
	4. Update the VSS states (run the state machine)

Timer expires	1. Evaluate the timer start/stop conditions
	2. Update the VSS states (run the state machine)
	3. Evaluate the timer start/stop conditions

5.1.1.2.1 Note that the double VSS update on PTD and TTD information (front and rear end) can lead to a very short intermediate state.

5.1.1.2.2 When a transition condition contains the state of a VSS on which a train is or was located, it shall use the state after the update of the train location has been processed by the state machine.

5.1.1.2.3 Note: Some timers must be evaluated before running the state machine (e.g. integrity lost propagation start condition) and some timers must be evaluated after running the state machine (e.g. all propagation timers stop condition). The easiest way to implement this is to evaluate all start/stop conditions before and after each run of the state machine. Then it is ensured that the conditions will always be correctly evaluated.

5.1.1.3 Events are handled in the order of reception as atomic events for all VSS sections, i.e. the sequence related to an event shall be processed completely before the next event is taken into account.

5.1.1.3.1 Note: This means that time differences between information received from PTD and TTD are by definition taken into account in the state machine.

5.1.1.4 At the start-up of the trackside system all VSS are first put in state “unknown” and then the state machine is run once, which will set all VSS on free TTD to "free".

5.1.1.5 The term “TTD” without a qualifier like “previous” refers to the TTD of the VSS for which the condition is checked (the evaluated VSS).

5.1.1.6 A timer is only considered as “not expired” if it is running, i.e. was activated by a start event in the context of the concerning train run.

5.1.1.7 Whenever a transition condition refers to a previous TTD or VSS, and in case there is no known previous TTD/VSS (e.g. when entering a HTD area), the condition is not fulfilled.

5.1.1.8 When the word "train" / "timer" is used more than once in a transition condition, the same train / timer is meant.

5.1.1.9 For readability the states to which the transition condition refers are indicated with F (free), O (occupied), A (ambiguous) and U (unknown). E.g. F>O means transition from "free" to "occupied".

#	Condition	Priority over	Section ref.
#1A F>U	(TTD becomes occupied) AND ((in each direction no FS MA exists covering the first VSS of this TTD) OR (the TTD is part of an MA)		4.2.2

#	Condition		Priority over	Section ref.
		AND (the train to which the MA was sent could not have reached the TTD in the time between the last position report and the moment the TTD becomes occupied)) 		
	AND	(no train located on this TTD)		
#1B F>U		(TTD is occupied)		3.9.1.3 4.2.1.3
	AND	(the evaluated VSS is part of the MA sent to a train for which the mute timer is expired)		
	AND	(the evaluated VSS is located in advance of the VSS of the memorised train location)		
#1C F>U		(TTD is occupied)		4.2.1.4
	AND	(there is(/are) only “free” or “unknown” VSS or none between the evaluated VSS and the VSS for which the “disconnect propagation timer” is expired)		
	AND	(the evaluated VSS is located on the same TTD as the VSS for which the timer is expired)		
#1D F>U		(TTD is occupied)		4.2.1.4
	AND	(there is(/are) only “free” or “unknown” VSS on an occupied TTD or none between the evaluated VSS and the VSS for which the “disconnect propagation timer” is expired)		
	AND	(the evaluated VSS is not located on the same TTD as the VSS for which the timer is expired)		
	AND	(the evaluated VSS is not part of an MA)		
#1E F>U		(TTD is occupied)		4.3.1.1
	AND	(there is(/are) only “free” or “unknown” VSS or none between the evaluated VSS and the VSS for which the “integrity loss propagation timer” is expired)		
	AND	(the evaluated VSS is located on the same TTD as the VSS for which the timer is expired)		
#1F F>U		(TTD is occupied)		4.3.1.1
	AND	(there is(/are) only “free” or “unknown” VSS on an occupied TTD or none between the evaluated VSS and the VSS for which the “integrity loss propagation timer” is expired)		
	AND	(the evaluated VSS is not located on the same TTD as the VSS for which the timer is expired)		
	AND	(the evaluated VSS is not part of an MA)		
#1G F>U		(TTD is occupied)		4.2.2
	AND	(there is(/are) only “free” or “unknown” VSS on an occupied TTD or none between the evaluated VSS and the TTD for which the “ghost train propagation timer” is expired)		

#	Condition	Priority over	Section ref.
	AND (the evaluated VSS is not located on the TTD for which the timer is expired) AND (it cannot be excluded by means of detection at the TTD border that the ghost train has entered the evaluated TTD)		
#2A F>O	(TTD is occupied) AND (train is located on the evaluated VSS) AND (VSS where the train was located before it was located on the evaluated VSS, was “occupied”) AND (VSS where the train was located before it was located on the evaluated VSS, is not in advance of the train)	#3	3.3.2.3 4.5.1.6
#3A F>A	(TTD is occupied) AND (train is located on the evaluated VSS)		3.3.3.6.1 4.5.1.2
#4A U>F	(TTD is free)		3.1.1.5 5.1.1.4
#4B U>F	(train reconnects with the same train orientation) AND (the evaluated VSS is part of the FS MA sent to this train) AND (the evaluated VSS is in advance of the VSS where the reconnected train is located) AND (the MA sent to this train is still valid)	#5, #12	3.9.1.3.3
#5A U>A	(train is located on the evaluated VSS)		3.9.1.3.3 4.5.1.2
#6A O>F	(TTD is free)		3.1.1.5
#6B O>F	(train has left the evaluated VSS) AND (train treated as integer)		3.5
#7A O>U	((mute timer expires) OR (train becomes disconnected)) AND (the evaluated VSS becomes part of the memorised train location)	#8	3.9.1 4.2.1.2
#8A O>A	(train is located on the evaluated VSS) AND (train is not treated as integer)		a) 4.2.2.1.2 4.4.1.1 4.5.1.2
#9A A>F	(TTD is free)		3.1.1.5

#	Condition		Priority over	Section ref.
#10A A>U		(the evaluated VSS is left by all reporting trains, i.e. the assumed rear end of the train as defined in 3.3.4 is in advance of the evaluated VSS)		3.7 3.8 3.3.4.5
#10B A>U	 AND AND	((mute timer expires) OR (train becomes disconnected)) (the evaluated VSS becomes part of the memorised train location) (no other train is located on the evaluated VSS)		3.9.1 4.2.1.2
#11A A>O	 AND	(train treated as integer) (train is located on the evaluated VSS)		3.5.1.2 4.5.1.4
#12A U>O	 AND AND AND AND AND	(train reconnects with the same train orientation) (VSS where the train was located when the connection was lost, was "occupied") (train treated as integer) (In rear of the evaluated VSS and subsequent VSS(s) that had become "unknown" because of the lost connection of this train is a "free" VSS on an "occupied" TTD) (train is located on the evaluated VSS) (the MA sent to this train is still valid)	#5	3.5.1.2 3.9.1.3.3
#12B U>O	 AND AND AND AND	(train is located on the evaluated VSS) (VSS where the train was located before it was located on the evaluated VSS, was "occupied") (VSS where the train was located before it was located on the evaluated VSS, is in rear of the train) (the train is not re-connecting, i.e. the mute timer was not expired) (train treated as integer)	#5	3.10.1

Table 3: Transition between states for VSS sections

5.2 Adapted transitions with axle counter info

5.2.1.1 If the information of individual axle counter sensors is available to the central trackside safety system, this information can be used to detect train movement over a border between two TTD sections, even if both sections are occupied. This chapter describes how such information can be used to optimise the state machine.

5.2.1.1.1 See also chapter 3.5 for the impact of axle counter information on the conditions to treat the train as integer.

5.2.1.2 The transition conditions which are modified when axle counter info is used, are indicated with *. E.g. modified condition #1D* replaces the original condition #1D.

5.2.1.3 Additional to the ghost train detection transition #1A, a modified transition #1D* is introduced to respond to any unexpected movements across axle counters at TTD borders. The modified condition #1D* would be applicable when a TTD is already occupied, which is enabled by the use of axle counters. This way transitions #1D* and #1A take on the responsibility of propagation beyond the TTD border, formerly managed by transitions #1D, #1F, and #1G. These transitions can be omitted.

#1D* F>U	(TTD is occupied) AND (trackside system detects movement into TTD section) AND (there is no train located between this VSS and the limit of the TTD where the movement is detected) AND ((no connected train is located at the TTD border) OR (no connected train could have reached the TTD border in the time between their last position report and the moment movement is detected at the TTD border))
#1F*	Void
#1G*	Void

5.2.1.4 Transition #1B is adapted to stop the propagation at the TTD border. A condition is added that the VSS that change to “unknown” are located on the same TTD section as the evaluated train. The propagation is automatically continued onto the next TTD section by transitions #1A or #1D* if the train does continue to move into the next TTD section.

#1B* F>U	(TTD is occupied) AND (the evaluated VSS is part of the MA sent to a train for which the mute timer is expired) AND (the evaluated VSS is located in advance of the VSS of the memorised train location) AND (the evaluated VSS is located on the same TTD as the VSS of the memorised train location)

6 Annex A: Operational scenarios

6.1 Normal running of a single train with integrity confirmed by external device

Step 1 - Train 1 has entered from the left side with an FS MA until end of VSS 33 and occupies VSS 11 (#2A). Integrity is confirmed. Established rear end inside VSS 11.

Step 2 - Train 1 has moved to VSS 12 which becomes “occupied” (#2A). The established rear end has not been updated since step 1 (position reports with integrity not available *). The wait integrity timer is running and VSS 11 remains “occupied”.

Step 3 - Train 1 confirms integrity before the integrity timer expires. Established rear end inside VSS 12. VSS 11 becomes “free” (#6B)

Step 4 - Train 1 has passed the TTD section border and has moved on to VSS 21 which becomes “occupied” (#2A). The established rear end has not been updated since step 3 (position reports with integrity not available *). TTD 10 becomes “free”, the rear end of the train location of train 1 is moved to the border between TTD 10 and TTD 20, and therefore VSS 12 becomes “free” (#6A).

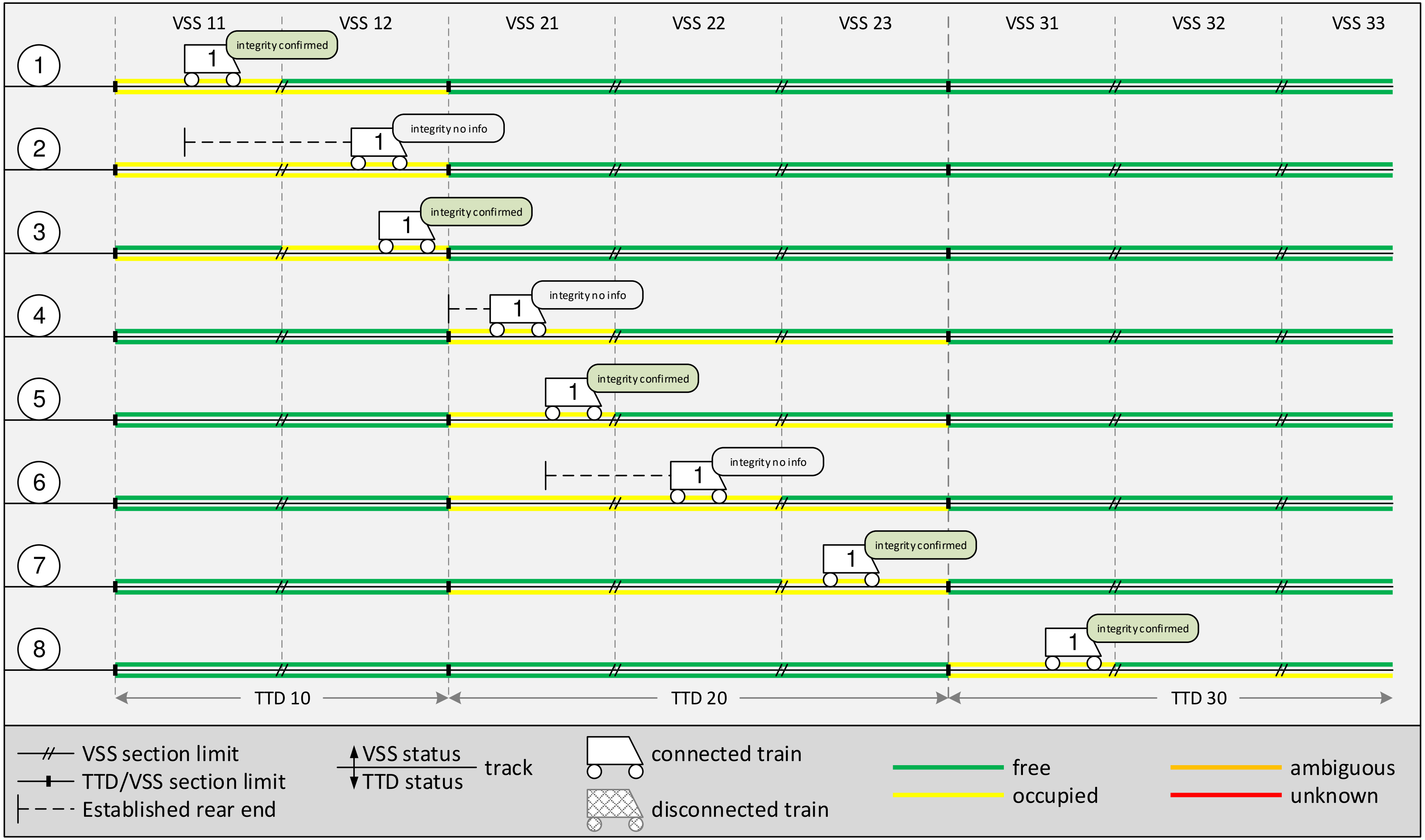
Step 5 - Train 1 confirms integrity before the wait integrity timer expires. There is no impact on VSS 21.

Step 6 - Train 1 has moved to VSS 22, which becomes “occupied” (#2A). The established rear end has not been updated since step 5 (position reports with integrity not available *). The wait integrity timer is running and VSS 21 remains “occupied”.

Step 7 - Train 1 has moved to VSS 23 which becomes “occupied” (#2A). Integrity is confirmed before the wait integrity timer expires. VSS 21 and 22 become “free” (#6B).

Step 8 - Train 1 has moved to VSS 31 which becomes “occupied” (#2A). TTD 20 becomes “free”. VSS 23 becomes “free” (#6A or #6B, whichever comes first).

**) For performant operation the update frequency of the TIM functionality should be higher than the frequency of the position reports. The situation in this is either degraded or low performant behaviour of the TIM functionality and is only included in this scenario to show that the concept is robust against this behaviour.*



VSS 11
VSS 12
VSS 21
VSS 22
VSS 23
VSS 31
VSS 32
VSS 33
1
2
3
4
5
6
7
8
integrity confirmed
integrity no info
integrity confirmed
integrity no info
integrity confirmed
integrity no info
integrity confirmed
integrity confirmed
TTD 10
TTD 20
TTD 30
VSS section limit
TTD/VSS section limit
Established rear end
VSS status
TTD status
track
connected train
disconnected train
free
occupied
ambiguous
unknown

6.2 Splitting of a composite train with integrity confirmed by external device

Step 1 - Trainset 1-2 has entered from the left side with an FS MA until end of VSS 12 and occupies VSS 12. It has stopped.

Step 2 - Train 1 and 2 are split. Train 1 remains connected with the trackside and reports the newL_TRAIN. Except for the reporting of the mode change, train 2 is not connected to the trackside. Until the newly reported L_TRAIN of train 1 is acknowledged by the trackside, train 1 can only send "no info" for the integrity status (see CR940). Due to the reported change of L_TRAIN, train 1 is not treated as integer anymore (a)) and as a consequence VSS 12 becomes “ambiguous” (#8A). The change of L_TRAIN also starts the integrity loss propagation timer for VSS12. Note that if trainset 1-2 would perform an EoM before the split, the scenario would not change fundamentally. Only this step would be slightly different. VSS 12 would go to "unknown" (#7A) and after the disconnect propagation timer expires VSS 11 becomes "unknown" (#1C). When train 1 performs SoM VSS 12 would become "ambiguous" (#5A) and, if this happens before the disconnect propagation timer expires, we are back in the same situation.

Step 3 - Train 1 receives an MA (with optionally for VSS 12 an OS mode profile) until end of VSS 33, starts to run again, passes the TTD section border, and reports its position on VSS 21, which becomes “ambiguous” (#3A). VSS 12 becomes "unknown" (#10A). *)

Step 4 - Train 1 moves on to VSS 22, which becomes “ambiguous” (#3A). VSS 21 becomes "unknown" (#10A).

Step 5 - Train 1 moves on to VSS 23, which becomes “ambiguous” (#3A). VSS 22 becomes "unknown" (#10A). The integrity loss propagation timer of VSS12 has expired and all VSS in TTD 10 become “unknown” (#1E).

Step 6 - Train 1 is moving on to VSS 31, with the physical rear still in VSS 23. VSS 31 becomes “ambiguous” (#3A) and VSS 23 remains "ambiguous".

Step 7 - Train 1 has physically left VSS 23, but no position report received yet. The shadow train timer of TTD20 for train 1 keeps running, but is not reset anymore. TTD 20 becomes “free”. As a consequence, VSS 21, 22 and 23 (all VSS sections in TTD 20) go to “free” (#4A for VSS 21, 22 and #9A for VSS 23). See 4.2.1.7 and 3.9.1.3.3 for a recommendation to avoid performance penalty due to (too much) propagation. Because TTD 20 is free, the established rear end of the train location of train 1 is moved to the border between TTD 20 and TTD 30. Train 1 is now located on VSS 31 (3.3.4.4) while the shadow train timer of TTD 20 for train 1 is not expired. Train 1 is treated again as integer (3.5.1.2) and VSS 31 becomes "occupied" (#11A).

Step 8 - Train 1 reports its position, including the confirmed rear end, inside VSS 31. This has no further effect.

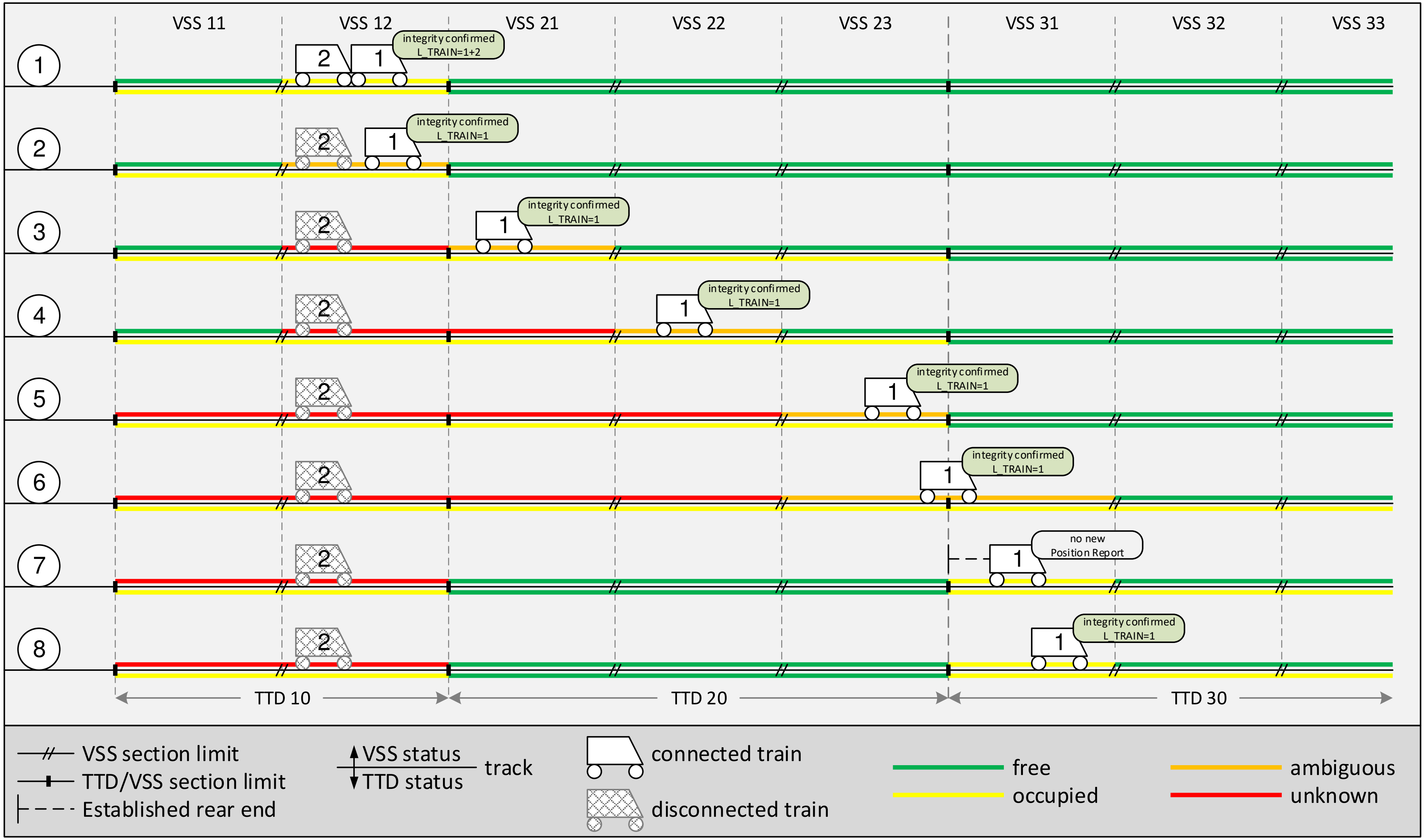
*) If the functionality in 5.2 is used, the following alternative VSS status would be applicable:

Step 3 - Train 1 receives an MA (with optionally for VSS 12 an OS mode profile) until end of VSS 33, starts to run again, passes the TTD section border, and reports its position on VSS 21, which becomes “ambiguous” (#3A) on the front-end evaluation. On the rear end evaluation train 1 becomes "treated as integer" (3.5.1.2.1) and as a consequence VSS 21 becomes "occupied" (#11A). VSS 12 becomes "unknown" (#10A).

Step 4 - Train 1 moves on to VSS 22, which becomes “occupied” (#2A). VSS 21 becomes "free" (#6B).

Step 5 - Train 1 moves on to VSS 23, which becomes “occupied” (#2A). VSS 22 becomes " free " (#6B). The integrity loss propagation timer of VSS12 has expired and all VSS in TTD 10 become “unknown” (#1E).

Step 6 - Train 1 is moving on to VSS 31, with the physical rear still in VSS 23. VSS 31 becomes “occupied” (#2A) and VSS 23 remains "occupied ".


VSS 11
VSS 12
VSS 21
VSS 22
VSS 23
VSS 31
VSS 32
VSS 33
1
2
3
4
5
6
7
8
integrity confirmed L_TRAIN=1+2
integrity confirmed L_TRAIN=1
no new Position Report
TTD 10
TTD 20
TTD 30
VSS section limit
TTD/VSS section limit
Established rear end
VSS status
TTD status
track
connected train
disconnected train
free
occupied
ambiguous
unknown

6.3 Joining two trains

Step 1 - Train 1 has performed EoM on VSS 22 (see scenario 6.5 step 8).

Step 2 - Train 2 is approaching on VSS 12 (see scenario 6.1 step 1 to 3).

Step 3 - Train 2 receives an MA until end of VSS 23 with an OS mode profile for TTD 20 and moves to VSS 21 which becomes "occupied" (#12B). VSS 12 becomes "free" (#6A or #6B, whichever comes first).

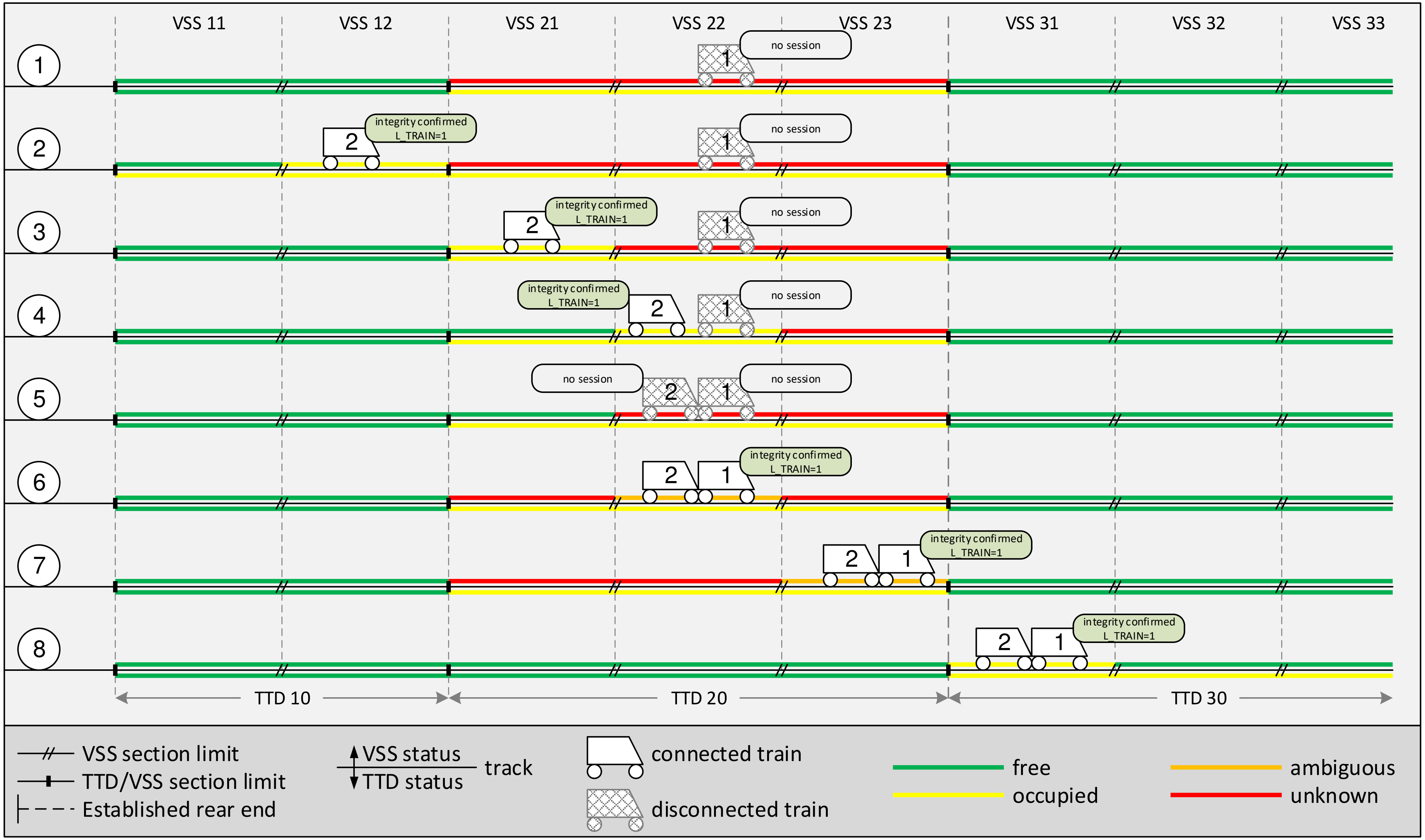
Step 4 - Train 2 moves to VSS 22, which becomes “occupied” (#12B). VSS 21 becomes "free" (#6B).
Note: If train 1 was a connected train, VSS 22 would have been "ambiguous" already. As soon as the front end of train 2 is reported on VSS 22, train 2 would not be treated as integer anymore (a)d) and VSS 21 would become "ambiguous" (#8A). When the assumed rear end has moved to VSS 22, VSS 21 becomes "unknown" (#10A). The scenario would continue with the situation after the SoM in step 6, with the only difference that VSS 21 is already "unknown".

Step 5 - Train 2 joins train 1 and performs EoM. VSS 22 becomes "unknown" (#7A). The disconnect propagation timer of VSS 22 is started.

Step 6 - Trainset 1-2 performs the Start of Mission procedure, i.e. the session with the trackside is established. Trainset 1-2 is not yet treated as integer (shadow train risk). VSS 22 becomes “ambiguous” (#5A). The established session does not stop the disconnect propagation timer of VSS 22, because it is a different train (ETCS on-board) that is connected. The timer expires and VSS 21 becomes "unknown" (#1C).

Step 7 - Trainset 1-2 moves to VSS 23 which becomes "ambiguous" (#5A). VSS 22 becomes "unknown" (#10A).

Step 8 - Trainset 1-2 moves to VSS 31 which becomes "occupied" and all VSS on TTD 20 become "free" (see scenario 6.2 step 5 to 8).



VSS 11
VSS 12
VSS 21
VSS 22
VSS 23
VSS 31
VSS 32
VSS 33
1
2
3
4
5
6
7
8
no session
integrity confirmed L_TRAIN=1
TTD 10
TTD 20
TTD 30
VSS section limit
TTD/VSS section limit
Established rear end
VSS status
TTD status
track
connected train
disconnected train
free
occupied
ambiguous
unknown

6.4 Shadow train

Step 1 - Integer train 1 occupies VSS 12 with state “ambiguous” and a disconnected train 2 is located on the same VSS, just behind train 1. VSS 11 is already "unknown" because the integrity loss propagation timer has expired. This is the situation some time after split of train 1 and train 2. Train 1 is not treated as integer due to the previous split. The shadow train timer of TTD 10 for train 1 is running and continuously reset by the position reports.

Step 2 - Train 1 receives an MA (with optionally an OS mode profile) until end of VSS 33 and moves to VSS 21, which becomes “ambiguous” (#3A). VSS 12 goes to “unknown” (#10A). The shadow train timer of TTD 10 for train 1 keeps running, but is not reset anymore. *)

Step 3 - Train 1 moves to VSS 22, which becomes “ambiguous” (#3A). VSS 21 goes to “unknown” (#10A). Shadow train timer of TTD 10 for train 1 expires, but this has no further effect in the scenario. Train 2 starts to follow train 1 (operational procedure).

Step 4 - Train 1 moves to VSS 23, which becomes “ambiguous” (#3A). VSS 22 goes to “unknown” (#10A). Train 2 moves to VSS 21. TTD 10 becomes free and therefore all VSS in TTD 10 become "free" (#4A).

Step 5 - Train 1 moves on to VSS 31, but due to a glitch in the radio communication no new position report is received, i.e. no train reported inside VSS 31. TTD 30 becomes occupied, but as long as the mute timer of train 1 does not expire, the VSS in TTD 30 remain “free”. The assumed rear end of train 1 is still in VSS 23 which remains “ambiguous”. Train 2 has moved to VSS 22. Because there is no position report from train 1, the shadow train timer of TTD 20 for train 1 is not reset anymore.

Step 6 - The shadow train timer of TTD 20 for train 1 has expired before train 2 could leave TTD 20, thus avoiding transition #11A. Train 1 has moved on to VSS 32 with the assumed rear end in VSS 31. A position report from train 1 is received again before the mute timer expires. VSS 31 and VSS 32 both go to “ambiguous” (#3A). VSS 23 becomes “unknown” (#10A). In the meantime, train 2 has moved to VSS 23 and is close to VSS 31.

Step 7 - Train 1 is still in VSS 32, but now with assumed rear end in VSS 32. VSS 31 becomes “unknown” (#10A). VSS 32 remains “ambiguous”. Train 2 has moved to VSS 31. TTD 20 becomes “free”. As a consequence, all VSS sections in TTD 20 go to “free” (#4A).

Step 8 - Train 1 moves on and is followed by train 2.

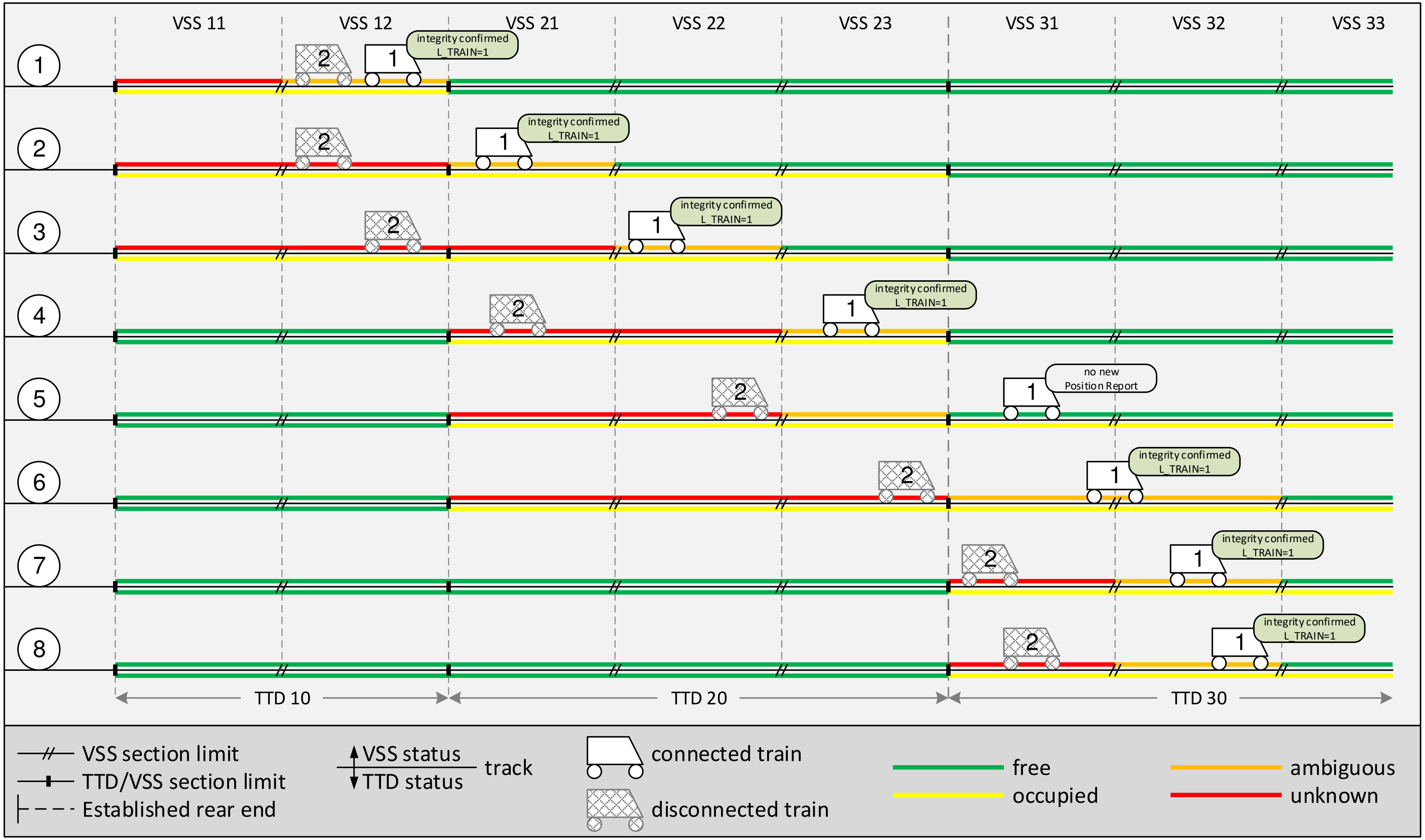
*) If the functionality in 5.2 is used, the following alternative VSS status would be applicable:

Step 2 - Train 1 receives an MA (with optionally an OS mode profile) until end of VSS 33 and moves to VSS 21, which becomes “ambiguous” (#3A) on the front-end evaluation. On the rear end evaluation train 1 becomes "treated as integer" (3.5.1.2.1) and as a consequence VSS 21 becomes "occupied" (#11A). VSS 12 goes to “unknown” (#10A). The shadow train timer of TTD 10 for train 1 keeps running, but is not reset anymore.

Step 3 - Train 1 moves to VSS 22, which becomes “occupied” (#2A). VSS 21 goes to “free” (#6B). Shadow train timer of TTD 10 for train 1 expires, but this has no further effect in the scenario. Train 2 starts to follow train 1 (operational procedure).

Step 4 - Train 1 moves to VSS 23, which becomes "occupied" (#2A). VSS 22 becomes "free" (#6B). Train 2 moves to VSS 21. TTD 10 becomes free and therefore all VSS in TTD 10 become "free" (#4A). Train 2 triggers the ghost train protection. VSS 21 and VSS 22 become "unknown" (#1D*). Train 1 is not treated as integer anymore 3.5.1.3(e) and as a consequence VSS 23 becomes "ambiguous" (#8A).

Note that there is no change in step 6 because the shadow train timer of TTD 20 for train 1 has expired.



VSS 11
VSS 12
VSS 21
VSS 22
VSS 23
VSS 31
VSS 32
VSS 33
1
2
3
4
5
6
7
8
integrity confirmed
L_TRAIN=1
no new
Position Report
TTD 10
TTD 20
TTD 30
VSS section limit
TTD/VSS section limit
Established rear end
VSS status
TTD status
track
connected train
disconnected train
free
occupied
ambiguous
unknown

6.5 Start of Mission / End of Mission

Step 1 - Train 1 is standing on VSS 11 with desk closed and no communication session. All VSS in TTD 10 are “unknown”.

Step 2 - Train 1 performs the Start of Mission procedure, i.e. the session with the trackside is established. Integrity is confirmed. Because train 1 reports its position on VSS 11, this VSS becomes "ambiguous" (#5A).

Step 3 - Train 1 receives an MA until end of VSS 22 with optionally an OS mode profile protected with the ATAF function at the border of TTD20 and moves to VSS 12 which becomes "ambiguous" (#5A). VSS 11 goes to "unknown" (#10A).

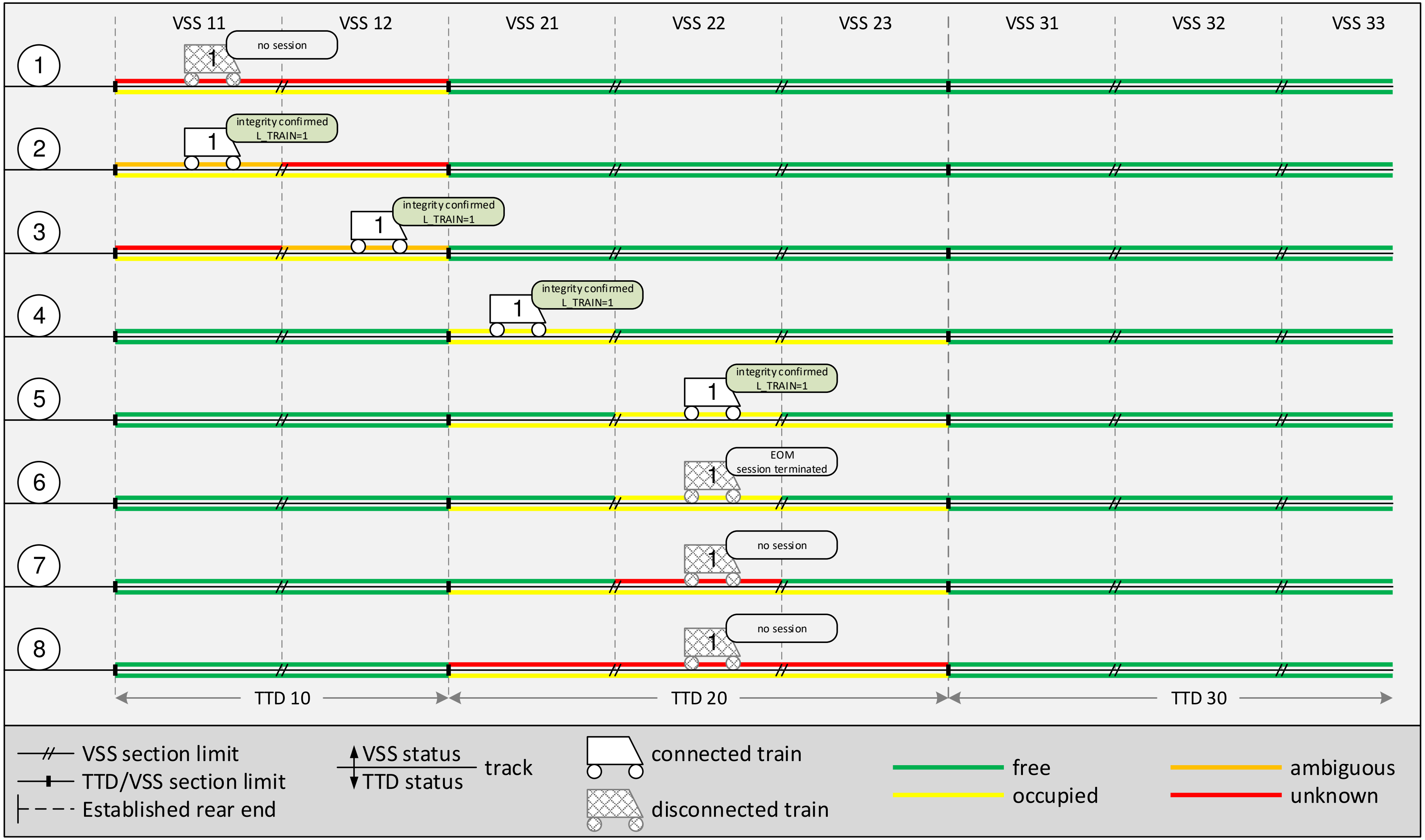
Step 4 - Train 1 moves to VSS 21 which becomes occupied (see step 6, 7 and 8 in the scenario 6.2 for the details when crossing the TTD border) and all VSS in TTD 10 become free, VSS 11 (#4A) and VSS 12 (#9A, or via #10A and #4A if the train reported itself completely on VSS 21 before TTD 10 was reported free).

Step 5 - Train 1 continues to VSS 22 which becomes “occupied” (#2A). VSS 21 becomes "free" (#6B).

Step 6 - Train 1 performs the End of Mission procedure. See 4.2.1.7 and 3.9.1.3.3 for a recommendation to avoid performance penalty due to (too much) propagation

Step 7 - Due to the EoM procedure VSS 22 goes to “unknown” (#7A) and the disconnect propagation timer of VSS 22 is started.

Step 8 - The disconnect propagation timer of VSS 22 expires. All remaining VSS in TTD 20 go to “unknown” (#1C).


VSS 11
VSS 12
VSS 21
VSS 22
VSS 23
VSS 31
VSS 32
VSS 33
1
no session
2
integrity confirmed
L_TRAIN=1
3
integrity confirmed
L_TRAIN=1
4
integrity confirmed
L_TRAIN=1
5
integrity confirmed
L_TRAIN=1
6
EOM
session terminated
7
no session
8
no session
TTD 10
TTD 20
TTD 30
VSS section limit
TTD/VSS section limit
Established rear end
VSS status
TTD status
track
connected train
disconnected train
free
occupied
ambiguous
unknown

6.6 Start of Mission with unknown position

Step 1 - Train 1 is standing on VSS 12 and train 2 on VSS 11, both with desk closed and no communication session. All VSS in TTD 10 are “unknown”.

Step 2 - Train 1 performs the Start of Mission procedure, i.e. the session with the trackside is established. Train position is unknown. Integrity is confirmed, but train 1 is not yet treated as integer (shadow train risk). Condition #5A is not fulfilled and VSS 12 remains "unknown".

Step 3 - Train 1 receives SR authorisation, starts moving and passes a balise group which is located just before the TTD border. Train 1 sends a position report with valid position and enters TTD 20. Exceptionally, the occupation of TTD 20 is detected by the trackside while the position report is not yet received (some delay in the radio communication). All VSS of TTD 20 become "unknown" (#1A). The ghost train propagation timer of TTD 20 is started (3.4.2.3.1a).
Note: Normally the position report would be received before TTD 20 becomes occupied. In that case the scenario would continue as in scenario 6.2 from step 2 onwards.

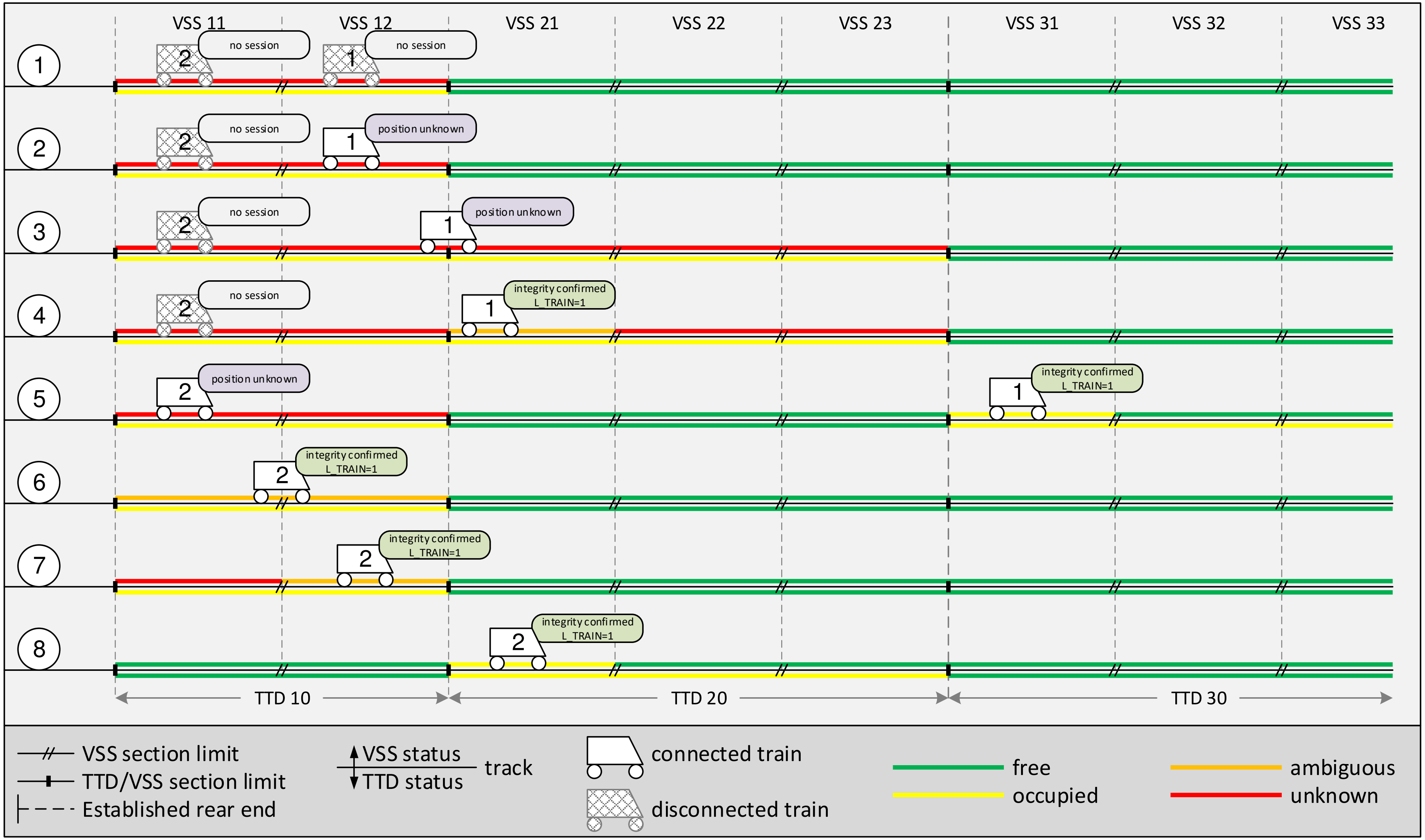
Step 4 - The position report with valid position is received while the rear end of train 1 is still on TTD 10. VSS 12 and VSS 21 become "ambiguous" (#5A). Train 1 moves on and the assumed rear end leaves VSS 12, which becomes "unknown" again (#10A).

Step 5 - Train 1 may receive an OS MA and continues until it is located on VSS 31 which becomes "occupied" (see scenario 6.2 step 3 to 8). TTD 20 becomes "free". Train 2 performs the Start of Mission procedure, i.e. the session with the trackside is established. Train position is unknown. Integrity is confirmed, but train 2 is not treated as integer. Condition #5A is not fulfilled and VSS 11 remains "unknown".

Step 6 - Train 1 has moved beyond TTD 30. Train 2 receives SR authorisation and moves to VSS 12. Train 2 passes a balise group (located at the VSS border) and reports valid position with the front end on VSS 12 and the established rear end on VSS 11. Both VSS 11 and VSS 12 become "ambiguous" (#5A).

Step 7 - Train 2 receives an MA until end of VSS 23 with optionally an OS mode profile for VSS 12, protected with the ATAF function at the border of TTD20. The assumed rear end has left VSS 11 which becomes "unknown" again (#10A).

Step 8 - Train 2 moves to VSS 21 which becomes "occupied" (see scenario 6.2 step 5 to 8). TTD 10 becomes "free". VSS 11 (#4A) and VSS 12 (#9A) become "free".


VSS 11
VSS 12
VSS 21
VSS 22
VSS 23
VSS 31
VSS 32
VSS 33
1
2
3
4
5
6
7
8
no session
position unknown
integrity confirmed
L_TRAIN=1
TTD 10
TTD 20
TTD 30
VSS section limit
TTD/VSS section limit
Established rear end
VSS status
TTD status
track
connected train
disconnected train
free
occupied
ambiguous
unknown

6.7 Integrity lost

Step 1 - Train 1/2 has entered from the left side with an FS MA until end of VSS 33 and occupies VSS 12. Integrity is confirmed. Established rear end inside VSS 12.

Step 2 - The connection between train 1 and train 2 is broken. Train 1 reports integrity loss. VSS 12 becomes “ambiguous” (#8A) and the integrity loss propagation timer of VSS 12 is started. Trackside takes L_TRAIN as the assumed train length. Both parts of the broken train will brake to standstill (TSI requirement for broken trains).

Step 3 - While braking, train 1 moves on and comes to standstill on VSS 21 which becomes “ambiguous” (#3A). VSS 12 becomes “unknown” (#10A). Train 2 comes to standstill on VSS 12. The integrity loss propagation timer of VSS 12 is still running.

Step 4 - The integrity loss propagation timer of VSS 12 expires. All remaining VSS in TTD 10 go to “unknown” (#1E). Train 1 reports the changed L_TRAIN and confirms integrity related to this new L_TRAIN *) and moves on to VSS 22 which becomes “ambiguous” (#3A). VSS 21 becomes “unknown” (#10A).

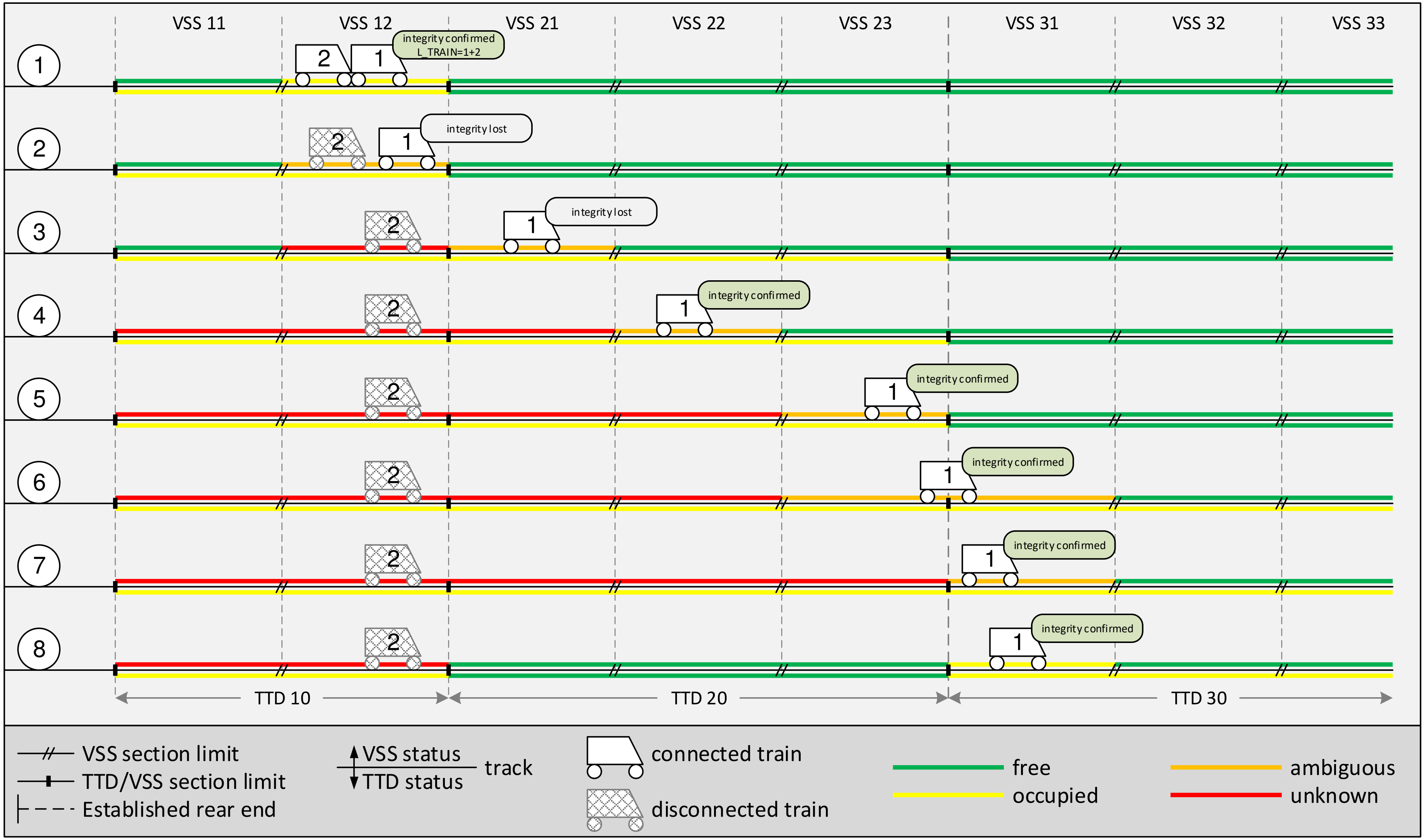
Step 5 - Train 1 moves on to VSS 23 which becomes “ambiguous” (#3A). VSS 22 becomes “unknown” (#10A).

Step 6 - Train 1 is moving on to VSS 31, with the physical rear still in VSS 23. VSS 31 becomes “ambiguous” (#3A) and VSS 23 remains "ambiguous".

Step 7 - Train 1 reports to have left VSS 23, which means that the shadow train timer of TTD 20 for train 1 is not reset anymore. This position report was received immediately after the train 1 has left VSS 23 and due to the delay time of the TTD detection system, the TTD is still considered occupied. Therefore, the position report triggers VSS 23 to become "unknown" (#10A). VSS 31 remains ambiguous.

Step 8 - TTD 20 becomes free and all VSS in TTD 20 become "free" (#4A). This happens while the shadow train timer of TTD 20 for train 1 is still running and therefore VSS 31 becomes "occupied" (#11A).

**) If it is not possible to confirm integrity related to the new L_TRAIN, the scenario would continue from here in the same way, except in step 8, where VSS 31 would remain "ambiguous".*


VSS 11
VSS 12
VSS 21
VSS 22
VSS 23
VSS 31
VSS 32
VSS 33
1
integrity confirmed
L_TRAIN=1+2
2
integrity lost
3
integrity lost
4
integrity confirmed
5
integrity confirmed
6
integrity confirmed
7
integrity confirmed
8
integrity confirmed
TTD 10
TTD 20
TTD 30
VSS section limit
TTD/VSS section limit
Established rear end
VSS status
TTD status
track
connected train
disconnected train
free
occupied
ambiguous
unknown

6.8 Connection lost and reconnect

Step 1 - Train 1 has entered from the left side with an FS MA until end of VSS 22 and occupies VSS 12. Integrity is confirmed. Established rear end inside VSS 12.

Step 2 - The radio connection of train 1 is lost.

Step 3 - The mute timer of train 1 expires. VSS 12 goes to “unknown” (#7A). The disconnect propagation timer of VSS 12 is started.

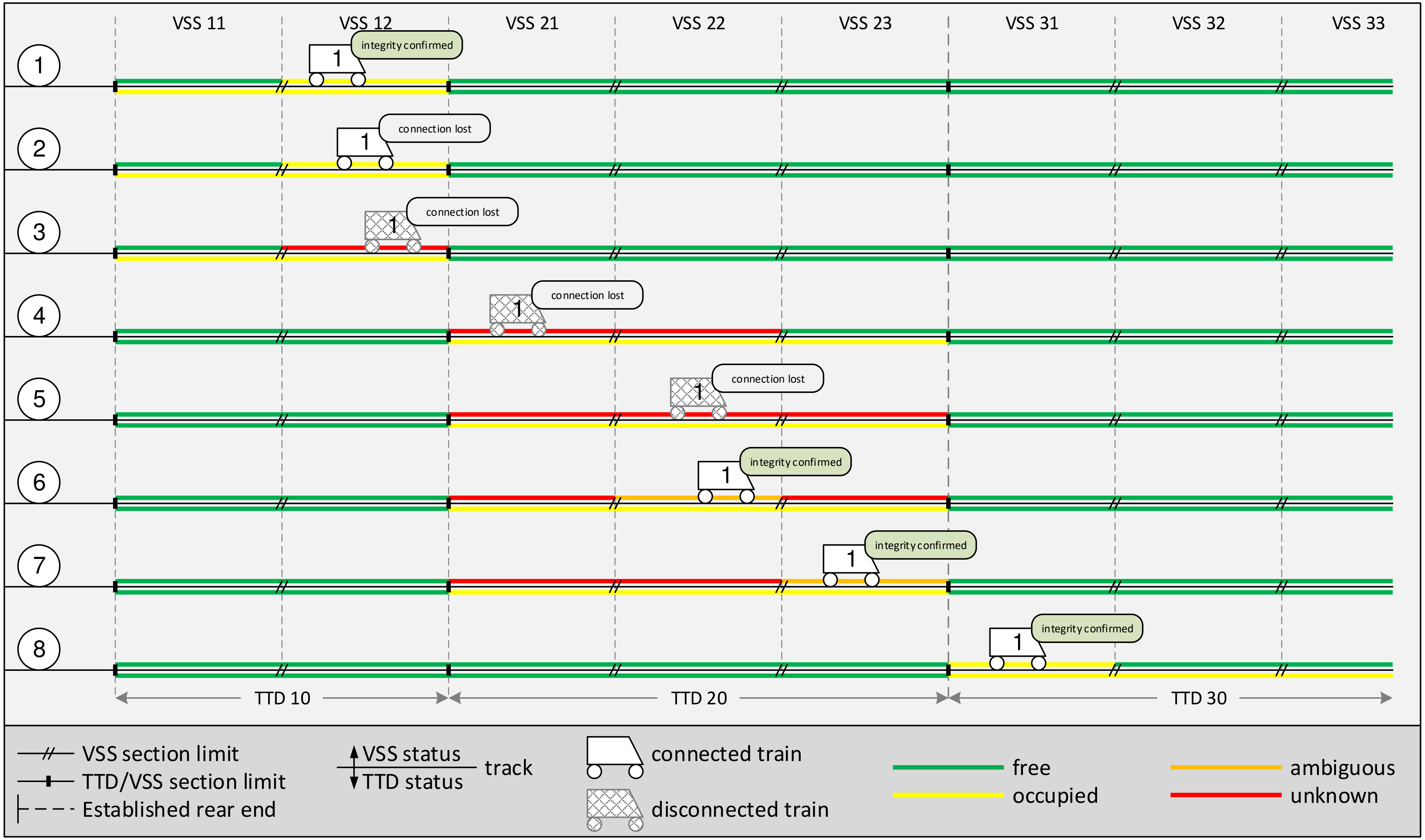
Step 4 - Train 1 moves on to VSS 21. The MA of train 1 is up to the end of VSS 22, therefore VSS 21 and VSS 22 become “unknown” (#1B) and the disconnect propagation timers of VSS 21 and 22 are started. TTD 10 becomes “free” and VSS 12 goes to “free” (#4A), which stops the disconnect propagation timer of VSS 12. The shadow train timer of TTD10 for this train expires.

Step 5 - Train 1 moves on to VSS 22 which remains “unknown”. The disconnect propagation timer of VSS 21 and/or 22 (whichever comes first) expires, VSS 23 goes to “unknown” (#1C).

Step 6 - Train 1 reconnects and reports confirmed integrity. As the train is not treated as integer anymore after the propagation VSS 22 becomes “ambiguous” (#5A). No further transition to "occupied" (#11A) because the shadow train timer of TTD10 for this train has expired in step 4. VSS 23 remains “unknown”. The train location is reinstated from the memorised location (VSS 12). After the front-end update of train 1, VSS 21 becomes "ambiguous" (#5A) because the rear end is still on VSS 12. After the established rear end update, VSS 21 goes back to "unknown" (#10A).

Step 7 - Train 1 receives OS MA and moves on to VSS 23 which becomes “ambiguous” (#5A). VSS 22 goes to “unknown” (#10A).

Step 8 - Train 1 moves on to VSS 31 which becomes “occupied” due to the sequence with the shadow train timer, see also scenario 6.2 (splitting) and 5 (integrity lost) for a detailed description. TTD 20 becomes “free”. VSS 21 and VSS 22 become “free” (#4A) and VSS 23 becomes “free” (#9A, or via #10A and #4A if the train reported itself completely on VSS 31 before the TTD 20 was reported free).


VSS 11
VSS 12
VSS 21
VSS 22
VSS 23
VSS 31
VSS 32
VSS 33
1
integrity confirmed
2
connection lost
3
connection lost
4
connection lost
5
connection lost
6
integrity confirmed
7
integrity confirmed
8
integrity confirmed
TTD 10
TTD 20
TTD 30
VSS section limit
TTD/VSS section limit
Established rear end
VSS status
TTD status
track
connected train
disconnected train
free
occupied
ambiguous
unknown

6.9 Connection lost and reconnect with release of VSS

Step 1 - Train 1 has entered from the left side with an FS MA until end of VSS 32 and occupies VSS 21. Integrity is confirmed. Established rear end inside VSS 21.

Step 2 - Train 1 moves on to VSS 22 which becomes “occupied” (#2A) and VSS 21 becomes “free” (#6B).

Step 3 - The radio connection of train 1 is lost.

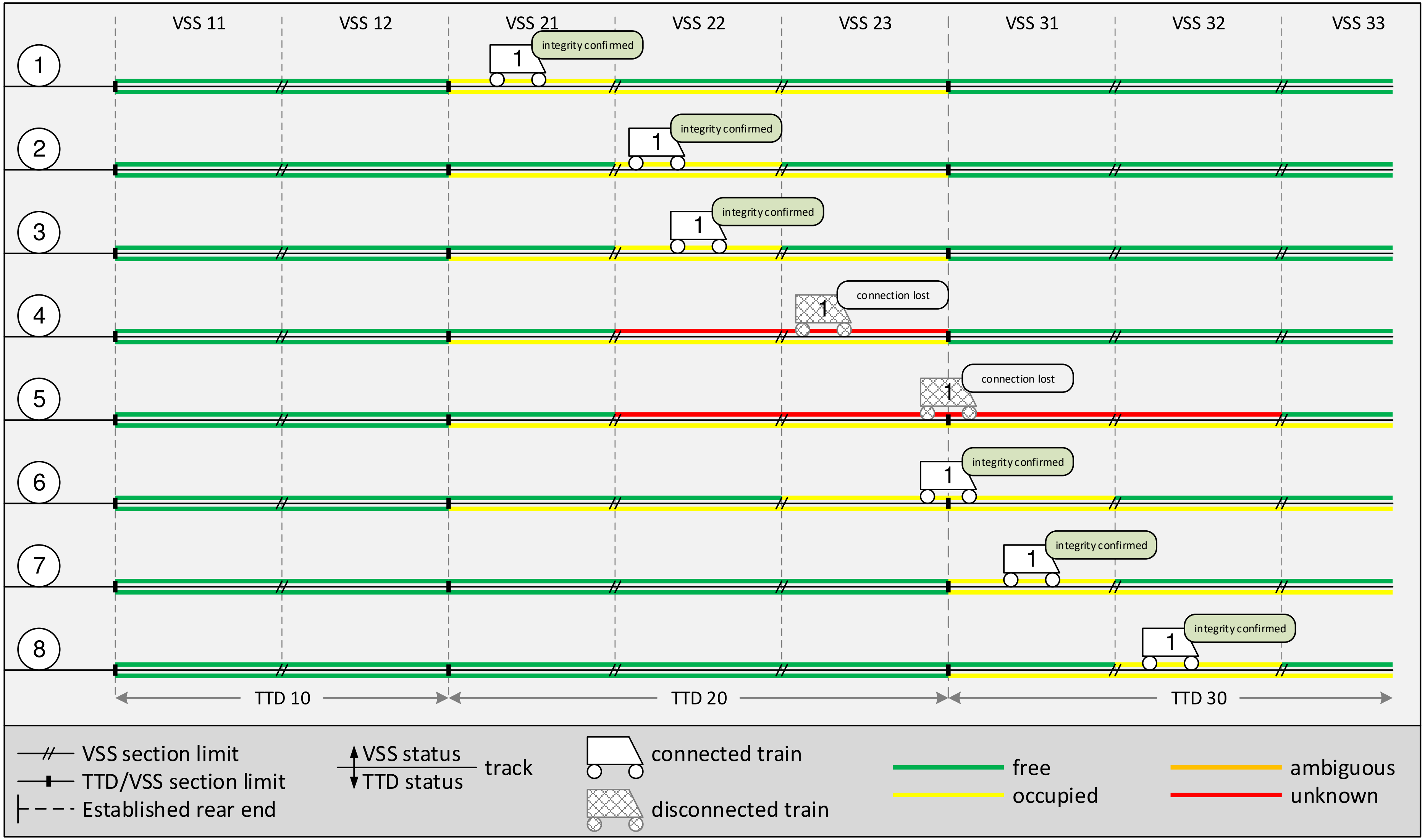
Step 4 - Train 1 moves on to VSS 23. However, this is not detected because the connection is lost. The mute timer of train 1 expires. VSS 22 goes to “unknown” (#7A). VSS23 goes to “unknown” (#1B). The disconnect propagation timers of VSS 22 and 23 are started.

Step 5 - Train 1 moves on to VSS 31 with the rear end still on VSS 23. The MA of train 1 is up to the end of VSS 32, therefore VSS 31 and VSS 32 become “unknown” (#1B).

Step 6 - Train 1 reconnects while its MA is still valid and reports confirmed integrity. VSS 22, VSS 23 and VSS 31 become “occupied” (#12A) after front end update (note that the memorised rear end is on VSS 22). VSS 22 becomes "free" after established rear end update (#6B). VSS 32 becomes “free” (#4B).

Step 7 - Train 1 leaves TTD 20 and VSS23. As a result, VSS 23 becomes “free” (#6A or #6B, whichever comes first).

Step 8 - Train 1 moves on to VSS 32 which becomes “occupied” (#2A) and VSS 31 becomes “free” (#6B).


VSS 11
VSS 12
VSS 21
VSS 22
VSS 23
VSS 31
VSS 32
VSS 33
1
2
3
4
5
6
7
8
integrity confirmed
connection lost
TTD 10
TTD 20
TTD 30
VSS section limit
TTD/VSS section limit
Established rear end
VSS status
TTD status
track
connected train
disconnected train
free
occupied
ambiguous
unknown

6.10 Sweeping, jumping and two trains in a VSS

Step 1 - Train 1 has entered from the left side with an FS MA until end of VSS 12 and occupies VSS 12. Integrity is confirmed. Established rear end inside VSS 12. Train 2 has entered from the left side and occupies VSS 11. Integrity is confirmed. Established rear end inside VSS 11.

Step 2 - Train 2 receives an OS MA into VSS12 and enters VSS12. VSS 11 and VSS 12 become “ambiguous” (#8A).

Step 3 - Train 2 leaves VSS 11 which becomes “unknown” (#10A). Train 1 receives an MA (with optionally an OS mode profile) beyond VSS 33 and enters VSS 21 which becomes “ambiguous” (#3A). *)

Step 4 - Train 1 moves on to VSS 23 and reports it position inside VSS 23 which becomes “ambiguous” (#3A). VSS 21 becomes “unknown” (#10A). VSS 22 also becomes “unknown” via the intermediary state of “ambiguous” because first the update of the front-end position was considered (#3A) and then the update of the established rear end (#10A). Train 2 receives an OS MA until end of VSS 22 and moves to VSS 21, which becomes "ambiguous" (#5A).

Step 5 – Train 1 moves on to VSS 32 and reports its position. VSS 32 becomes “ambiguous” (#3A), After front end update VSS 31 becomes “ambiguous” (#3A) and after established rear end update "unknown" (#10A). VSS 23 becomes “unknown” (#10A). Train 2 leaves TTD 10 which becomes free. The shadow train timer of TTD 10 for train 2 is not reset anymore. VSS 11 becomes "free" (#4A) and VSS 12 becomes “free” (#9A). VSS 21 becomes “occupied” because train 2 is located inside VSS 21 due to the shift of the established rear end to the TTD border while the shadow train timer of TTD 10 for train 2 has not expired (#11A). Note: If train 2 had waited for train 1 to leave TTD 20, sweeping of TTD 20 would not have been needed.

Step 6 – Train 1 has left TTD 30. TTD 30 has become free, and all VSS in TTD 30 have become "free". Train 2 receives an OS MA until end of VSS 23 and moves to VSS 23. No position report is received while the train is on VSS 22, i.e. the train "jumps" VSS 22. Train 2 reports its position when it is already completely on VSS 23. This step shows the status of the VSS after the processing of the front end position of train 2. Since the established rear end is still considered to be on VSS 21, train 2 is now located on VSS 21, VSS 22 and VSS 23. As a result, VSS 22 and VSS 23 become "occupied" (#12B). Note that the processing of this event is split in two separate steps (6 and 7) to show the short intermediate state of VSS 22.

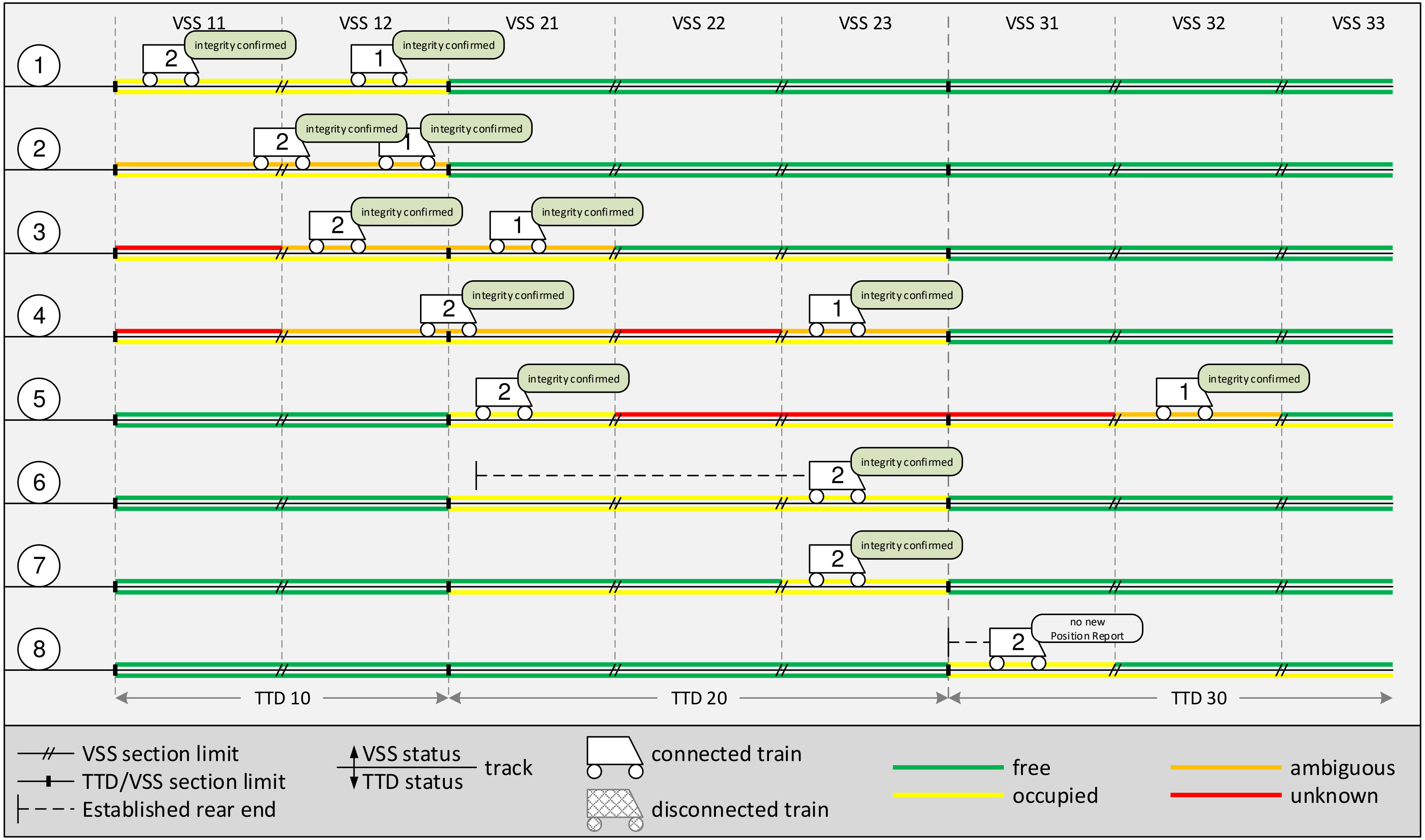
Step 7 - Train 2 has not moved. The established rear end (located on VSS 23) is now processed and VSS 21, VSS 22 become "free" (#6B).

Step 8 – Train 2 receives an FS MA until end of VSS 33, moves on to TTD 30 and leaves TTD 20 but does not report this position yet. Because TTD 20 becomes free all VSS in TTD 20 become "free" (#6A). To prevent losing the train 2, the train location is moved to VSS 31 (3.3.3.6) which becomes "occupied" (#2A).

*) If the functionality in 5.2 is used, the following alternative VSS status would be applicable:

Step 3 - Train 2 leaves VSS 11 which becomes “unknown” (#10A). Train 1 receives an MA (with optionally an OS mode profile) beyond VSS 33 and enters VSS 21, which becomes “ambiguous” (#3A) on the front-end evaluation. On the rear end evaluation train 1 becomes "treated as integer" (3.5.1.3.1) and as a consequence VSS 21 becomes "occupied" (#11).

Step 4 - Train 1 moves on to VSS 23 and reports it position inside VSS 23 which becomes "occupied" (#2A). VSS 21 becomes "free" (#6B). As a result, train 2 may follow short after train 1.


VSS 11
VSS 12
VSS 21
VSS 22
VSS 23
VSS 31
VSS 32
VSS 33
1
2
3
4
5
6
7
8
integrity confirmed
no new Position Report
TTD 10
TTD 20
TTD 30
VSS section limit
TTD/VSS section limit
Established rear end
VSS status
TTD status
track
connected train
disconnected train
free
occupied
ambiguous
unknown

6.11 Ghost train

Step 1 - Train 1 with an FS MA beyond VSS 33, occupies VSS 23. Integrity is confirmed.

Step 2 - Train 2, not known by PTD to the trackside (ghost train), enters TTD 10. VSS 11 and VSS 12 become “unknown” (#1A) and the ghost train propagation timer of TTD 10 is started.

Step 3 - Train 2 is still on TTD 10 and the ghost train propagation timer for TTD 10 expires. VSS 21 and VSS 22 become “unknown” (#1G) and VSS 23 becomes “ambiguous” (#8A).

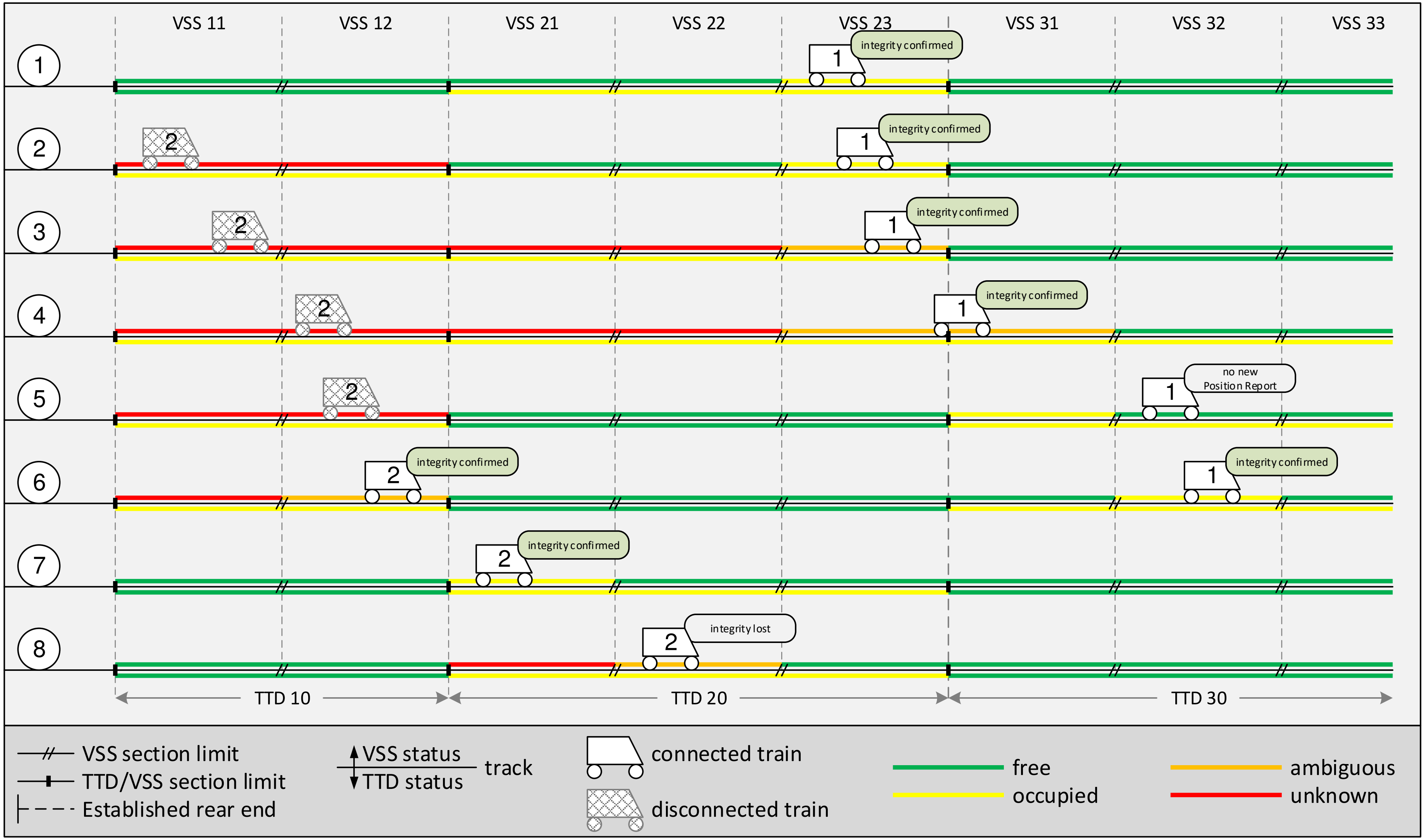
Step 4 - Train 1 moves on to VSS 31 which becomes “ambiguous” (#3A). Train 2 moves to VSS 12 which remains "unknown".

Step 5 - Train 1 moves to VSS 32, but does not yet report its position. TTD 20 becomes free and all VSS of TTD 20 become free (#4A, #9A). Because TTD 20 is free, the established rear end of the train location of train 1 is moved to the border between TTD 20 and TTD 30. The shadow train timer of TTD 20 for train 1 is not reset anymore. Because TTD 20 is free, the location of train 1 is moved to VSS 31, which becomes "occupied' (#11A).

Step 6 - Train 1 reports its position in VSS 32 which becomes "occupied" (#2A). VSS 31 becomes "free" (#6B). Train 2 connects to the trackside, receives an MA until end of VSS 31, and VSS 12 becomes “ambiguous” (#5A).

Step 7 - Train 1 leaves TTD 30 and VSS 32 becomes “free” (#6A). Train 2 moves to VSS21 which becomes “occupied” via the state "ambiguous" due to the sequence with the shadow train timer (#3A, #11A).

Step 8 - Train 2 moves to VSS 22 and loses train integrity. The position report will start the integrity loss propagation timer of VSS 21 (because the train was still located on VSS 21 when the position report is received). With the update of the front-end, VSS 22 becomes “occupied” (#2A) and VSS 21 becomes "ambiguous" (#8A). With the update of the assumed rear end VSS 22 becomes “ambiguous” (#8A) and VSS 21 “unknown” (#10A).


VSS 11
VSS 12
VSS 21
VSS 22
VSS 23
VSS 31
VSS 32
VSS 33
1
2
3
4
5
6
7
8
integrity confirmed
no new Position Report
integrity lost
TTD 10
TTD 20
TTD 30
VSS section limit
TTD/VSS section limit
Established rear end
VSS status
TTD status
track
connected train
disconnected train
free
occupied
ambiguous
unknown

6.12 Change of direction

Step 1 - Train 1 with cab A active and an FS MA until VSS 22 has arrived from the left and occupies VSS 22. Integrity is confirmed.

Step 2 - Train 1 performs EoM and the communication session is terminated. VSS 22 becomes "unknown" (#7A). The disconnect propagation timer of VSS 22 is started.

Step 3 - Train 1 activates cab B (a different on-board unit or the same on-board unit with opposite train orientation) in the opposite direction.

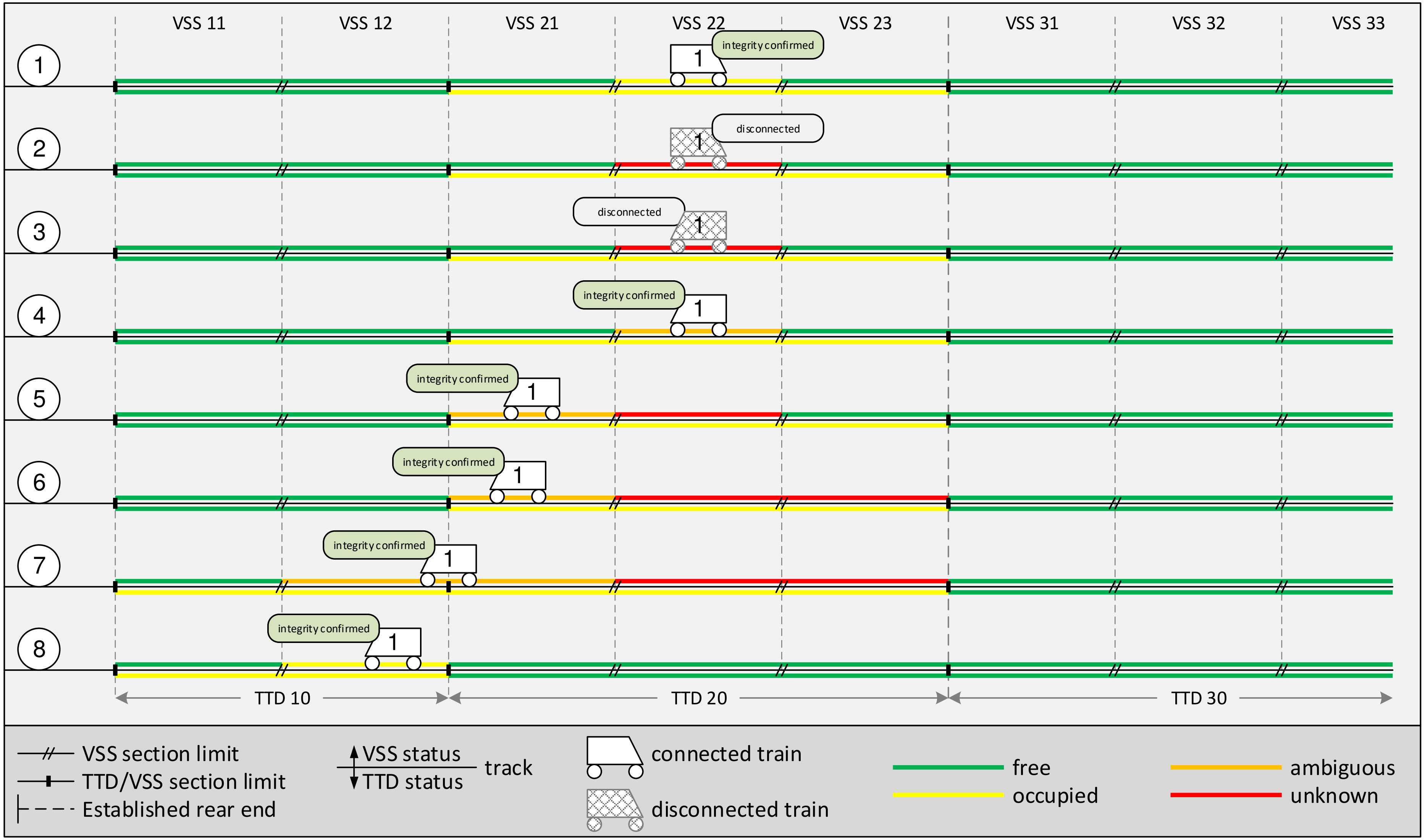
Step 4 - Train 1 performs SoM. VSS 22 becomes “ambiguous” (#5A). The disconnect propagation timer of VSS 22 is not stopped, because it is a different on-board which connects to trackside or the same on-board with a different train orientation.

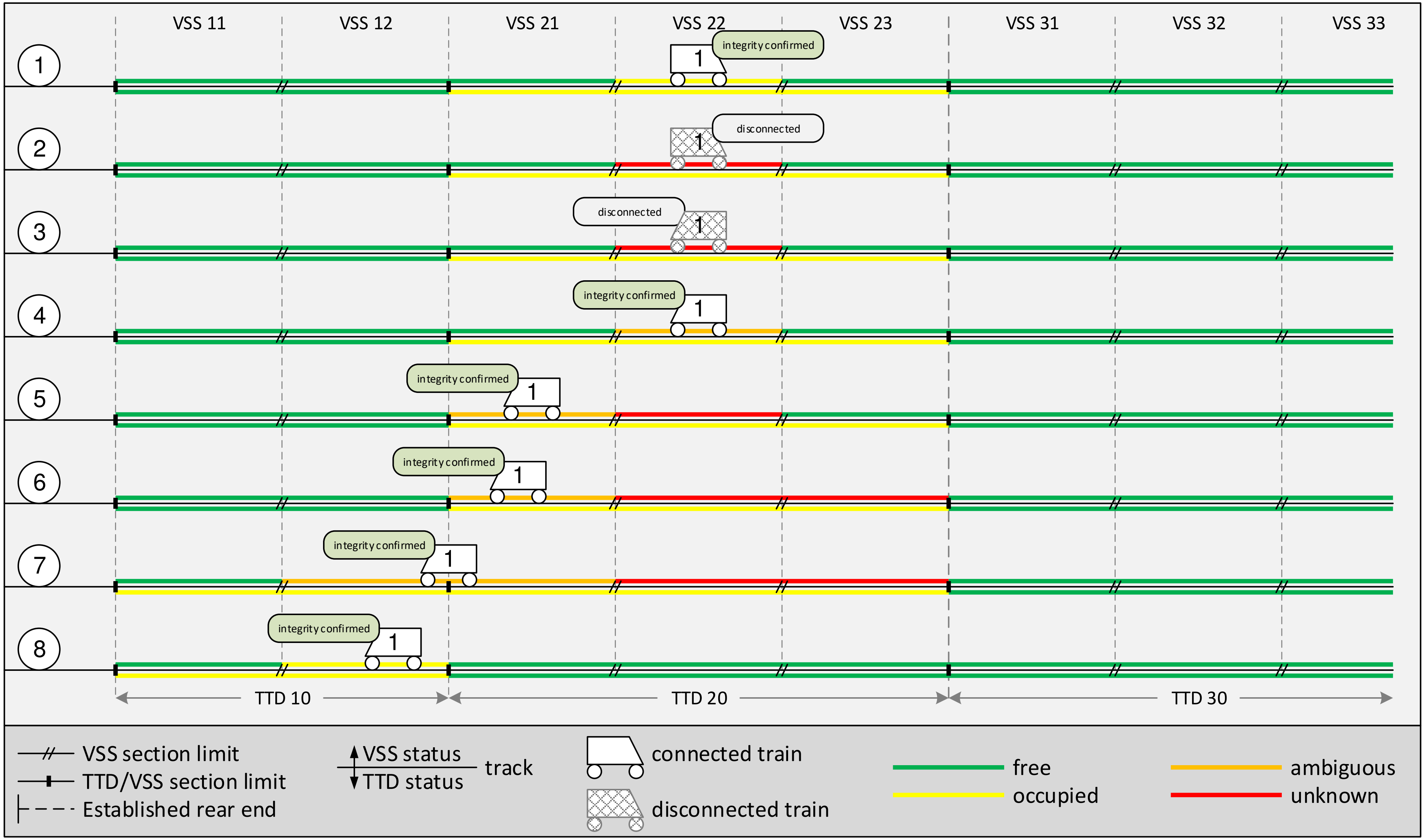
Step 5 - Train 1 receives an MA until VSS 11 and moves on to VSS 21 which becomes “ambiguous” (#3A). VSS 22 becomes "unknown" (#10A).

Step 6 - The disconnect propagation timer of VSS 22 expires. As a consequence, VSS 23 becomes "unknown" (#1C). VSS 21 remains "ambiguous". See 4.2.1.7 and 3.9.1.3.3 for a recommendation to avoid performance penalty due to (too much) propagation

Step 7 - Train 1 occupies VSS 12 which becomes "ambiguous" (#5A). The VSS on TTD 20 remain unchanged.

Step 8 - Train 1 leaves TTD 20 while the shadow train timer of TTD 20 for train 1 is not expired. VSS 12 becomes "occupied" (#11A). All VSS on TTD 20 become "free" (#4A and #9A).


VSS 11
VSS 12
VSS 21
VSS 22
VSS 23
VSS 31
VSS 32
VSS 33
1
integrity confirmed
2
disconnected
3
disconnected
4
integrity confirmed
5
integrity confirmed
6
integrity confirmed
7
integrity confirmed
8
integrity confirmed
TTD 10
TTD 20
TTD 30
VSS section limit
TTD/VSS section limit
Established rear end
VSS status
TTD status
track
connected train
disconnected train
free
occupied
ambiguous
unknown


VSS 11
VSS 12
VSS 21
VSS 22
VSS 23
VSS 31
VSS 32
VSS 33
1
2
3
4
5
6
7
8
integrity confirmed
disconnected
TTD 10
TTD 20
TTD 30
VSS section limit
TTD/VSS section limit
Established rear end
VSS status
TTD status
track
connected train
disconnected train
free
occupied
ambiguous
unknown

7 Annex B: Mitigation of specification shortcomings

7.1 Introduction

7.1.1.1 There are some shortcomings in the B3MR1 and B3R2 specifications which can affect operation in a HTD trackside. All these shortcomings are addressed by Change Request 940 [7] and 1304 [8] and therefore solved in the B4R1 specifications. This chapter describes the issues and possible mitigation if CR 940 is not available.

7.2 Performance issue when leaving an RBC area

7.2.1.1 It is possible that a train leaving an HTD RBC area (RBC handover, level transition) disconnects before sending a position report to confirm that the min safe rear end has left the last VSS of the RBC area.

7.2.1.2 The result is that one or more VSS at the border of the RBC area cannot become "free" based on integrity confirmation from the leaving train.

7.2.1.3 This can be mitigated by covering the last TTD section of an RBC area by a single VSS.

7.2.1.3.1 Note that such a scenario and mitigation would also be applicable when entering an announced radio hole.

7.3 Protection against undetected train splitting

7.3.1.1 Up to version 3.6.0 of [1] it is not foreseen to take the change of train data into account for the integrity status. Therefore, it is possible that a train split which results in a change of L_TRAIN is not recognised immediately by the trackside. This can result in setting a VSS to "free" where actually the second part of the split train is still located.

7.3.1.2 A mitigation is to end the mission before splitting. This is a normal procedure for train-sets.

7.3.1.3 Note: The changed train data information will be repeated by the train until acknowledged by the trackside. This will minimise the risk of releasing infrastructure as a result of not detecting a train split.

7.4 Unspecified reporting behaviour of integrity information

7.4.1.1 Up to version 3.6.0 of [1] it is not specified under which conditions the status of the integrity information to be reported to the trackside changes. A trackside implementation should take into account that on-boards up to 3.6.0 could either report several times "integrity confirmed" with increasing train length (L_TRAIN_INT) before a new integrity confirmation is received by the on-board or report "no information" as it is specified for future on-boards in [7].

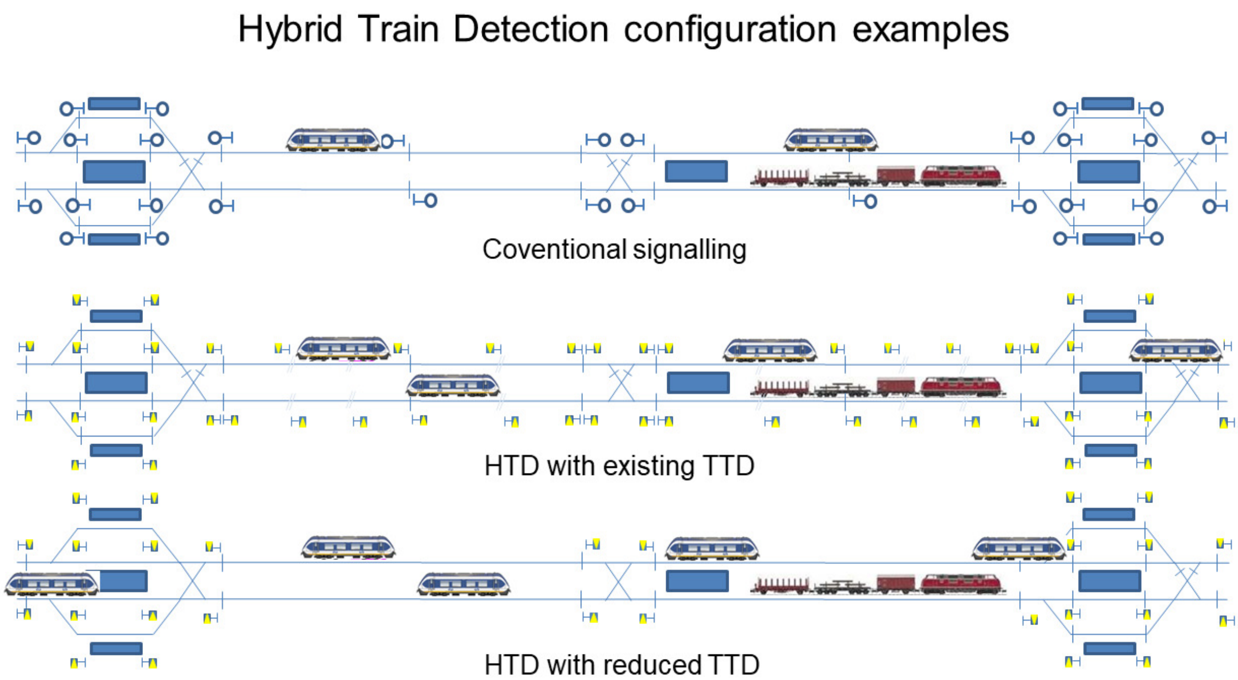
8 Annex C: Implementation examples

8.1.1.1 The HTD concept allows an increase of capacity and a reduction of trackside train detection on lines where most of the trains are fitted with train integrity. The example below depicts a simple layout with two stations and a stopping place with crossing points in the middle of the connecting line between the stations. The passenger trains are equipped with TIMS functionality and the cargo train not.

8.1.1.1.1 The top layout in the example shows a conventional signalling layout with trackside train detection. The depicted train separation is one detection block and one block for the brake distance (with blocks size=B, minimal headway ≈ 2 B).

8.1.1.1.2 The middle layout in the example shows a HTD configuration with the existing trackside train detection re-used and sub-divided with virtual sub section, increasing the capacity for integer trains. For normal running only one train is allowed in a block (between marker boards). The depicted train separation in rear of an integer train is approximately the brake distance plus the virtual block size plus the periodic time between position reports with integrity confirmation (minimal headway ≈ 1.4B).

8.1.1.1.3 The bottom layout in the example shows a HTD configuration with a reduced trackside train detection. On the line between the point areas, no marker boards are placed only to protect (danger) points. Multiple trains are allowed running between marker boards and the size of the virtual sub sections can be reduced to a minimal size (e.g. 25m) providing a capacity comparable with “moving block”. The depicted train separation in rear of an integer train is approximately the brake distance plus the virtual block size plus the periodic time between position reports with integrity confirmation (minimal headway ≈1.1B).


Hybrid Train Detection configuration examples
Coventional signalling
HTD with existing TTD
HTD with reduced TTD