ERTMS UNIT

INTRODUCTION TO ETCS BRAKING CURVES

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	Edited by	Quality review	Approved by
Name	A. HOUGARDY	A. CHIAPPINI	P. GUIDO
Position	ERTMS Unit Project Officers	ERTMS Unit Quality Manager	ERTMS Head of Unit
Date & Signat.			

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1. REFERENCES, TERMS AND ABBREVIATIONS

1.1. REFERENCE DOCUMENTS

Table 1 : Reference documents

Ref. N°	Document Reference	Title	Last Issue
[1]	SUBSET-026	ERTMS/ETCS System Requirements Specification	3.2.0
[2]	ERA_ERTMS_015560	ETCS Driver Machine Interface	3.2.0
[3]	SUBSET-041	Performance Requirements for Interoperability	2.1.0
[4]	UIC 544-1	Brakes – Braking power	4th edition
[5]	EN15595	Railway applications - Braking - Wheel Slide Protection	2009

2. GENERAL OVERVIEW

2.1. BRAKING CURVE: WHAT?

A CCS system does not brake, i.e. it is not responsible for the braking system of the train, which will do the actual job. ETCS (and also some elaborated legacy CCS systems) supervises both the position and speed of the train to ensure they continuously remain within the allowed speed and distance limits, and -if necessary- it will command the intervention of the braking system to avoid any risk of the train exceeding those limits.

To do so the ETCS onboard computer must predict the decrease of the train speed in the future, from a mathematical model of the train braking dynamics and of the track characteristics ahead. This prediction of the speed decrease versus distance is called a braking curve.

From this prediction the ETCS on-board computer calculates in real time braking distances, which will also be used to assist the driver and to allow him to drive comfortably, by maintaining the speed of the train within the appropriate limits.

2.2. HARMONISED BRAKING CURVES FOR ETCS: WHY?

2.2.1. BACKGROUND

Two of the ETCS frequently asked questions are why to fully harmonise the ETCS braking curves and why it has been so difficult and controversial.

The main reason is the clear split of responsibility between the Railway Undertaking and the Infrastructure Manager, which has been enforced by the EU directives. The CCS system has naturally stuck to the same logic, resulting into two separate ETCS trackside and on-board subsystems.

However this has to be put in perspective with the very high degree of integration of the legacy CCS systems, which have been developed on a national basis and with a speed/distance control philosophy closely linked to the underlying signalling system. For instance, the required safety level of the railway operation with legacy systems is obtained according to assumptions with regards to the braking (safety margins) that can vary drastically from one country to another one, that very often cannot be apportioned between trackside and on-board or even worse that are not clearly identifiable.

Therefore the move towards a unified speed and distance control, together with a clear split of responsibility between the Infrastructure Manager and the Railway Undertaking, implies that:

- the behaviour of the train with respect to its braking curves must be fully predictable

- the safety margins, which tell how reliable is the braking curve itself, can be unambiguously apportioned between the trackside and on-board subsystems. Note that the reliability of the braking curve used for the ETCS supervision is related to the braking system only and should not be mixed up with the reliability of the ETCS system itself.

2.2.2. CURRENT SITUATION

Today the ETCS baseline 2 specifications lay down the basic principles for the braking curves and the associated information displayed to the driver, but there is still no harmonised method/algorithm to compute them; as a result, the following consequences arise:

- In the absence of any requirement, the algorithms of the ETCS on-board suppliers lead to different braking distances for a given type of rolling stock. This makes the engineering of the ETCS trackside and potentially the granting of slots not only dependent on the pure performance of the rolling stock braking system, but also on the ETCS on-board supplier itself.

- For cross border trains, the differences through national rules/practices require the implementation in the ETCS on-board of several national braking curves. It can obviously induce increased costs (software design, cross acceptance tests, software upgrade necessary whenever a national parameter is amended...).

More than ten years after the start of the first discussions between the stakeholders, the convergence towards a stable specification of the ETCS braking curve functionality has now been achieved and is reflected in the baseline 3 draft SRS 3.2.0 (ref [1]).

3. ETCS BRAKING CURVES DESCRIPTION

3.1. ACHIEVING THE ETCS CORE FUNCTIONALITY

3.1.1. PROVIDING THE PARACHUTE

The braking curve related to the speed decrease due to the emergency brake is called EBD (Emergency Brake Deceleration) curve. Each specific target location (corresponding either to a speed reduction or to a stop location) given by the ETCS trackside is used by the ETCS on-board to compute a fully deterministic EBD curve, which depends on both train and track characteristics. The shape of the EBD curve, for a given piece of track, will therefore vary according to the type of rolling stock: the less the emergency braking system is efficient, the flatter the EBD curve will be.

From the EBD and the measured (i.e. estimated) train speed, the ETCS computer calculates in real time, several times per second, the distance necessary to stop (or decelerate) the train from the time the ETCS on-board would command the intervention of the emergency brake. To do so, it is necessary to make worst case assumptions:

- on the train dynamics during the lapse of time before the full emergency brake effort is developed (emergency brake build up time), by taking into account the measured acceleration

- on the actual speed of the train, by taking into account the inaccuracy of the speed measurement

This distance determines a location called the EBI (Emergency Brake Intervention) supervision limit, i.e. the point beyond which ETCS will bypass the human in charge (see Figure 1).

The EBD curve and the resulting EBI supervision limit are the elements of the ETCS speed and distance monitoring function, which materialize the so called ETCS parachute.

<u>Important note</u>: the term parachute must be understood as the preventive reaction of a CCS system, against any exceeding of the speed and distance limits. On the other hand, a legacy “Warning/Stop” CCS system, which for instance only reacts when passing a signal at danger, should not be strictly considered as a parachute (or at most considered as a parachute that opens up too close from the ground).

3.1.2. ADVISING THE DRIVER

In addition to the parachute functionality, ETCS provides the driver with advance information related to braking. Its purpose is to assist the driver and to allow him to drive comfortably, by maintaining the speed of the train within the appropriate limits.

Therefore the ETCS on-board calculates in real time other supervision limits: Indication (I), Permitted speed (P), Warning (W) and Service Brake Intervention (SBI) (only if the ETCS on-board is designed to command itself the service brake). They consist of locations that, when crossed by the train, will trigger some information to be given to the driver through appropriate graphics, colours and sounds on the Driver Machine Interface (see document ref [2] for details).

These locations are defined in order to:

- For the “I” supervision limit: leave the driver enough time to act on the service brake so that the train does not overpass the Permitted speed, when this latter will start to decrease. Without the indication it would not be possible for the driver to perform a transition from ceiling speed supervision to the target speed supervision without overpassing the Permitted speed (see Figure 2).

- For the “P” supervision limit: in case of overspeed, to leave the driver an additional time to act on the service brake so that the train will not overpass the point beyond which ETCS will trigger the command of the brakes.

- For the “W” supervision limit, to give an additional audible warning after the Permitted speed has been overpassed.

- For the “SBI” supervision limit, to take into account the service brake build up time so that the EBI supervision limit is not reached after the command by ETCS of the full service brake effort. The SBI supervision limit is facultative and can be implemented on-board the train in order to avoid too frequent emergency braking, which can be damaging for both the rolling stock and the track.

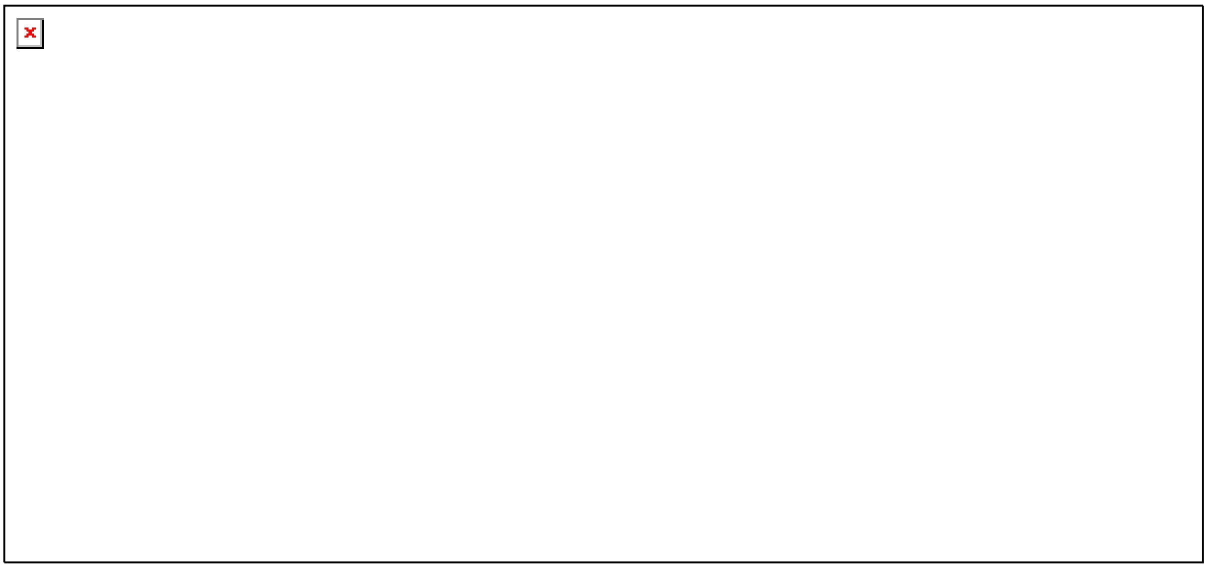


Figure 1: Overview of the EBD braking curve and its related supervision limits

Moreover the ETCS computer has to continuously display the Permitted speed to the driver. Even though it is customary to call this displayed Permitted speed a “braking curve”, in reality the ETCS computer does never calculate such a braking curve as a whole. Only the mental image of ETCS plotting on a graph a decreasing displayed Permitted speed versus distance could be seen as a braking curve but here it does not consist of a prediction made by the ETCS computer: this latter has only to consider the “P” supervision limit, which is a single location (normally ahead of the train unless there is an overspeed) calculated for the currently measured train speed.

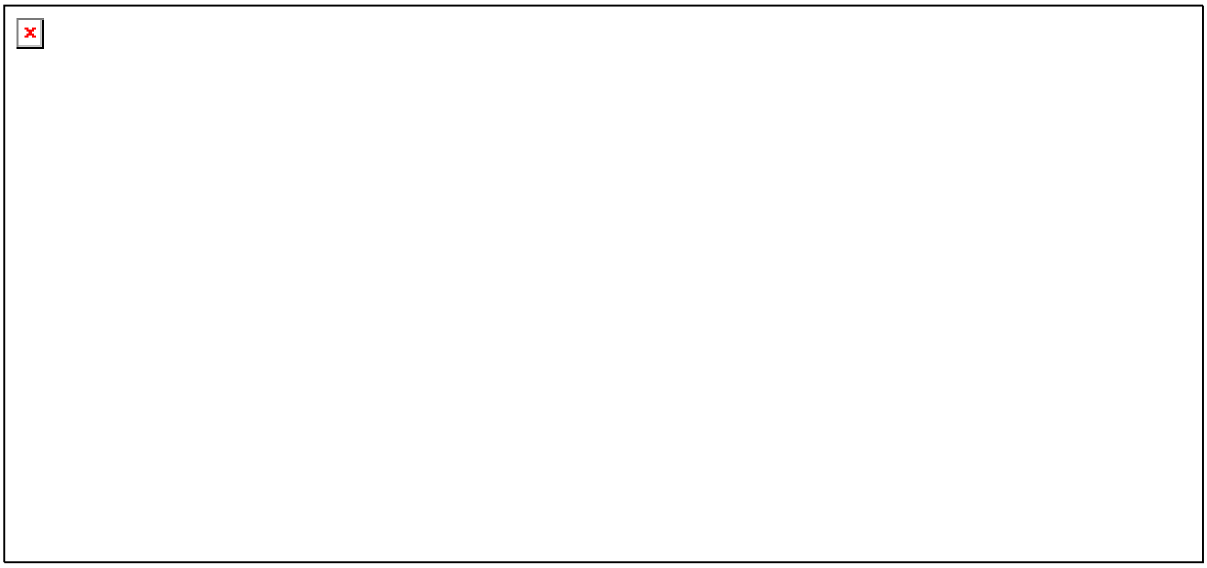


Figure 2: Indication to the driver before the Permitted speed starts to decrease

The main purpose of the ETCS display is to invite the driver to keep the train speed as close as possible to the Permitted speed (see Figure 2). However the driver might eventually fail to do it and should be the case, ETCS offers him/her a second chance to brake the train before it takes over the responsibility to command the brakes. This is materialised by a more visible and audible warning and an additional time left to act on the service brake in order to avoid the ETCS intervention, i.e. to avoid that the EBI or the SBI supervision limit (depending on whether the ETCS command on the service brake is implemented) is reached (see Figure 3).

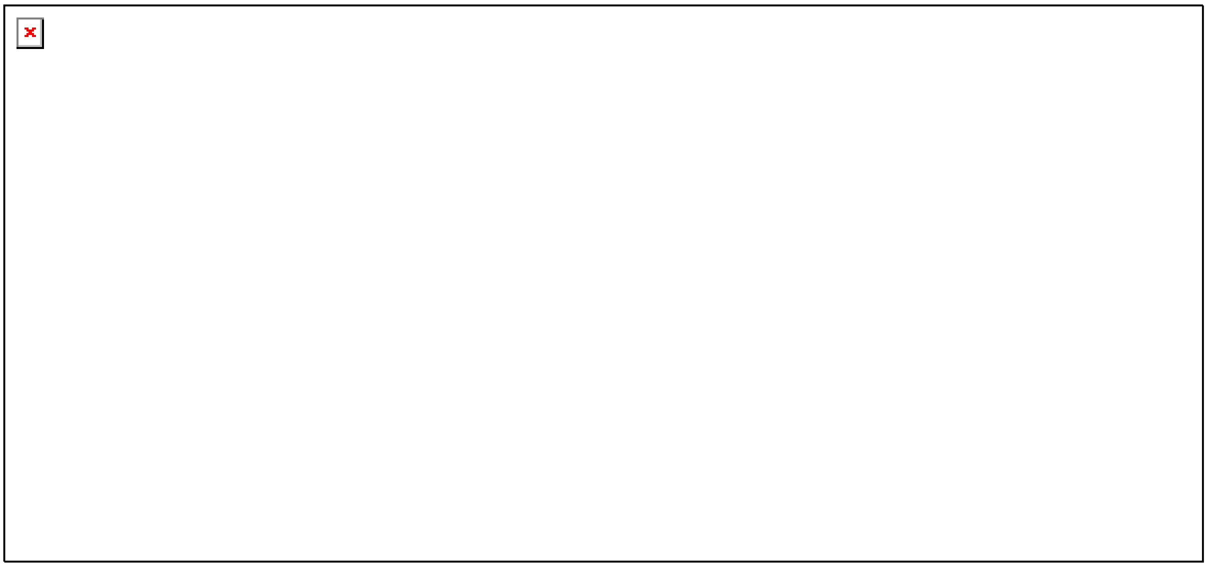


Figure 3: Overspeed, driver is left additional time to avoid the ETCS intervention

3.2. INPUT PARAMETERS

Numerous input parameters are necessary to feed the ETCS braking curve algorithms and to allow the ETCS on-board computer to perform in real time its supervision and advisory functions; they can be classified in four categories:

- Physical parameters, which results from the real time measurements by the

ETCS on-board equipment: instantaneous position, speed and acceleration;

- ETCS fixed values, which are invariant within a given ETCS baseline. They mostly relate to the ergonomics of the braking curve model itself (e.g. driver reaction times, see Figure 1);

- ETCS trackside data. It consists of signalling data (target speed/locations), infrastructure data (downhill/uphill slopes) and also some of the so called ETCS National Values, which can affect the ETCS braking curve model. These parameters are under the strict control of the Infrastructure Manager and are transmitted through the relevant ETCS transmission medium (balise, loop or radio).

- On-board parameters, which are captured before the Start of mission as part of the so called ETCS Train Data. They mostly relate to the rolling stock braking system itself.

Amongst the two last categories of input parameters, a particular care must be paid to the ones contributing to the computation of the EBD curve. Indeed, the responsibility of the ETCS being solely to command the emergency brake in due time, the overall safety of a railway system highly relies on the fact that the trains will be effectively braked according to the predicted EBD.

Therefore the EBD curve must fulfil the relevant safety, which is required for the operation of ETCS trains on a given infrastructure. This is materialised in the ETCS braking curve model by the so called “correction factors”.

3.3. HOW TO GET THE EBD CURVE– GUARANTEED EMERGENCY BRAKE DECELERATION

3.3.1. EBD DEFINITION

The EBD is a parabolic shaped curve that starts from the target location and is computed with the deceleration resulting from:

- the guaranteed deceleration due to the emergency brake system itself (A_brake_safe)
- the deceleration/acceleration due to the uphill/downhill slopes (A_gradient)

To that effect, the emergency brake deceleration is modelled through a step function of deceleration against speed (“emergency brake deceleration profile”), while the track slopes are sent by the ETCS trackside as a step function of constant slopes against distance (“gradient profile”). The combination of both gives a set of interconnected parabolic arcs, each of them corresponding to a speed and distance “region” with a constant deceleration (see Figure 4).

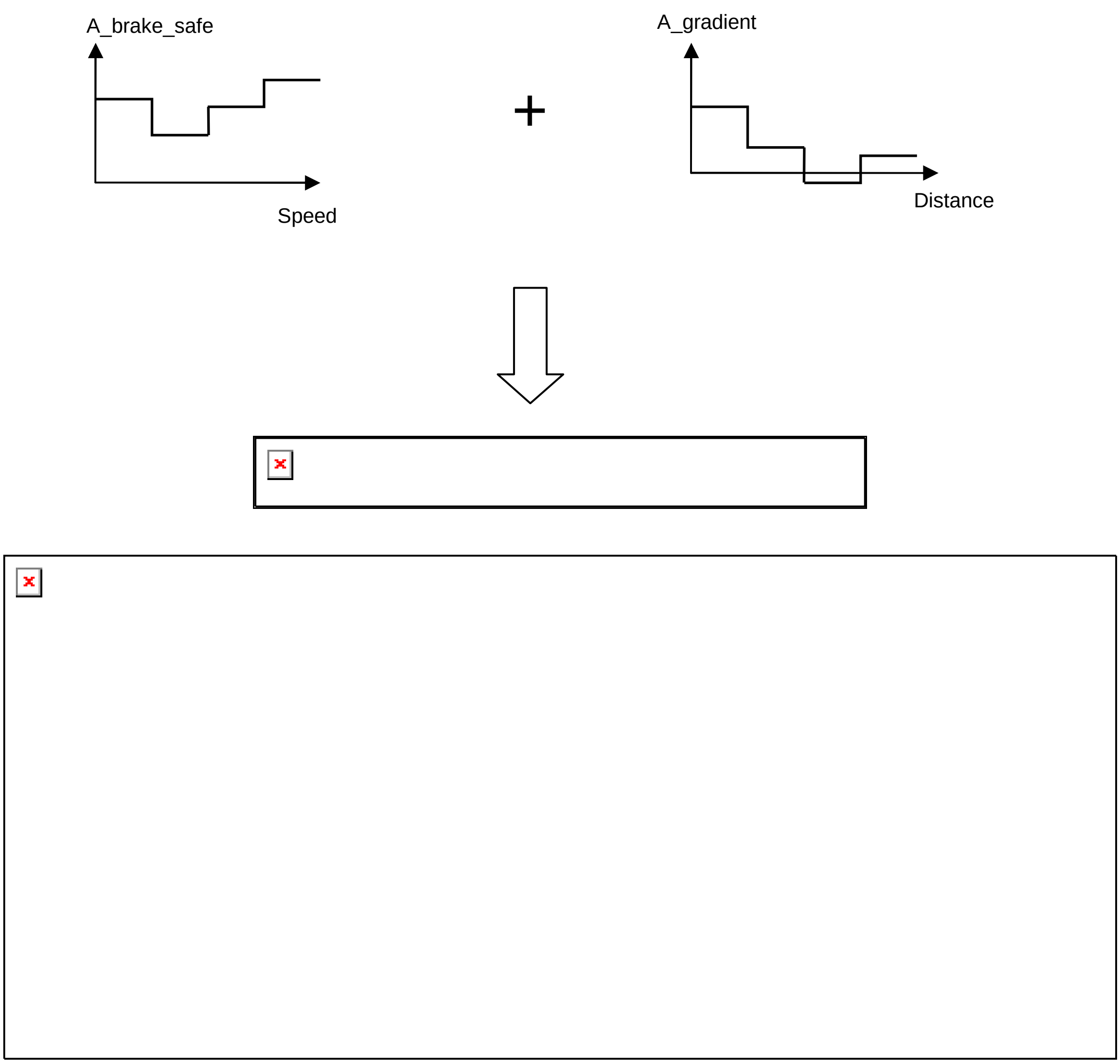


Figure 4: Construction of the EBD

3.3.2. GUARANTEED EMERGENCY BRAKE DECELERATION

Even though the current ETCS baseline 2 specification introduces the concept of EBD curve, they do not tell how reliable must be the EBD curve, or in other terms what do represent the margins that are taken in order to obtain the guaranteed emergency brake deceleration.

A mistake usually made is to mix up the reliability with which the train will develop the guaranteed deceleration with the ETCS on-board safety target (i.e. Tolerable Hazard Rate set to 10^{-9}/h). Indeed, the ETCS on-board THR only represents the acceptable failure rate for the ETCS on-board equipment to <u>command</u> the brakes when it is expected to do so, based on the input information given to ETCS. In other terms the reliability of the emergency braking system itself will have an impact on the overall safety of a railway system, but it is just a contributor distinct from the ETCS on-board THR.

The ETCS braking curve model is tailored to allow a clear responsibility split between the Railway Undertaking and the Infrastructure Manager, for what regards the determination of the EBD curve.

With the ETCS braking curve model, the margin between the nominal emergency brake performance (A_brake_emergency) and the guaranteed one is quantified by the so called <u>correction factors</u>. This margin is essentially related to characteristics of the rolling stock itself and depends on:

- The dispersion of the performance of some braking elements (pads, cylinders,…)
- The reliability of the braking system components
- The architecture of the braking system (number of independent components)
- The efficiency of the Wheel Slide protection (WSP) system in case of wet rail
- Others...

Since there can be a natural tendency in some countries to already include hidden margins when establishing the nominal braking performance of a rolling stock, first of all ETCS sets the reference conditions under which the nominal emergency deceleration must be established: environmental conditions, friction elements, track profile, wear of the wheels, all braking systems considered for the emergency braking up and running.

While it is relatively easy to represent through a statistical model the dispersion of the braking performance on dry rails (see Figure 5), the physical phenomenon that occur when braking on wet rails are still today extremely difficult to model. In order to overcome this difficulty, two distinct rolling stock correction factors have been created in order to get the guaranteed emergency brake deceleration:

- Kdry_rst, to quantify the dispersion of the emergency braking performance on dry rails. Kdry_rst is relevant for confidence levels, which represent the probability that one emergency braking will effectively ensure a deceleration at least equal to A_brake_emergency * Kdry_rst. This correction factor can be calculated offline e.g. through the Monte-Carlo methodology;
- Kwet_rst, to quantify the loss of emergency braking performance on a

reference reduced wheel/track adhesion, with regards to dry rails. It can be retrieved from the field tests prescribed to qualify the WSP system, as per standard EN15595 (ref [5]).

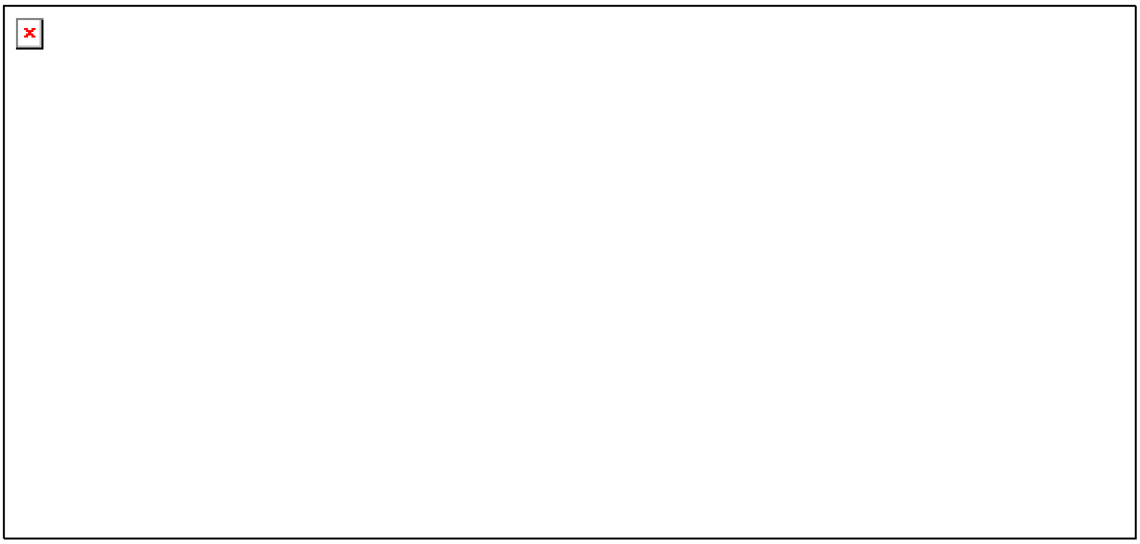


Figure 5: Dispersion of emergency braking performance on dry rails

On the one hand, these two correction factors offer the advantage to be strictly under the responsibility of the Railway Undertaking, because only related to the rolling stock characteristics. On the other hand, the ETCS braking curve model offers the Infrastructure Manager two levers in order to interact on the computation of the EBD curve:

- the selection of the confidence level with which the guaranteed emergency braking on dry rails will be considered;
- a weighting factor that can mitigate Kwet_rst, in case the available wheel/rail adhesion is higher than the reference one defined in the standard EN15595.

As a matter of fact, these two parameters (sent by ETCS trackside as National Values) are under the sole Infrastructure Manager responsibility and can be used to derive the overall safety target applicable to a given infrastructure.

3.3.3. *CAPTURE OF THE BRAKING INPUT PARAMETERS - GAMMA TRAINS VS LAMBDA TRAINS*

As explained above, the main prerequisite for the ETCS braking curve model is to capture the emergency braking performance of a train as both deceleration profile and brake build up time.

When the ETCS on-board equipment is fitting a train with a fixed composition or a finite number of predefined compositions, all the nominal deceleration profiles, their corresponding rolling stock correction factors and the brake build up times can be preconfigured in the ETCS on-board equipment (see Figure 6). The trains for which it is possible to store such predefined data are called "Gamma trains".

At the Start of Mission, ETCS on-board automatically uses the preconfigured data corresponding to the relevant train composition, if needed from a train preparer/driver selection or from a dedicated train input (see Figure 6).

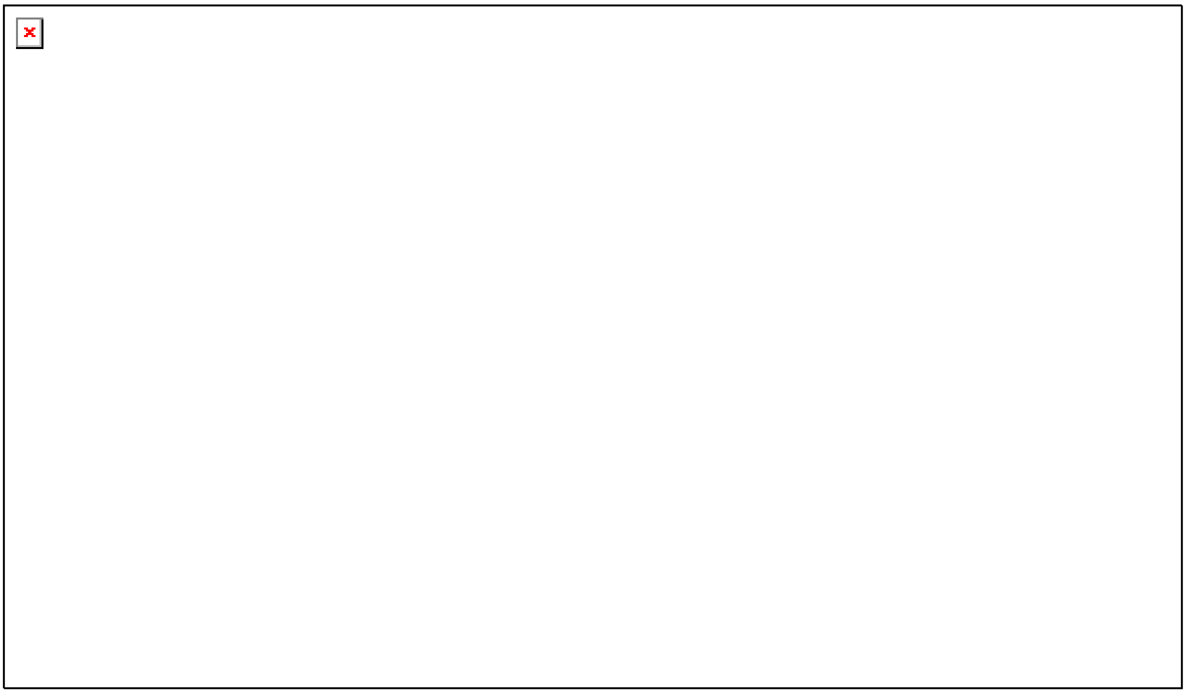
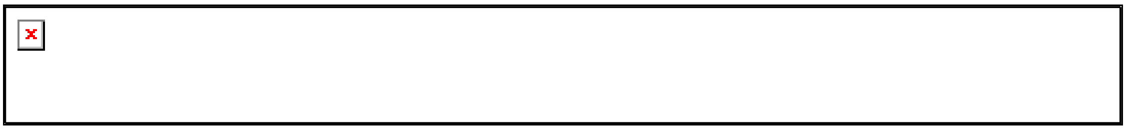


Figure 6: Rolling stock correction factors for Gamma trains – split of responsibility RU/IM



In case of variable composition trains, it is neither possible to directly express nor to predefine the braking performance with deceleration data. The only alternative is to request the train preparer/driver to enter the braked weight percentage as the unique data characterising the braking power of the train. Then the ETCS on-board converts it into an emergency brake deceleration profile and build up time.

The braked weight percentage of the train is obtained by dividing the sum of the braked weight of all the individual vehicles (determined according to UIC Leaflet 544-

1) by the total weight of the train. The trains for which the braking performance is captured (through the train preparer or the driver) as braked weight percentage and is converted into deceleration data are called "Lambda trains".

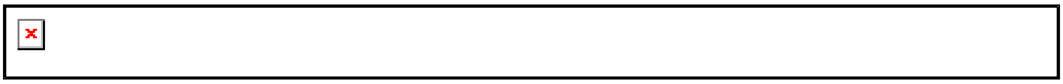
It must be underlined that the deceleration profile and brake build up time so obtained are pure mathematical artefacts without any physical meaning. Indeed the conversion consists of a unique algorithm, which has been designed and validated through a comparison with the braking distances measured during an extensive field tests campaign performed by UIC with a large variety of train types.

Since the driver cannot reasonably be requested to enter any explicit correction factor, it has been chosen, in order to obtain a deceleration profile suitable for the EBD curve, to offer the Infrastructure Manager the possibility to define "Integrated correction factors", which will be sent by the ETCS trackside:

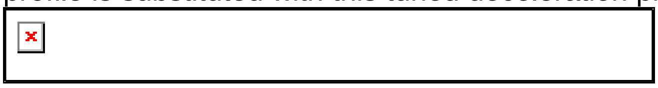
- A pair of correction factors given as a step function of speed, for both Passenger (P) and freight (G) trains

- A correction factor given as a step function of the train length

Figure 7: Integrated correction factors for lambda trains



In order to compute the EBD curve, the guaranteed emergency brake deceleration profile is substituted with this tuned deceleration profile:



These integrated correction factors are actually used as tuning factors, allowing the Infrastructure Manager to tweak the ETCS braking curves so that they could fit to the legacy signalling system. Such approach, which reflects to some extent the current integrated railway practice, has the following disadvantages:

- There is an overlap of responsibility between the Railway Undertaking and the Infrastructure Manager: for a given value of the braked weight percentage, the shape of the EBD curve is “imposed” by the IM regardless of the architecture and performance of the rolling stock braking system. As a result the (not quantified) reliability of the EBD curve may vary from one train type to another one and the integrated correction factors may have to be aligned to the less performing train in terms of dispersion and resilience to wet conditions.

- The validity domain of the conversion model is limited: maximum speed 200 km/h, braked weight percentage between 30% and 250% and maximum train length 900m (Passenger trains) or 1500m (Freight trains).

- Unlike the National Values for gamma trains, it has been impossible to the railways to find a consensus for the default values of the integrated correction factors. The default values are fixed values stored on-board and can be enforced in case of cross border cold movements (e.g. locomotives pulled as wagon with the ETCS on-board equipment switched off).

For conventional passenger trains, the Railway Undertaking has the full freedom to opt for the preconfigured emergency deceleration profile and rolling stock correction factors or for the capture of the braked weight percentage and its associated conversion. ETCS even offers the possibility for the train preparer/driver, if the ETCS on-board is so configured, to select one or the other method, this feature being useful for locomotives that alternatively pull passenger trains and freight trains.

4. ETCS BRAKING CURVES KEY IMPACTS ON THE RAILWAY SYSTEM

4.1. ETCS CAB SIGNALLING VS CONVENTIONAL LINESIDE SIGNALLING

Today, almost all the conventional lines are fitted with optical signals. Even on those lines fitted with an underlying legacy CCS system, the driving of the trains is primarily based on the observance by the driver of the optical signal aspects. The warning signal requires the driver to start braking in due time when the train must be brought to a stop from the nominal line speed.

These signals are therefore located in order to match the braking performance of the preferred type of rolling stock operating on the concerned line, taking into account the slopes and possibly some safety margins.

When trains with less good braking performance (e.g. freight trains) have to operate on a line designed for better trains, the driver is instructed (generally through its driver's route book or eventually through the legacy CCS system) to run at a lower speed than the nominal line speed, keeping in mind that the location from which he starts to brake (the warning signal) remains the same for all trains.

In a few words, driving with optical signals implies that the location where to start braking is fixed, while the initial speed is adapted in order to match the braking performance of the train. With ETCS, this is exactly the contrary: the initial speed is constant, while the location where to start braking is adapted according to the braking performance of the train.

This is why running under the ETCS full supervision can only be achieved with the concept of "Cab Signalling": in normal situation while running the driver must observe the displayed information on the DMI and he/she is not required to look outside the lineside signals.

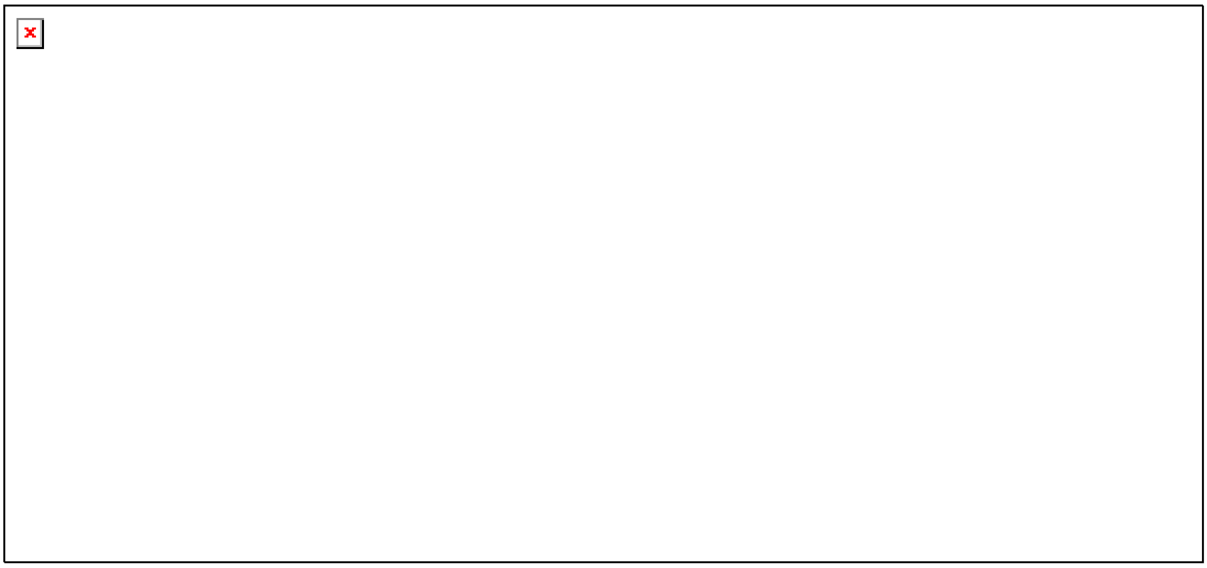


Figure 8: Train braking performance fitting the line (warning signal location and line speed), analogy between Cab signalling and Lineside signalling,

Figure 9: Lower train braking performance, Lineside signalling without ETCS

Figure 10: Lower train braking performance, Cab Signalling with ETCS braking curve

4.2. BRAKING CURVES IN RELATION TO SIGNALLING HEADWAY

When operating trains under the ETCS full supervision, the Indication distance (i.e. the distance from the Indication supervision limit to the stop location) is a major contributor to the headway that can be achieved on a line. The headway is generally expressed as the time between two consecutive trains, but can also be represented by the minimum distance between trains that allows them to safely run at the desired line speed, without being disrupted.

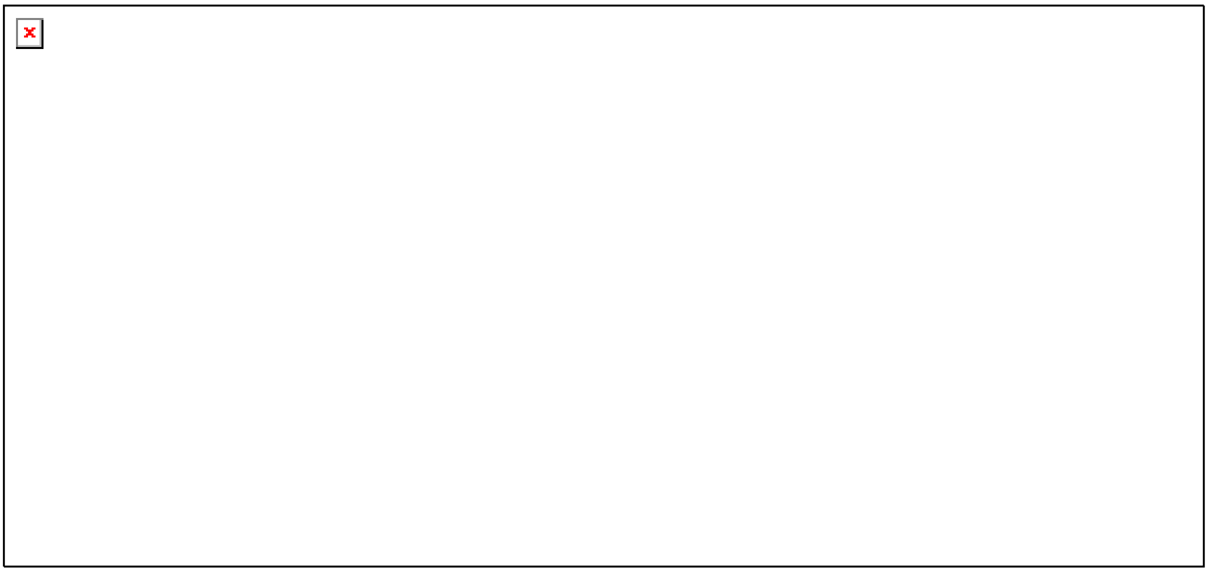


Figure 11: Contribution of the ETCS braking curve to the headway

Note: the system delays in Figure 11 include all the processing and transmission delays (Interlocking, ETCS trackside and on-board, GSM-R in case radio is used), which happen from the time the first train has left a signalling block section to the time the information displayed to the driver of the second train is refreshed.

It is therefore clear that the Indication distance, which is only partly based on the braking performance committed by the Railway Undertaking, must be fully predictable since it is used by the Infrastructure Manager in order to check whether a train can fit into an ETCS fitted line.

4.3. ENGINEERING ETCS LEVEL 1 LINES FITTED WITH EUROBALISES ONLY

The Figure 11 here above illustrates the fact that, as soon as the first train leaves a signalling block section, the system reacts to forward to the ETCS on-board of the second train a new Movement Authority including the released section. With a semi-continuous transmission medium (Radio or Loop), the renewal of the Movement Authority can always be ensured in due time regardless of the value of the Indication distance.

However for a level 1 line only fitted with spot transmission devices (balises), the renewal of the Movement Authority before the train reaches the Indication supervision limit relies on the fact that the information point (infill balise group) is installed at the suitable location, which is as close as possible to the Indication point.

In case of mixed traffic (i.e. trains with different braking performances), there could be the need to install more infill information points, but again their location will depend on the advance knowledge of the respective Indication distances.

5. NUMERICAL EXAMPLES

5.1. INTRODUCTION

Braking a train is more demanding than braking a road vehicle: the low wheel-rail grip which makes rail transport so energy efficient also makes for longer braking distances. For instance, a high speed passenger train requires several kilometres to brake to standstill.

This section gives quantitative examples of apportionment of the braking distances that are computed by the ETCS on-board computer in relation to the ETCS braking curve model.

5.2. HIGH SPEED PASSENGER TRAIN

The Table 2 includes typical input parameters for a high speed passenger train, fitted with pneumatic disc/shoe brakes and with electrical regenerative brake on some of its bogies. The emergency brake data is preconfigured in the ETCS on-board equipment (Gamma method).

Input parameter	**Value**	**Origin**
Driver time between I and P supervision limits	5 s	ETCS fixed value
Driver time between P and EBI supervision limits (no SBI)	4 s	ETCS fixed value
Speed measurement inaccuracy	2.58 %	ETCS performance requirement (SUBSET-041)
Emergency brake equivalent build up time	2.5 s	Rolling stock
Track slope	-10 ‰ (downhill)	Trackside
Confidence level for emergency braking on dry rails	99.9999999 % (equivalent probability 10^{-9})	Trackside (National Value)
Correction factor Kdry_rst		Rolling stock (Monte Carlo)
Weighting factor for Kwet_rst	0 (wet rails)	Trackside (National Value)
Correction factor Kwet_rst	0.893	Rolling stock (EN15595:2009)

Nominal emergency brake deceleration		Rolling stock

Table 2: High speed train, example of input parameters

The Figure 12 here below shows the resulting braking distance apportionment.

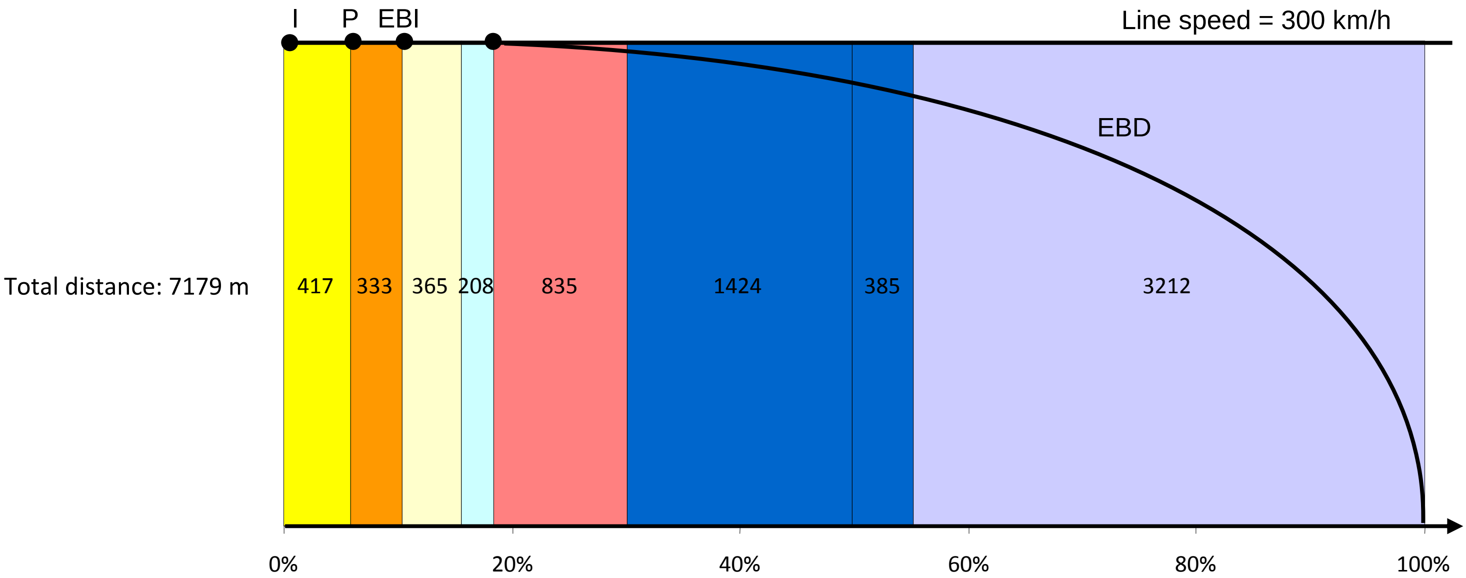


Figure 12: Distance apportionment for high speed train

5.3. CONVENTIONAL PASSENGER TRAIN

The Table 3 includes typical input parameters for a trainset of three coaches, fitted with pneumatic disc brakes and with electro-magnetic brakes on some of its bogies. The emergency brake data is preconfigured in the ETCS on-board equipment (Gamma method).

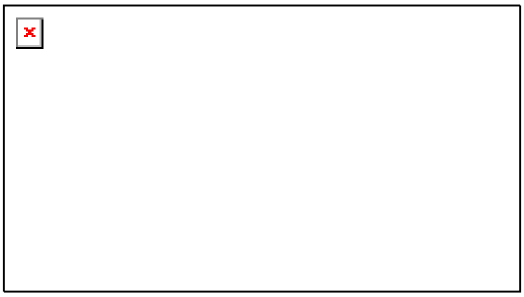
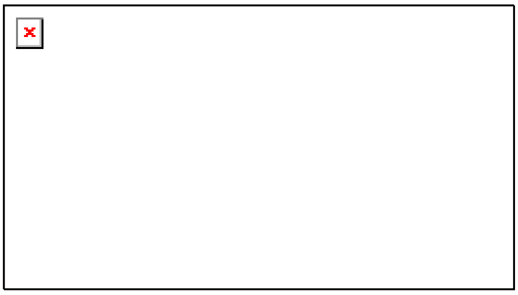
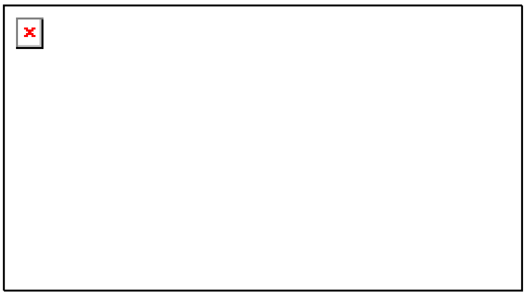
Input parameter	**Value**	**Origin**
Driver time between I and P supervision limits	5 s	ETCS fixed value
Driver time between P and EBI supervision limits (no SBI)	4 s	ETCS fixed value
Speed measurement inaccuracy	2.98 %	ETCS performance requirement (SUBSET-041)
Emergency brake equivalent build up time	3.5 s	Rolling stock
Track slope	-10 ‰ (downhill)	Trackside
Confidence level for emergency braking on dry rails	99.999999 % (equivalent probability 10^{-8})	Trackside (National Value)
Correction factor Kdry_rst		Rolling stock (Monte Carlo)
Weighting factor for Kwet_rst	0 (wet rails)	Trackside (National Value)
Correction factor Kwet_rst		Rolling stock (EN15595:2009)
Nominal emergency brake deceleration		Rolling stock

Table 3: Conventional passenger train, example of input parameters (Gamma method)

The Table 4 includes the corresponding input parameters for the same train, but with braking performance expressed as braked weight percentage.

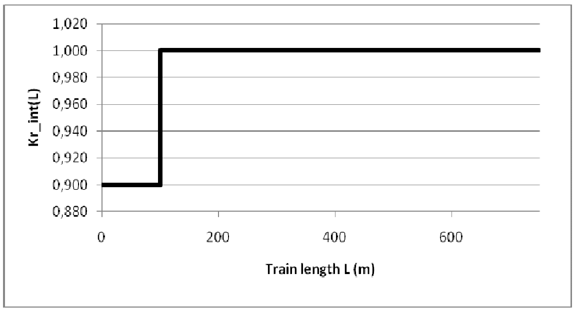
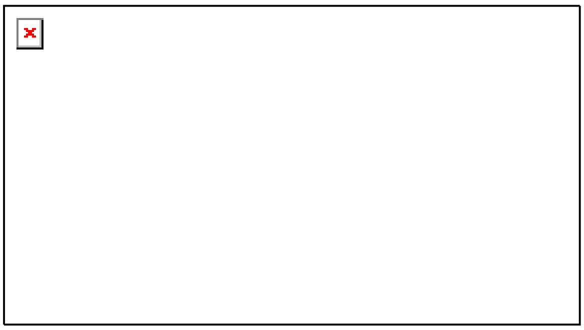
Input parameter	**Value**	**Origin**
Brake weight percentage	143 % (R+Mg)	Rolling stock (UIC leaflet 544-1)
Train length	83 m	Rolling stock
Driver time between I and P supervision limits	5 s	ETCS Fixed value
Driver time between P and EBI supervision limits (no SBI)	4 s	ETCS Fixed value
Speed measurement inaccuracy	2.98 %	ETCS Performance requirement (SUBSET-041)
Emergency brake equivalent build up time	5.02 s	Conversion model
Kt_int	1	Trackside (National Value)
Track slope	-10 ‰ (downhill)	Trackside
Kv_int	0.77 (no speed dependency)	Trackside (National Value)
Kr_int		Trackside (National Value)
Nominal emergency brake deceleration		Conversion model

Table 4: Conventional passenger train, example of input parameters (Lambda method)

The Figure 13 and Figure 14 here below show the braking distance apportionment obtained with the ETCS on-board configured respectively as a “gamma train” and “lambda train”.

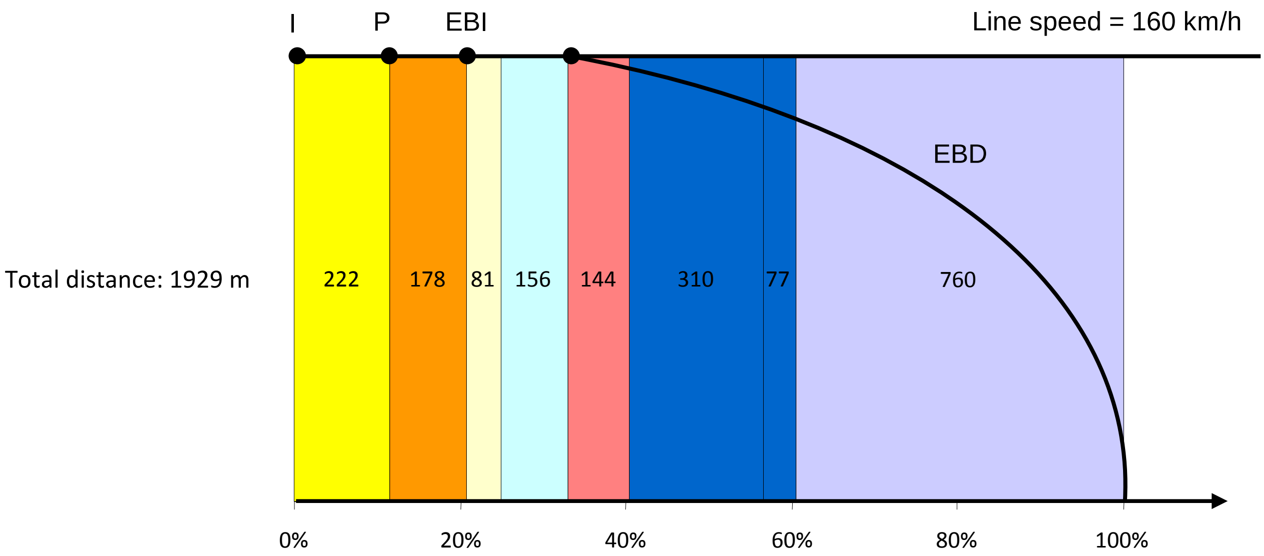


Figure 13: Distance apportionment for Conventional passenger train- gamma approach

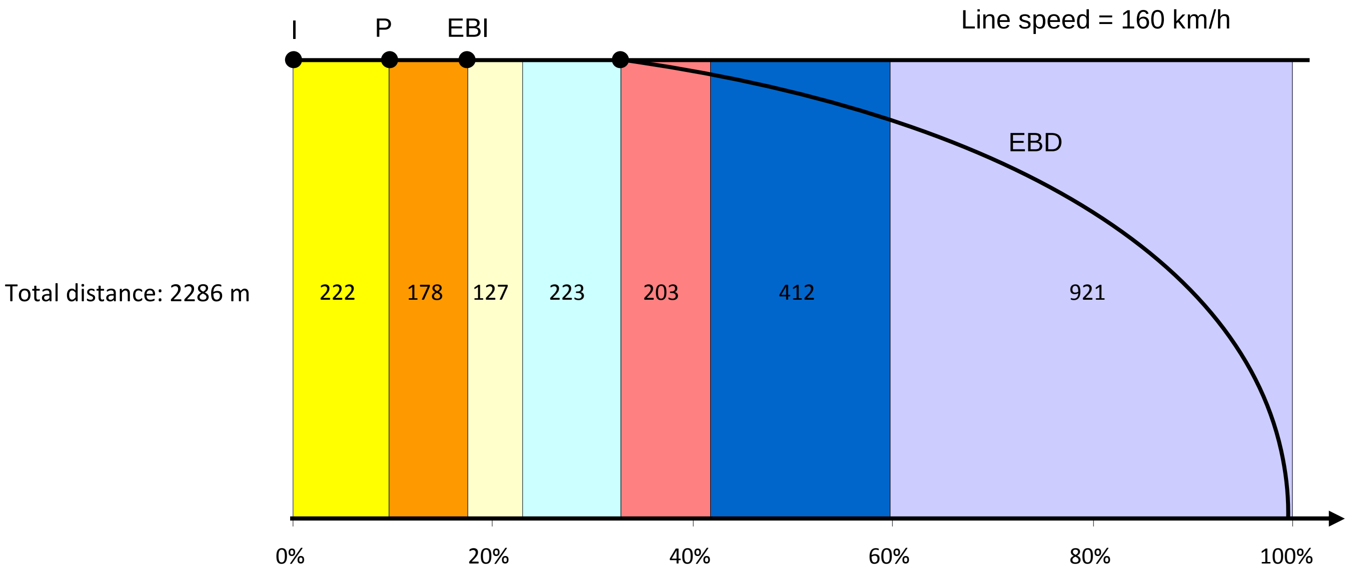


Figure 14: Distance apportionment for Conventional passenger train - lambda approach

5.4. FREIGHT TRAIN BRAKED IN P MODE

The Table 5 includes the input parameters for a freight train braked in P mode, with the braking performance expressed as braked weight percentage.

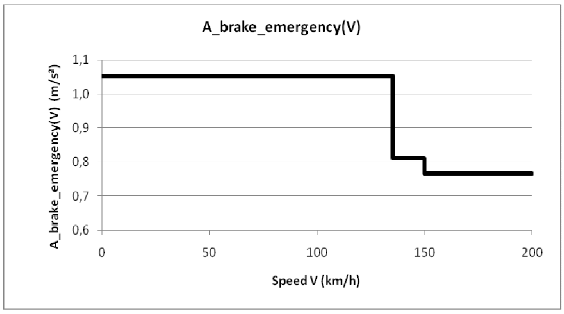
Input parameter	**Value**	**Origin**
Brake weight percentage	130 % (R)	Rolling stock (UIC leaflet 544-1)
Train length	400 m	Rolling stock
Driver time between I and P supervision limits	11.3 s (0.8* eq. service brake build up time)	Conversion model
Driver time between P and EBI supervision limits (no SBI)	4 s	ETCS Fixed value
Speed measurement inaccuracy	2.98 % (160 km/h)	ETCS performance requirement (SUBSET-041)
Emergency brake equivalent build up time	5.0 s	Conversion model
Kt_int	1.1	Trackside (National Value)
Track slope	-10 ‰ (downhill)	Trackside
Kv_int	0.7 (no speed dependency)	Trackside (National Value)
Kr_int	1 (no length dependency)	Trackside (National Value)
Nominal emergency brake deceleration		Conversion model

Table 5: Freight train braked in P mode, example of input parameters

The Figure 15 here below shows the resulting braking distance apportionment.

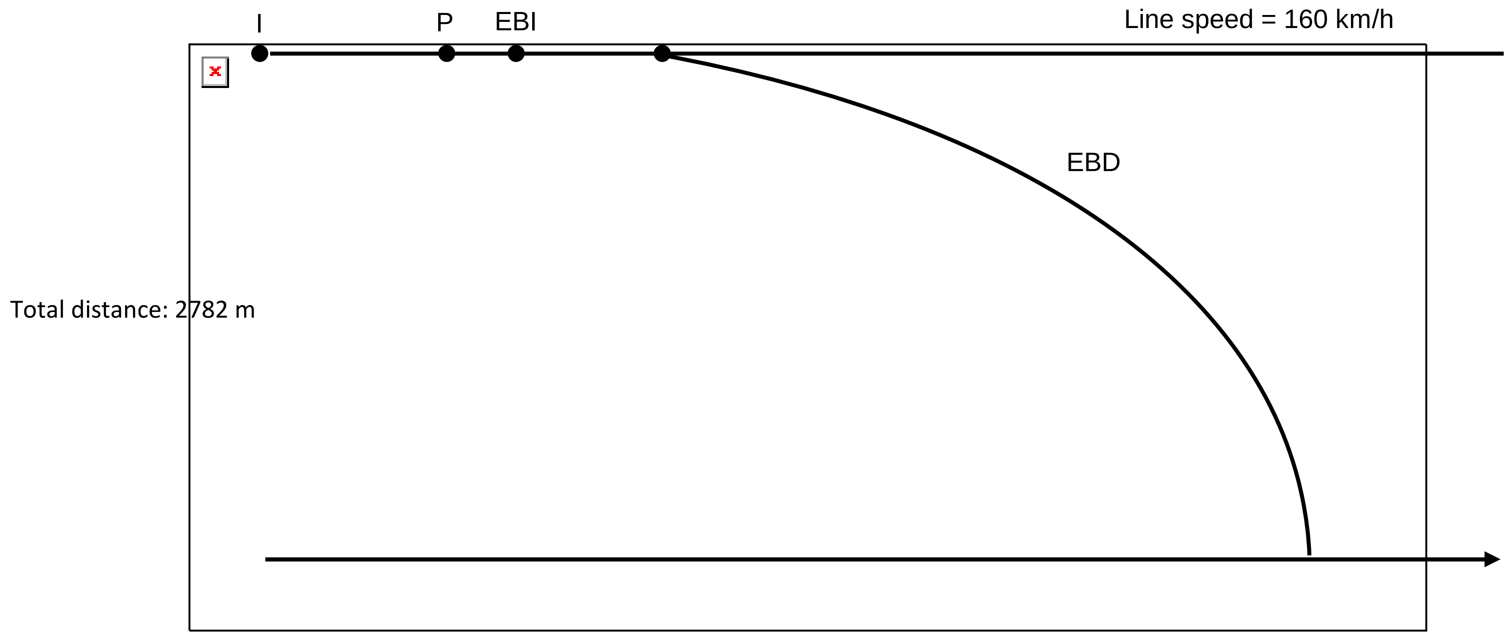


Figure 15: Distance apportionment for freight train braked in P mode

5.5. FREIGHT TRAIN BRAKED IN G MODE

The Table 6 includes the input parameters for a freight train braked in G mode, with the braking performance expressed as braked weight percentage.

Input parameter	Value	Origin
Brake weight percentage	80 %	Rolling stock (UIC leaflet 544-1)
Train length	600 m	Rolling stock
Driver time between I and P supervision limits	15.7 s (0.8* eq. service brake build up time)	Conversion model
Driver time between P and EBI supervision limits (no SBI)	4 s	ETCS Fixed value
Speed measurement inaccuracy	3.49 % (100 km/h)	ETCS performance requirement (SUBSET-041)
Emergency brake equivalent build up time	12.8 s	Conversion model
Kt_int	1.1	Trackside (National Value)
Track slope	-10 ‰ (downhill)	Trackside
Kv_int	0.7 (no speed dependency)	Trackside (National Value)
Kr_int	1 (no length dependency)	Trackside (National Value)

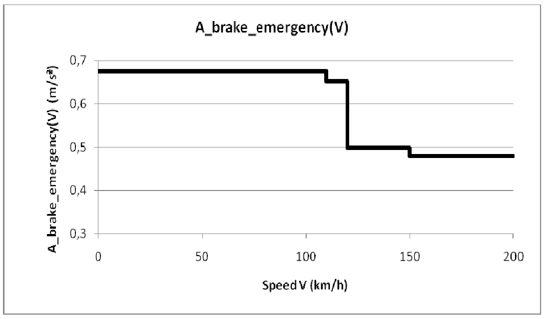
Nominal emergency brake deceleration		Conversion model

Table 6: Freight train braked in G mode, example of input parameters

The Figure 16 here below shows the resulting braking distance apportionment.

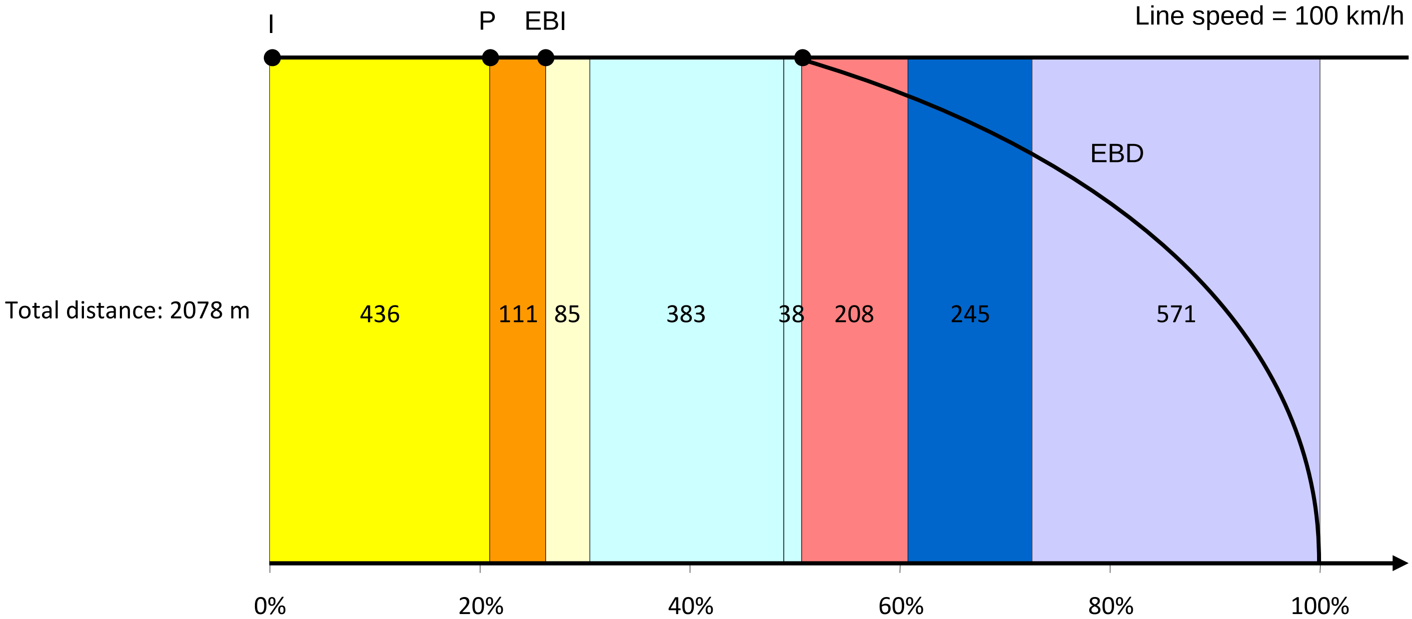


Figure 16: Distance apportionment for freight train braked in G mode