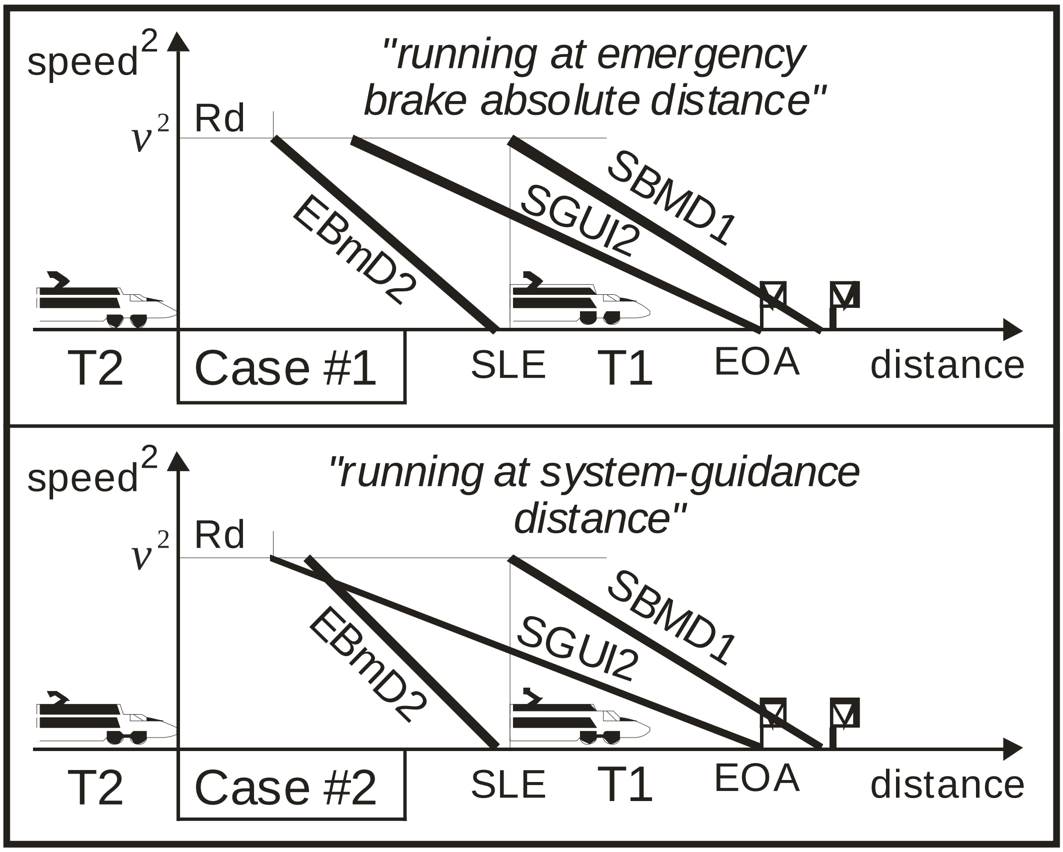

Reducing the headway on high-speed lines

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Abstract

ETCS L2, the European train control system level 2, is standard for providing signalling and automatic train protection (ATP) on new high-speed lines. It does not need physical line-side signals and communication between track and train is done via a dedicated GSM system for railways (GSM-R).

At very high speeds, the headway between trains is mainly determined by the braking performances of the trains. In conventional operation, the distance between the rear of the leading train and the front of the following one must be at least as long as the maximal stopping distance of the following train. This distance is calculated taking into account minimal service brake deceleration. In spite of the division of the track in short block sections, and high-performance interlocking and radio block centre (RBC), practical headways are not shorter than 3 minutes.

The new train operation principle REBAD (Running in accordance with Emergency Brake Absolute Distance), envisioned in this contribution, is based on the ETCS L2 (or L3) ATP system. The main innovation compared with the current systems is that a train doesn't need necessarily a full stopping distance based on service braking in front of it. While both trains brake, the leading train frees up room for the following train. However, in order to fully ensure safety, an emergency stopping distance must be kept free at any time for the following train, to cover the case of an abrupt stop of the leading train. In some situations, the distance to be maintained free should be greater than the emergency stopping distance. Actually, the service braking of the leading train should not lead to an emergency braking of the following one.

This article analyses the safety conditions for running with a headway based on the emergency braking and ambitions to pave the way to further reduce headways on ETCS L2 high-speed lines.

Keywords

Capacity - Headway - Braking curves - ATP - ETCS - HSL - SATO

1. Introduction

The European Train Control System (ETCS) was developed in the first place to offer to the railways in Europe a common Automatic Train Protection (ATP) system in replacement of the multitude of existing ones. In theory, this is needed urgently as more than 15 different and incompatible ATP systems equip the European main rail network (cf. **table 1**), which obviously increases the challenge of interoperability of international train traffic.

	Crocodile (France, Belgium)	KVB, ZUB (France, Switzerland)	INDUSI, PZB (Germany)	ETCS L1 and higher
Transmission system	Electric through mechanical contact	Transponder	Magnetic	Transponder

Table 1: ETCS and some ATP spot transmission (cf. [1][1])

ETCS knows several levels, with level 1 using line-side signals, which are in levels 2 and 3 replaced by signalling in the cabin of the engine driver. This makes levels 2 and 3 (ETCS L2, ETCS L3) very convenient for signalling and ATP on high-speed lines (HSL, cf. **table 2**). ETCS L2 continues to use track-side detection of train occupancy, but ETCS L3 is a level using moving blocks.

	TVM 430 (France)	BACC (Italy)	LZB (Germany)	ETCS L2 and higher
Data transmission	coded track circuit		trackside cable	radio transmission
Data flow limitations	mono-directional		bi-directional	

Table 2: ETCS and high-speed line signalling systems [2]

The introduction of cab signalling, precise positioning and very-frequent bi-directional transmissions on HSL is an opportunity for trying to reduce headway and increasing capacity as a result.

Equation (1) gives a general formula to calculate the minimum technical headway h_{min}.

$$h_{\min} = t_w + \frac{\left(1+\frac{1}{n}\right)\cdot v}{2\cdot d} + \frac{L_o + L_t}{v} + t_i \ \text{[sec]} \quad (1)$$

With: t_w=watching time [sec], n=number of block sections needed by a train to stop from cruising speed, d=safe mean service deceleration [m/s^2], v=speed [m/s], L_o=overlap length [m], L_t=train length [m] and t_i=interlocking time [sec]

[1] Numbers between brackets point to the reference list at the end of the paper

Comprehensive explanations of equation (1) can be found in [3], [4] and many other documents. As soon as v is high and n higher than 5 or 6, h_{min} does not differ significantly from the minimum technical headway obtained by moving block systems (cf. [5]).

$$h_{\min} = \frac{0.6 \cdot v}{d} + \frac{500}{v} + 10 \text{ [sec]} \quad (2)$$

With: d=safe mean deceleration [m/s2], v=speed [m/s], n=5, Lo=100m, Lt=train length=400m, and tw+ti=10sec

Considering **equation (2)** deduced from **equation (1)**, v=300/3.6 m/s and d=1.0 m/s^2, the part 0.6 v/d is 75% of h_{min} and significant increasing of the service deceleration is quite challenging.

Thus, the only way to further reduce significantly the minimal technical headway is to investigate more deeply relative braking distances in normal operation (cf. [3]). This was already said by Alstom in 2004, despite the fact that they dealt incorrectly with the main objections to run in accordance with relative distance (cf. [6] and §.2.2). More recently, RFF, responsible for the saturated HSL Paris-Lyon, confirmed this opinion: "A significant increase in the capacity of the lines will only be possible by taking in account, at least partially, of the relative distance from braking of the trains, rather than the absolute distance as is used in the railway system" [7]. This opinion is also published today by a well-informed magazine [8].

2. Getting over the absolute service brake distance

2.1 Two main objections

Psychologically, absolute service brake distance seems to be an irremovable concept. Indeed, two main relevant objections are commonly made regarding relative brake distances: "When points are to be moved between two trains the second one has to have full braking distance to the points until the points are locked in the new position. Another problem is that in case of an accident of the first train the second train has no chance to stop and is going to collide with the first train. Because of these problems train separation in relative braking distance is only a theoretical idea with no realistic chance to be adopted in railway transportation." [9]

The recent major disaster in Eschede-Germany (the derailment of an ICE which collided with a bridge pillar and decelerated in a couple of meters from 200 km/h to zero) reminds signalling designers to always consider all kind of risks, and specially the risk of consecutive accidents.

2.2 Relative service braking distances but absolute emergency braking distances

Both of those objections, however, can be addressed as it is actually possible to use relative distances without reducing the safety. The main and indispensable condition is to use simultaneously the emergency brake absolute distance. Such distance should be kept free in any case between trains running on the same track in the same direction and between a train and a turnout which is not locked. To provide high reactivity according to speed variations of the first train, the second one has to be driven automatically (SATO). This new mode could be seen as a "Full Control" mode (FC) to be added to other ETCS modes. It has been shown that if the first train does not brake with more than the service brake maximum deceleration (SBMD), the second train could brake safely without use of the emergency brake (cf. [3]).

In this mode the Service Brake Intervention curve (SBI) is no more the First Level Of Intervention (FLOI): The very first level of intervention is a new braking curve, which could be seen as a kind of System-guidance brake curve (SGUI). This curve, as well as the whole brake curve family, is permanently recalculated in order to follow speed variation of the first train. Especially in ETCS L2, adequate filtering should prevent strong changes from braking to traction of the second train at each Movement Authority (MA) change, in case of close train succession.

In this paper, this new operation mode will be called "Running in accordance with Emergency Brake Absolute Distance" (REBAD). This operation mode is presented in [3].

To reduce considerably headways, the emergency brake distance must be short enough, as shown in [3] and in the next chapter. Higher reduction of this distance allows changing the position of turnouts without having to slow down trains. This can be obtained by improving the train braking capabilities. The way proposed here is to use eddy-current brakes consistently.

2.3 Reducing the absolute emergency brake distance with eddy-current brakes

Eddy-current brakes work through train-bound electrical magnets, which are held in place a couple of millimetres above the rail. On the contrary to magnetic rail brakes, they do not touch the rail and thus do not cause any mechanical wear. The deceleration is reached by electric currents which heat up the rail.

Eddy-current brakes (ECBs) have at least two advantages (cf. [10]):

- they are independent of adhesion between wheel and rail, what is specially favourable at high speed and under low adhesion conditions;
- they avoid harder and longer application of conventional friction brakes leading to excessive wear of the pads or overheating.

But they have also two undesirable secondary effects, rail heating and uplift of the track panel.

Rail heating

The effect of heating the rail has to be taken into account in order to avoid track buckling, especially in warm and sunny conditions [11]. Use of extremely stable tracks, e.g. those on a concrete slab instead of using sleepers and ballast, is then recommended to allow higher rail temperature.

If ECBs are not used for service braking, the available temperature gap can serve exclusively the emergency braking. New high-speed train generations have distributed motorization with multiple motors under several carriages, instead of motorized power-heads. This allows high two-directional transmission (acceleration and deceleration) of efforts between train and rail, even in case of low adhesion conditions. So, dynamic brakes could not only restrain the speed on steep slopes as high as 30‰, but could also produce significant deceleration on flat sections. To reach 360 km/h, new HST will develop about 25 kW/t (cf. [12]). Such power allows dynamic brakes to decelerate trains with more than 0.3 m/s^2 for speeds under 300 km/h, at level, and to provide the total service brake requirement under 100 km/h. Only on particular HSL sections, 40‰ slopes need help of another brake system to control the speed.

Uplift of the track panel

The braking effort of ECBs is always accompanied by an attraction effort, which could be very high locally at low speed. If reasonable attraction efforts increase only the axle load to some extent, too high attraction efforts have to be prohibited as they could bend the ECBs on the train side, and uplift the track panel on the track side. The limitation of the attraction effort is therefore necessary to maintain a quasi-constant air gap between brakes and rail and to prevent loss of track lateral stability [10]. For obvious reasons, ECBs are not to be used under about 50 km/h as the deceleration/attraction effort ratio becomes very unfavourable.

2.4 Determining the emergency brake minimal deceleration

The emergency brake minimal deceleration (EBmD) is the sum of three components: ECB deceleration, adhesion-dependent brakes deceleration and aerodynamic resistances. For such high-speeds potential wind effect (e.g. wind in running direction) is considered as insignificant.

Eddy-current brake deceleration

Determining the ECB effort is made on the base of the ECBs of the ICE 3 (cf. [11], [13], [14]), and with the assumption that, at a given speed, the ratio between attraction (Fa) and braking (Fb) efforts is constant, independently of the braking intensity. The idea is to raise the deceleration effort until having a constant attraction effort between 50 and 300 km/h equal to the today maximum attraction effort of ECBs of the ICE 3.

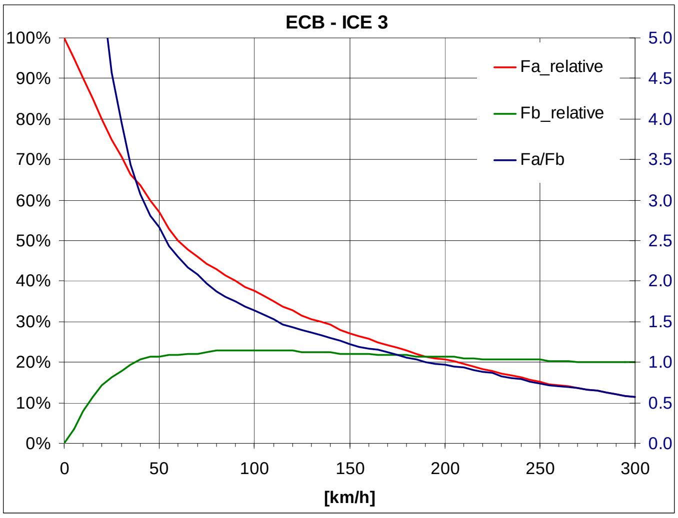


Figure 1: Theoretical characteristic curves of a linear ECB according to [13]

Not only carrying bogies but also motor bogies should be equipped by very high-performance ECBs – this differs from the current situation, where only the non-powered bogies of ICE3 trains are equipped with ECBs. However, the ECB braking effort for a motor bogie would be only the half of the one of a carrying bogie, to limit the axle extra load due to the ECB units. For an ICE 3 equipped with 16 ECB units on carrying bogies and 16 ECB units on motor bogies of very high-performance ECBs, mean deceleration of about 1 m/s^2 from 300 km/h to 50 km/h is expected from ECBs.

That modification, if possible, will lead to electric currents significantly higher than today in ECB coils. Joule losses will increase drastically. However, the emergency deceleration from 300 km/h to 50 km/h will be done in only 40 seconds, what is quite different than long use of ECBs on steep slopes or frequent applications. Further studies will have to deal with the maximal current and coil heating issues of linear ECBs.

Heating of rails remains low, even if many trains have to stop one after the other in emergency conditions. Indeed, each stretch of rail is heated by no more than one train.

Adhesion-dependent brakes

Mean minimal deceleration from 300 km/h to 0 km/h for adhesion-dependent brakes is limited to **0.78 m/s^2**, according to the Case B (emergency braking with certain equipment isolated and unfavourable climatic conditions) of Table 4.1.5c of HSL-RS-TSI [15].

Emergency brake minimal deceleration

The total emergency brake minimal deceleration, function of the speed, takes into account ECB deceleration, adhesion-brake deceleration possibly slightly increased[2], and aerodynamic resistances. According to calculations and assumptions, mean emergency brake minimal deceleration (EBmD) from 300 km/h to 0 km/h can reach the significant **1.5 m/s^2** level.

With use of today's ECBs, EBmD between 300 km/h and 0 km/h is about **1.0 m/s^2**.

With no use of ECBs, EBmD between 300 km/h and 0 km/h is about **0.8 m/s^2**.

2.5 Determining the service brake maximal deceleration

The service brake maximum deceleration (SBMD) is not easy to determine. In order to allow powerful service braking, limiting service brake efforts occurs only in rare situations. In this paper, the value of SBMD is considered as being the double of the minimum deceleration on HSL according to TSI [15]: 1.2 m/s^2 (0-230 km/h) and 0.7 m/s^2 (230-300 km/h). From 300 km/h to 0 km/h, SBMD is about **1.05 m/s^2**. Tests by SBB have shown that 1.2 m/s^2 is

[2] Attraction forces of EBCs improve transmission of efforts between rail and wheels for the same adhesion coefficient.

above the usual service brake deceleration, and of the same order of magnitude than full service brake deceleration for national (IC2000, EWIV) and international (EC) rolling stocks (cf. [16]).

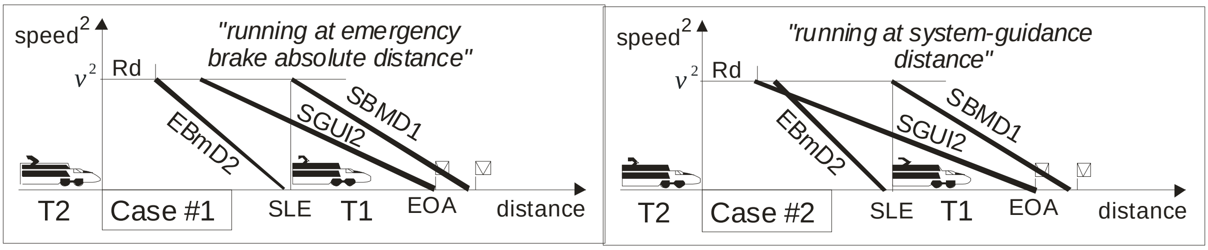
2.6 Determining the guidance curves

The system-guidance curve (SGUI) should also be defined. Future studies should deal with this curve. At this point, the minimum deceleration on HSL according to TSI [15], which is the same of the GUI curve for the TGV POS, is taken into account. From 300 km/h to 0 km/h, mean system-guidance deceleration is about **0.5 m/s^2**.

3. Reducing headways

3.1 Headways with REBAD operation

Technical headways with REBAD operation can be determined for an ETCS L2 configuration according one of the two cases drawn in **figure 2**.



With: Rd: regulation distance, 1: train T1, 2: train T2, EBmD: Emergency Brake minimal Deceleration, SBMD: Service Brake Maximal Deceleration, SGUI: System-guidance deceleration, SLE: Supervised Location in case of Emergency

Figure 2: Two cases in REBAD (FC with ETCS L2)

The condition for being simultaneously in both cases at 300 km/h (83.3 m/s) is given by equation (3):

$$EBmD2 = 0.61 \quad [m/s^2] \quad (3)$$

(with an overlap distance between SLE and the rear of the first train of 100 m,
block section lengths of 1 km each, a SGUI2 of 0.5 m/s^2 and a SBMD1 of 1.5 m/s^2)

So, even with no use of ECBs, the long length of the block section and the low guidance deceleration put the Full Control mode in the "running at system-guidance distance" configuration (**figure 2 - case #2**). With an EBmD2 of 0.8 m/s^2, it's even possible to switch points after the passing of the first train without slowing down the second one[3].

It's is obvious that EBmD, SBMD, system-guidance curves and some margins, are depending on gradients and brake equivalent times (cf. [15], [16], [17], [18]). **Equation 3** should be adapted consequently, even if brake equivalent times of HSTs have practically no impact on such a long braking.

With ETCS L3, the border between the two cases is at EBmD2=1.02 m/s^2. If SGUI is raised, therefore the EBmD2 has to climb significantly to stay in the case #2, and even more to have the opportunity to operate points without impact of this operation on the speed of the second train.

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[3] At 300 km/h 0.8 m/s^2 instead of 0.6 m/s^2 for EBmD allows more than 30 sec for realizing the operation of points without the second train approaches the EBmD curve.

3.2 Comparison of technical headways

For a ceiling speed of 300 km/h and under the following assumptions, it's possible to compare technical headways of different solutions (**table 3**): at level, overlap of 100 m, train length of 400 m, regulation time of 10 sec, interlocking (without points to change) and RBC transmission of MA interval of 10 sec, indication time[4] of 10 sec, SBMD1 of 1.05 m/s^2, and SGUI2 or GUI2 of 0.5 m/s^2.

Operation mode	technical headway
FS ETCS L2 (fixed block section of 1 km length)	120 sec
FS ETCS L3 (moving block)	108 sec
FC REBAD with or without ECBs (fixed block section of 1 km length, EBmD>=0.8 m/s^2)	81 sec
FC REBAD with ECBs (moving block, EBmD>=1.05 m/s^2)	69 sec

Table 3: Technical headways

In conclusion, technical headways are reduced by REBAD by a little more than half a minute.

3.3 More capacity

The practical headway is normally a time value taking into account the technical headway and margins. **Table 4** presents the increase of capacity given in number of train paths by hour and by direction.

	practical headway	number of paths by train and direction according to UIC leaflet 406
TVM 430	4 min	12 (+0%)
FS ETCS L2/3 (optimised block section lengths or moving block)	3 min	16 (+33%)
FC REBAD (optimised block section lengths or moving block)	2½ min	19 (+58%)

Table 4: Practical headways and capacity according to different signalling systems

[4] Time between the reception of an ETCS-Indication information and the bringing into play of the ETCS guidance curve (or ETCS permitted speed curve).

4. Conclusions

Even without eddy-current, the operation with relative service brake distance but absolute emergency brake distance could reduce headways on high-speed lines with optimised block section lengths and for train set having guidance or permitted speed curves with relative low deceleration rates. This semi-automatic train operation could reduce the practical headway of half a minute to 1 minute offering about 19 train paths per hour and direction.

In the future, steeper guidance curve thanks to high-powered motors distributed along the train set, and very performing eddy-current brakes, will allow still more reductions of headways on high-speed lines.

5. Acronyms & Bibliography

Acronyms

AGV	Automotrice à Grande Vitesse
ATP	Automatic Train Protection
BACC	Blocco Automatico di Corrente Codificato
CIR-ELKE	Computer Integrated Railroading – Erhöhung der Leistungsfähigkeit im Kernnetz
EOA	End Of Authority (ERTMS-term)
EBC	Eddy-Current Brake
EBmD	Emergency Brake min Deceleration
EIM	European rail Infrastructure Managers
ERTMS	European Railway Train Management System
EP	Electro-Pneumatic
ETCS	European Train Control System (ERTMS-term)
ETML	European Train Management Layer (ERTMS-term)
FC	Full Control
FLOI	First Line OF Intervention
FS	Full Supervision (ERTMS-term)
GSM-R	Global System for Mobile communications - Railways
GUI	Guidance Curve (ERTMS-term)
HSL	High-Speed Line
HST	High-Speed Train
I	Indication Curve or Indication point (ERTMS-term)
ICE	High-Speed Train manufactured by Siemens
INDUSI	INDUktive ZugSIcherung
IXL	Interlocking
KVB	Contrôle de Vitesse par Balises
LOA	Limit Of Authority (ERTMS-term)
LZB	LinienZugBeeinflussung
MA	Movement Authority (ERTMS-term)
PZB	Punktförmige ZugBeeinflussung
RBC	Radio Block Centre (ERTMS-term)
REBAD	Running in accordance with Emergency Brake Absolute Distance
RFF	Réseau Ferré de France
RS	Rolling Stock
SATO	Semi-Automatic Train Operation
SBI	Service Brake Intervention Curve (ERTMS-term)
SBMD	System Brake Maximal Deceleration
SGUI	System-GUIdance Curve
SL	Supervised Location (ERTMS-term)
SLE	Supervised Location in case of Emergency
TSI	Technical Specification for Interoperability
TVM	Transmission Voie-Machine
UNIFE	Association of European Railway Industries

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