PMC

Lars Schnieder

AN INTRODUCTION TO ETCS

Components – Functions – Operations

ABSTRACT

eBOOK INSIDE

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What you can find in this ABSTRACT

- A quick start on the subject
- Numerous points of contact for further research
- Compact introduction to the structure and operation of ETCS
- Overview of operating modes and technical components
- Preparatory reading for tasks in project planning, development and application of ETCS

Summary

Over the last more than one hundred years, railway systems in Europe have developed with a strong national character. In the past, technical and operational obstacles made cross-border rail traffic difficult or even impossible in practice. As a result, rail transport was increasingly no longer competitive in intermodal competition. The Commission of the European Union recognised this in the mid-1990s and adopted a comprehensive package of measures. This package of measures aims not only at the realisation of the four fundamental freedoms in the European internal market (freedom of movement of capital, goods, services and passengers) but also at high-quality, efficient and economic rail transport.

This book covers the most important aspects of the European Train Control System (ETCS) as part of the European Rail Traffic Management System (ERTMS). Starting from the legal basis, the technical principles of ETCS are presented. The structure and the mode of operation of the different equipment levels as well as the individual components of the vehicle and track equipment are described. On the basis of the operating modes supported by ETCS, it is shown how ETCS can be integrated into the railway operations of the various countries. The presentation of basic technical interrelationships and safety functions creates an understanding of the future uniform European control-command and signalling system.

Foreword

Cross-border mobility in European rail transport has long been characterised by technical, operational and normative obstacles. Different traction current systems, different track or structure gauges, but also different train control and train protection systems were all reasons why the railway was increasingly less competitive with other modes of transport. In the last decade of the twentieth century, the legal framework for building a harmonised railway system in the European Union was created. Since then, comprehensive "harmonised standards" have been created to standardise approval processes for railway signalling systems. In the meantime, these have been revised several times and adapted progressively in the light of experience. At the same time, the European Train Control System (ETCS), a Europe-wide standardised train control and train protection system, was specified. ETCS removes a key technical obstacle in cross-border railway traffic. ETCS increases the competitiveness of the railways by increasing their performance, economy and safety.

My professional activity in the railway supply industry, my teaching experience at universities as well as my professional experience in my consulting and assessment projects shows the need to summarise the principles of the train control and train protection system ETCS in a dedicated publication. This book is intended to give students and practitioners in the rail industry a quick introduction to the topic. In addition, it should provide starting points for further research.

I also would like to thank the manufacturers of railway signalling system for the kind permission to use pictures of practical installations in this book.

Finally, I would like to thank Dr Bettina Guiot for the professional handling of the publication process on behalf of PMC Media. My sincere thanks also go to John Glover who ironed out linguistic discrepancies during his reviews.

PD Dr.-Ing. habil. Lars Schnieder

Content

1 ETCS – History and Motivation

Over the last two centuries, national railway systems have emerged in Europe. In the past, technical and operational barriers made cross-border rail traffic difficult or occasionally impossible in practice. As a result, the railway became less competitive in comparison with other modes of transport. This introductory chapter explains why the introduction of a uniform train control system in Europe is a necessity (section 1.1). Based on this, the goals associated with the harmonisation of train control systems are discussed (section 1.2). Finally, a brief outline of the development of harmonisation activities over time is given (section 1.3).

1.1 The Need for Harmonisation of Train Control Systems

For historical reasons, the European railways developed different technical solutions for train control systems. To this day, railway infrastructure operators and rail transport companies predominantly use their own national systems, with corresponding trackside signals for conventional rail traffic, or a national version of cab signalling for high-speed rail traffic. In some cases even a couple of different train control systems are used by a railway operator. For this reason, more than 20 different train control systems still exist today. Examples include Germany (PZB/Indusi, LZB, ZUB for tilting technology), France (Crocodile, KVB, TVM) and Switzerland (SIGNUM, ZUB 121). This has the following disadvantages:

– *Multiple equipment.* The equipment of vehicles with a large number of train control systems leads to considerable additional investment costs. Furthermore, approval processes are required in every country. This adds considerable cost and is time consuming.
– *Vehicle change at the national border.* Required changes of the locomotive at the national border lead to longer operating times and accordingly extend travel times. This reduces the attractiveness of rail compared with other modes.

1.2 The Goals of Harmonisation of Train Control Systems

The existing problems, especially in cross-border traffic with fragmented markets, triggered the European joint project of European Rail Traffic Management System (ERTMS). Its aim is to create a uniform train control system with the following expectations:

– *Creation of free market access.* Particularly for the public sector, public tendering and the transparent, non-discriminatory award of contracts for the delivery of goods and services is a fundamental right. In the past, competition from different railway signalling system suppliers was not possible due to proprietary signalling system solutions. Harmonised standards (e. g. those created by the European standards organisation CENELEC, Comité Européen de Normalization Électrotechnique) are the basis for the approval of technically uniform systems (ERTMS).
– *Interoperability.* Since passenger and freight trains are increasingly crossing borders and passing through several countries on their way, interoperability is a fundamental requirement for modern railway operations. Existing obstacles to interoperability are track gauges, clearance profiles and traction power supply, but also the train control and train protection systems. Europe-wide, more than 20 different national systems make it impossible to install the necessary antennae under the vehicle and the corresponding displays in the driver's cab for all train control systems. The compatibility of the train control systems creates the technical basis for non-discriminatory network access for different railway operators.

- *Safe operations with a high service quality.* Existing national train control systems often have restrictions regarding the achievable level of safety. In many railway networks, there is a need to replace old train control systems with newer and more reliable systems. For higher speeds due to the difficulty of being able to recognise colour light signals at an early stage, a transition to cab signalling is required. In this case, the automated train control system takes responsibility for the safe operation of the train (Winter et al. 2009).
- *Increasing line capacity.* Railway infrastructure companies have to adjust the capacity of existing infrastructure to meet increasing traffic demand. Since the construction of new railway lines and/or railway stations is cost-intensive, time-consuming or possibly not possible at all, the aim is to exploit the performance of the existing infrastructure by means of an advanced signalling system to reach the technical/physical limits (Bartholomeus et al. 2011 und Eichenberger, 2007). A key to this is – as is already the case with urban rail transport systems today (Schnieder 2019) – a move away from regulating the train spacing from driving at an interval determined by fixed blocks, to driving at an interval where the blocks themselves move (Pachl 2016).
- *Reduction of life cycle costs.* Railway infrastructure follows long-term technology cycles. Investment decisions once made determine the cost base of railway infrastructure companies in the long term. Investment costs (capital expenditure, CAPEX) are reduced through manufacturer-independent standards. A bi-directional radio-based transmission of signalling-related information also makes it possible to dispense with fixed signals or, where appropriate, also with technical systems which detect track vacancy. The resulting massive savings in maintenance (operational expenditure, OPEX) may justify higher initial investment costs for high-performance signalling systems.

The main components of ERTMS are the train control system (European Train Control System, ETCS) and the digital mobile communication system (Global System for Mobile Communication Railway, GSM-R). The focus of this book is the European Train Control System (ETCS). To understand a radio-based train control and train protection system, reference is only made to GSM-R to the extent necessary for understanding ETCS.

1.3 Implementation Steps of Harmonisation of Train Control Systems

The Commission of the European Union recognised the existing deficits in the mid-1990s and adopted a comprehensive package of measures to restructure the railway sector. In addition to realising the four basic freedoms in the European internal market (freedom of movement of capital, goods, services and people), this package is aimed at quality, efficient and economical rail transport. As a result, several railway packages were enacted, which aim to harmonise the legal framework for the construction and operation of railways within the European Union. In the process of specifying these legal requirements, the development of a uniform specification of the European Train Control System began.

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3.2.3 Transition to ETCS Level 0

The transition from ETCS Level 1 to ETCS Level 0 is shown in Figure 3.6. The exit to ETCS Level 0 takes place in several steps:

- The vehicle passes *balise group 1* and receives a movement authority and route information. In order to prevent the vehicle from entering the area behind the area limit at too high a speed; the route information can also include route areas behind the border.
- *Balise group 2* announces the release from the current ETCS level. If the front of the train travels the area in front of the area boundary, the driver is asked to confirm. If the driver confirms the transition, the area boundary is crossed at the speed permitted for this. The vehicle switches to equipment Level 0 and to UN mode (Unfitted; monitoring the maximum permissible speed for this mode). If the driver does not confirm this, the vehicle crosses the area limit at the permitted speed.
- *Balise group 3* commands the vehicle to ETCS Level 0. The driver must now acknowledge within five seconds at the latest. If this does not happen again, a service brake is triggered, which can only be cancelled by acknowledging the change in equipment level.

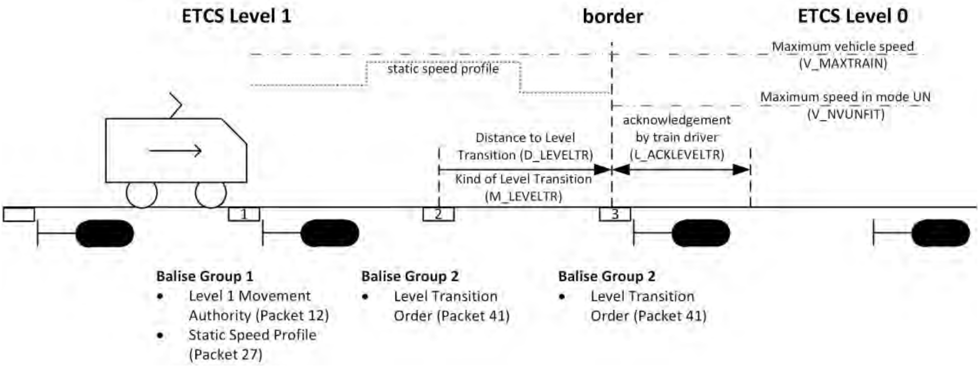

Figure 3.6: Transition from ETCS Level 1 to ETCS Level 0

3.2.4 Transition to and from ETCS Level NTC

The transition from a track section equipped with ETCS to a track section equipped with a national train control system is explained below. The transfer of safety responsibility from the ETCS to the national train control system takes place in the following steps (Dräger 2004):

- The request to activate a specific STM is transmitted from track to train via an "announcement balise". The driver is informed of the receipt of this command by a display on the driver's cab display (UNISIG SUBSET 35).
- The ETCS on-board unit commands the selected STM from the operating state "Cold Standby" (CS, receiving device switched off) to the operating state "hots standby" (HS). This means that the STM is authorised to activate its transmitting and receiving antennae in order to exchange information with the trackside equipment of the national train control system. It also now receives status information from the interface to the train control and management system (TCMS) and from the interface to the brake system. After the STM has reported back to the ETCS on-board unit that it is now in the "hot standby" operating state,

it can transfer its system-related parameters (speed and distance) to the ETCS on-board unit. The STM has a time window of 10 seconds to report the status of "hot standby" to the ETCS on-board unit. If it exceeds this time window, it is deemed to have failed for the ETCS device (UNISIG SUBSET 35).

- The STM transfers parameters for speed restrictions to the ETCS on-board unit so that these parameters can be taken into account by the ETCS on-board unit when calculating the permissible driving speed. The new system speed for travel with the national train control system and the distance to the location along the track at which the system speed is to be reached can be transmitted. The maximum speed at which the STM wants to take over control of the train is transmitted as a further parameter. This speed is used in the ETCS on-board unit for speed monitoring during the transition, i.e. in the time from the transfer of the safety responsibility from ETCS to the STM until the STM has reported back to the ETCS as "data available" (DA) (UNISIG SUBSET 35).
- So far, the driver has only been informed that he is approaching a transition location. From a distance before the transition defined in ETCS, the driver is prompted to acknowledge the change to the national train control system. He can comply with this request before the transition location and in a time-dependent area after the transition (5 s). If the driver does not acknowledge the request by this point in time, braking is initiated by the ETCS on-board unit (UNISIG SUBSET 35).
- When the transition location is reached, which can be the balise or the expiry of the distance to the transition which is specified in the announcement balise, the ETCS on-board unit commands the STM to the "data available" (DA) state. The STM must comply with this command within five seconds. If the status message does not arrive within the predefined time, the ETCS on-board unit triggers a safety-related reaction and the STM is deemed to have failed. Until the STM reports back the status "DA", the ETCS on-board unit still monitors for the previously transmitted maximum speed (UNISIG SUBSET 35).
- After the STM reports back the status "DA" to the ETCS on-board unit, the STM also has active access to the interface to the train control and management system (TCMS), the braking system and the driver's cab display. The system transition is now complete (UNISIG SUBSET 35).

The transition from a track section equipped with a national train control system to a track section equipped with ETCS is explained below. The transfer of safety responsibility from the national train control system to the ETCS takes place in the following steps:

- If the vehicle is under the supervision of a national train control system (STM), it is also possible to have a transition to ETCS while the train is running via an announcement balise and a subsequent transition balise. During this transition, the driver is informed about the announced transition.
- In the further course of a transition to ETCS Level 2, the ETCS on-board unit will now establish the radio connection with the radio block centre (RBC) and the vehicle will be considered in the determination of movement authorities (MA) after the "test activities" have been completed.
- At a defined distance before the transition, the driver is again asked for an acknowledgment, which can take place up to five seconds behind the transition location. If the acknowledgment is not made within this time, the ETCS on-board unit triggers a service brake.
- In order for the transition from the national train control system to the ETCS to take place without disruption, an ETCS movement authority (MA) which extends into the area beyond the border must be present on board the vehicle before reaching the location of the transition. ETCS then issues an "unconditional order CS" at the transition location, which

- A distance and speed measurement based on the counting of axle revolutions depends on the set wheel diameter and is therefore subject to a certain degree of uncertainty. The wheel diameter must be regularly re-parameterised in the on-board unit due to wear or maintenance activities including the turning of the wheel sets). If the wheel diameter is not adjusted, the distance actually travelled is less than that measured. If the diameter is not corrected when wheels are replaced, the distance travelled is that much greater than that measured.
- Wheels can also slip or slide on the rails. This depends on the traction force, but also how the rails are affected by various weather conditions.

In order to avoid the disadvantage of inaccurate localisation, the ETCS system manufacturers use supplementary sensor systems. Accuracy is increased by the use of sensors independent of the wheel-rail contact. In addition to the most accurate possible distance and speed measurement, a correct position of the vehicle is required. This is achieved by the synchronisation of the speed and distance measurement at fixed points (Eurobalises). This section describes the principles of localisation in the ETCS.

6.2.1 Assignment of a Coordinate System to Eurobalises

A balise group consists of one and up to eight Eurobalises. In each Eurobalise the respective number of the Eurobalise (1-8), the number of Eurobalises in a balise group and an identification number of the balise group are stored. Usually two Eurobalises are laid one after the other to derive the direction of travel. Additional Eurobalises can be installed if more data needs to be transmitted from track to train than is possible with a single Eurobalise or if they need to be duplicated in order achieve a higher availability. Eurobalises play a major role in the positioning of the vehicle. All information relevant to safe vehicle movement (movement authorities and speed profiles) is always transmitted in relation to a balise group. When planning these trackside data points, it must therefore be ensured that the position of a balise group is known with sufficient accuracy. A Eurobalise can contain information for both directions of travel (normal or reverse).

6.2.2 Linking

Balises contain the definition of location reference points, which serve as a common coordinate system for the interaction of trackside and on-board equipment. Reference variables for the vehicle such as speed profiles or movement authorities are always transferred in relation to a clearly referenced balise or balise group. In the course of the application-specific configuration of the balise telegrams, it must therefore be ensured that the position of the balises is known with sufficient accuracy. Linking is required for two purposes:

- *Error detection.* A balise (group) refers to neighbouring balises (groups) with target distance and a unique identifier. If the train does not pass the announced balises (groups) within a tolerance range around the target distance, the ETCS on-board unit triggers a safety-related reaction.
- *Correction of the location error.* Due to the physical effects of the wheel-rail contact, the speed and distance measurement of the vehicles is subject to increasing uncertainty depending on the distance travelled (slipping and sliding). Regular crossings of balises (groups) give the vehicle fixed points with which the confidence interval can be corrected for the true position of the train (see Figure 6.1). The location error is not reduced to zero when

a balise is passed over. In addition to the positioning accuracy of the balise, this is due also to the fact that the pyramid-shaped spreading cone of the balise antenna can have already received a telegram from the vehicle before the vehicle is vertically above it.

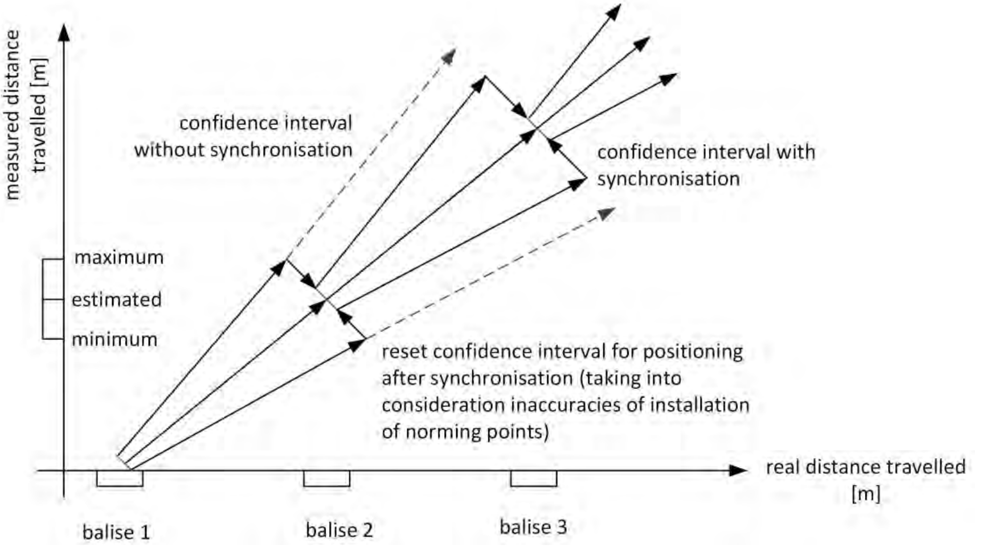

Figure 6.1: Correction of the location inaccuracy by means of linking information

6.2.3 Repositioning

When a train arrives at a station, the signal aspect cannot always be used to determine clearly which station track the train will enter. Since each of the routes possible from the entry signal has its own speed specifications, only the most restrictive movement authority and the most restrictive route information (speed profile) can be transmitted from track to train at the entry signal. In such cases, so-called respositioning is used. The movement authority received at the entry signal is updated when the train has reached a clearly defined position in the station (see Figure 6.2).

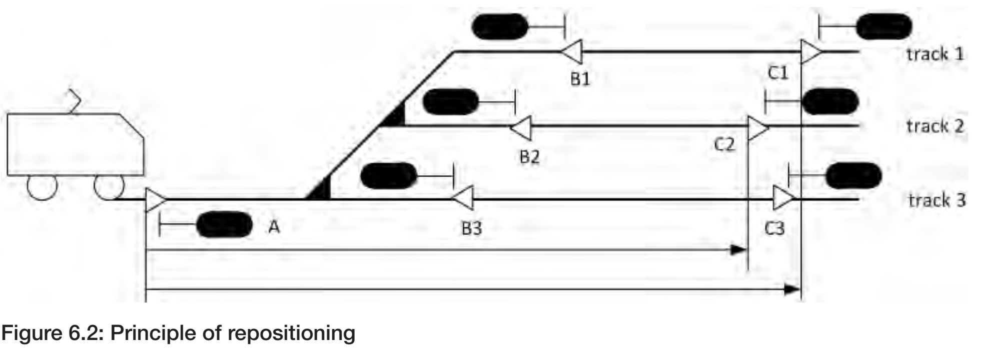

Figure 6.2: Principle of repositioning

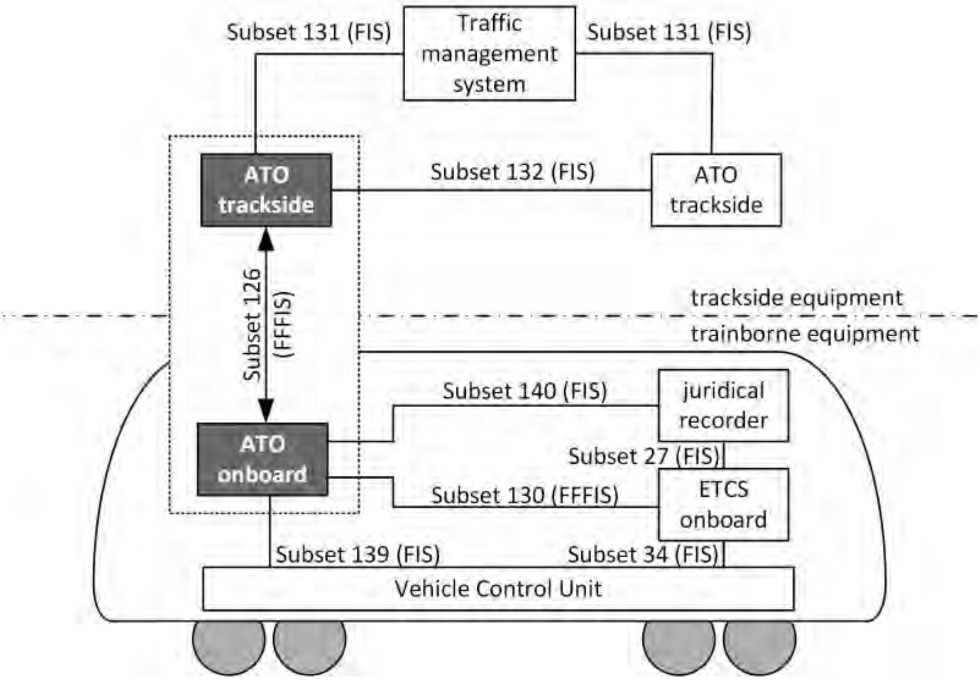

Figure 7.1: Reference architecture "ATO over ETCS" (grade of automation 2)

7.3 Increasing Line Capacity with ETCS

In order to meet the continuously increasing traffic demand and to be able to further expand a very intensive timetable, ETCS can make a contribution to increasing line capacity. The focus is on the *technical headway* ($t_{headway}$) (Eichenberger and Spori 2013). The headway describes the minimum distance between two trains, so that the following train never has to brake because of the previous train (Pachl 2016). The movement authority for the following train must therefore be available not later than at the brake application point. Braking as a result of the topology (e. g. curves, points using the diverging branch) should be avoided. In contrast, the *operational headway* is considered in the timetable (Heister et al. 2005). The *operational headway* is derived from the technical headway by adding an additional buffer time, which serves as an operational reserve.

The technical headway can be calculated very easily for constant speeds (Eichenberger and Spori 2013). According to Figure 7.2, the distance between two trains following each other at speed v is made up of train length d_{train}, the overlap $d_{overlap}$, the length of the track section between the signals $d_{section}$, the train's braking distance d_B and the system times, the route setting time t_{set} and release time $t_{release}$. The route setting time t_E includes all times from the initiation of route setting until the time the movement authority has been received on the vehicle. This includes the times required by the interlocking and the radio block centre (RBC), as well as the data transmission via GSM-R. By contrast, the release time $t_{release}$ includes the times from the section's clearing by the train to the completed release of the route, so that the next route can be set (Figure 7.2).

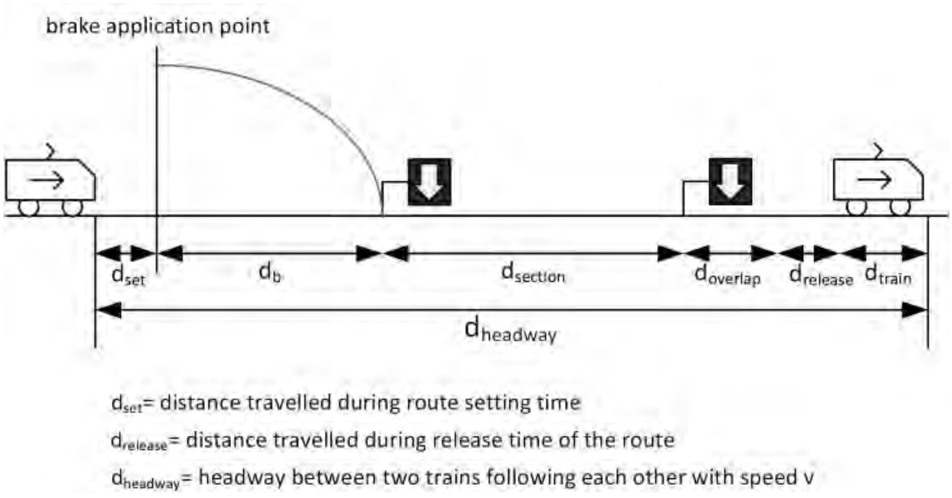

Figure 7.2: Elements of the technical headway (based on Eichenberger and Spori 2013)

Figure 7.3 shows the different approaches to increasing line capacity using ETCS. The individual contributions are described below.

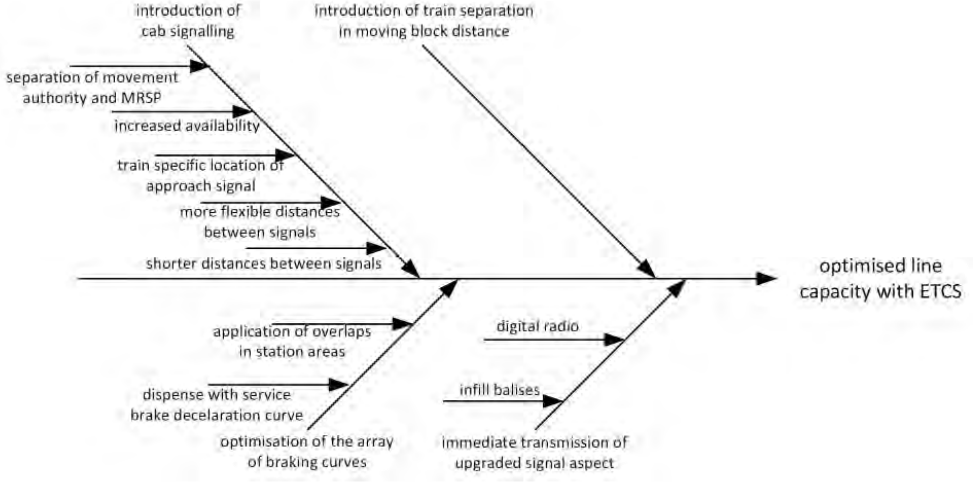

Figure 7.3: Contributing factors to increased line capacity using ETCS

The fulfillment of all conditions to be considered in the planning of trackside signals often complicates their optimal arrangement. By contrast, in cab signalling with ETCS, there are hardly any restrictions regarding signal locations and minimum distances between the signals. The advantages of a transition from trackside signals to cab signalling are shown below:

– *Cab signalling is the technical basis for the introduction of short block distances.* With fixed signals, the block distances have narrow limits, since it is not possible to divide the track into two (or more) small sections. Too small block divisions would lead to a “signal forest”,

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has long-standing professional experience in railway signalling. The specification and demonstration of reliability, availability, maintainability, safety and security (RAMSS) has been a focus area in his academic career. He received his PhD degree at the Technical University of Braunschweig. He later obtained a post-doctoral qualification in transportation systems engineering at the Technical University of Dresden, where he teaches in the faculty of transport and transport sciences.

In his current position as Chief Operation Officer (COO) at ESE Engineering und Software Entwicklung GmbH he is responsible for planning and directing conformity assessment activities of an inspection body accredited according to DIN EN ISO/IEC 17020 2012. As an independent safety assessor Lars Schnieder supports the customers with the conformity assessments in the fields of both functional safety and IT security of railway applications. As a technology consultant he works in close partnership with clients, advising them how to comply with the requirements of laws and standards applicable to railway operations.

What you can take with you from this ABSTRACT

- Knowledge of the legal basis and specifications for the European Train Control System (ETCS)
- Understanding of the various system equipment levels of ETCS
- Knowledge of the various on-board and trackside components of ETCS and the interfaces between them
- Understanding how the different modes of operation can support railway operations

Bonus for free: The e-book is available upon registration. Users of devices with a pdf reader (PC, tablet, smartphone) will have electronic access to all the terms and references through a search function.

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