COMPENDIUM on ERTMS

European **R**ail **T**raffic **M**anagement **S**ystem

edited by UIC
under the coordination of **Peter Winter**

Eurail press

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European **R**ail **T**raffic **M**anagement **S**ystem

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Preface by the Chairman of the UIC ERTMS Platform

The development of ERTMS under the patronage of the European Commission began in 1989 in the context of plans for a European high-speed railway network. This year we celebrate 20 years of work in this area, together with all the contributions of the people who have worked on the project to successfully overcome the problems of expanding and bringing to maturity the main ERTMS sub-systems ETCS and GSM-R. In terms of traffic management, the roll-out of the Europtirails concept is in full swing. Concerning signalling, a comprehensive European project entitled “Integrated European Signalling System” comprising 30 partners from railways, manufacturers and academia started in October 2008 in order to Europeanise the ERTMS project’s last frontier.

There is no longer any doubt as to the key role of ERTMS for the revitalisation of the European railways, and it is generally recognised that the point of no return on this road has been passed.

The International Union of Railways is extremely pleased to distribute this ERTMS compendium on the occasion of the ERTMS World Conference 2009 in Málaga, Spain, one of the EU Member State where ERTMS has most thoroughly and successfully been implemented, mainly on new high-speed lines.

The UIC ERTMS Platform, which I have the honour to chair, was established in 2006 to share experience on ERTMS implementation and determine strategies for a feasible migration. Its key task is to contribute to the promotion of a viable migration strategy for ERTMS which is compliant with the rail sector’s interests as a whole.

In this book, a team of authors actively involved in the ERTMS development process for many years provides an introduction to and overview of the current status achieved, including the consolidation to be brought about by the new formally approved baselines for the ETCS and GSM-R specifications.

I hope that this book will help improve understanding of the complex ERTMS concept and facilitate its further implementation, thus rendering the railways more attractive and competitive.

Thank you, Peter.

Chairman of the UIC ERTMS Platform
Michele Elia

Málaga, 31 March 2009

Preface by the main author

During the last 20 years, the second half of my career as a professional engineer in the rail sector, I have had the privilege of being actively involved in the development of ERTMS, an initiative jointly driven by the railways and manufacturers under the auspices of the European Commission. This broad Europeanising process will bring about profound reform of the rail system. The key driving factors are interoperability in the context of open-access infrastructure; safety and performance in rail operations; an open and competitive multi-vendor market for procurements; and cost efficiency over the system life-cycle as a whole. After a long history of national traditions in rail traffic management, a new harmonised European concept is becoming a reality, combining innovative approaches in technology, processes and the rules and regulations underpinning these.

In the course of ERTMS development, many difficult and conflicting issues have had to be faced by the numerous parties involved in the harmonisation of a multitude of completely different and incompatible points. Some of these controversial aspects are:

- National traditions versus European unification
- Integrated versus separated management of rail infrastructure and train operations
- Focus on high-speed versus universal application to all kinds of train services
- Users' interests versus suppliers' interests
- Infrastructure managers' interests versus operators' interests
- Signalling industry's interests versus GSM-R industry's interests
- Rolling stock suppliers' interests versus signalling suppliers' interests
- Short lifecycles in modern telematics versus long lifecycles in railway technology
- Technology versus rules and regulations
- Line side signalling versus cab-signalling
- Line side-based positioning versus train-based positioning
- Maximum safety integrity level across the board versus differentiated safety on existing lines achieving at least the same level as ensured by legacy systems
- Short-term benefit versus long-term benefit.

It has taken a long time to reach a common understanding on the scope of traffic management in the rail system, since traffic management goes far beyond traffic planning and dispatching, including as it does signalling, control-command and train communications, all of which have strongly rail-specific and highly safety-critical features.

This compendium is intended to introduce the reader to the complex ERTMS concept by giving an overview of all the relevant sub-projects. I hope it will help facilitate the work of all parties and players involved in the further generalised roll-out of ERTMS and thus benefit a safe, high-performance and sustainable rail transport system.

I would like to thank warmly all those who have contributed to the production of this book, especially the co-authors and the numerous proof-readers.

Berne, 31 March 2009

Peter Winter

Honorary Professor, Doctor in Engineering
Peter Winter

1 Introduction

Peter Winter

1.1 Traditional methods and means for rail traffic management

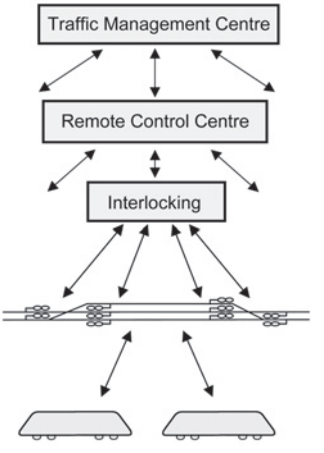

Figure 1.1: Functional structure of the rail traffic management system

The functional structure of the rail traffic management system is outlined in a very simplified and generalised way in the figure 1.1 on the right.

Several layers can be distinguished. In this hierarchy, the top layer deals with the strategic dispatching of trains and traffic planning for the whole geographical area of the system. Methods and means used are similar to those applied for other means of transport and do not affect directly the safety of train operation or the interoperability. At the next lower level, the signalling comprises the far more rail specific and safety relevant devices for remote control, the interlockings and the outdoor equipment along the track. The bottom level consists of the trains which are linked to the fixed installations by means of train control-command devices. By nature, the latter are strongly relevant for the interoperability between trains and the infrastructure. As in every other production system, there is a need for communication by voice and increasingly data based within and between each of the layers. This is achieved by fixed networks and – especially between infrastructure and trains – by wireless radio communication which is also relevant for interoperability.

1.1.1 Train dispatching and traffic planning

Originally, train operation was monitored at station level. In the 1950s dispatching centres were installed for the most important lines, where the movement of the trains was reported by telephone from the various stations and registered manually on paper by traffic controllers (see figure 1.2).

Figure 1.2: Traditional working place of a traffic controller

Since the 1980's, IT tools have been introduced to support the functions of timetabling, route planning and tracing of the trains in normal and degraded situations. The huge progress in general IT has allowed these processes to be automated to a large extent [1.a]. Paperless work with flat screen man-machine interfaces has become a state of the art standard as in many other sectors. Until now, these systems have basically been procured and operated at the national level. International cooperation is facilitated by the fact that many parameters relevant for timetabling, e. g. train numbering, have been harmonised by means of UIC codes.

1.1.2 Railway signalling

For safe and fast train running on lines and in stations, various methods and signalling technologies have been introduced over the years, using different kinds of signals for transmitting the information about movement authority and/or allowed maximum speed to the driver [1.b, 1.c]. These means have been developed basically at the national level with different types of signals and underlying philosophies. The range goes from semaphore, colour light code to speed indication by means of digital number (figure 1.3). Today it seems practically impossible to harmonise this panoply of devices and underlying rules and regulations.

Figure 1.3: Examples of lineside signals

Originally the signals (or flags) were activated locally. Later, interlockings were introduced for the control of signals within a certain area. Different designs have been developed in mechanical, electro-mechanical, relay or computer technology. In many European railways, there exists still a great variety of such devices which are highly relevant for safe operation of trains (figure 1.4).

Figure 1.4: Examples of non computerised interlockings in different technologies

For one or two decades, the design, engineering and operation of interlockings has been covered by general European CENELEC norms. However, de facto no European standardisation and unification has been achieved.

Track vacancy proving is another vital signalling functionality. Originally this had been achieved by station agents observing “physically” every train as it passed through the station. Later, different types of on-track technical device were introduced to automate this function: treadles, track-circuits and/or axle counters. These technologies, with elements on the track-side, have been fundamental to the development of railway signalling philosophy based on fixed block sections. For the block control between stations a step by step evolution took place from manual operation towards fully automatic control. Since the 1950’s, relay based and later computerised devices have been introduced for the remote control of complete interlockings. Here too, there has been until now a lack of European harmonised operational and technical standards.

Treadle Track circuit Axle counter

Figure 1.5: Examples of outdoor equipment for track vacancy proving

1.1.3 Train control-command

1.1.3.1 General characteristics and extent

Not surprisingly, the efforts for European standardisation originated in the field of control-command systems which are highly relevant for the interoperability between trains and infrastructure. These systems are necessary for supporting the driver in the observation of lineside signals or replacing the latter completely by in cab signalling. The following table1.6 illustrates that currently about 20 different and non interoperable systems are in use. Some of them are very

Country	CC-System (status 2003)	Functionality	Technology used for data transmission
Austria	PZB/Indusi	discrete speed supervision	intermittent/inductive coil
	LZB	cab signalling	continuous/cable loop
Belgium	Crocodile	warning	intermittent/galvanic contact
	TBL1	stop	intermittent/inductive coil
	TBL2	cab signalling	intermittent/inductive coil
	TVM	cab signalling	continuous/track-circuit
Bulgaria	Ebicab	continuous speed supervision	intermittent/transponder
Czech Republic	LS	discrete speed supervision	semicontinuous/track-circuit

Table 1.6: Characteristics of the various European legacy control-command systems

Country	CC-System (status 2003)	Functionality	Technology used for data transmission
Denmark	ZUB 123	cab signalling	intermittent/transponder and optional semicontinuous/cable-loop
	HKT	cab signalling	semicontinuous/cable-loop
France	Crocodile	warning	intermittent/galvanic contact
	KVB	continuous speed supervision	intermittent/transponder
	TVM	cab signalling	continuous/trackcircuit
Germany	PZB/Indusi	discrete speed supervision	intermittent/inductive coil
	ZUB 122/262	tilt and speed supervision	intermittent/transponder
	LZB	cab signalling	continuous/cable-loop
Great Britain	AWS/TPWS	discrete speed supervision	intermittent/inductive coil
	TVM	cab signalling	continuous/track-circuit
	TBL	cab signalling	intermittent/transponder
	Selcab	cab signalling	semicontinuous/cable-loop
	TASS	tilt and speed supervision	intermittent/transponder
Hungary	EVM	discrete speed supervision	semicontinuous/track-circuit
Italy	BACC	discrete speed supervision	semicontinuous/track-circuit
	SCMT	continuous speed supervision	intermittent/Eurobalise
	SSC	discrete speed supervision	intermittnet/transponder (microwave)
Luxembourg	Memor II+	warning/stop	intermittent/galvanic contact
Netherlands	ATB EG	discrete speed supervision	semicontinuous/track-circuit
	ATB EG+NG	continuous speed supervision	intermittent/transponder
Poland	SHP	warning	intermittent/galvanic coil
Romania	Indusi	discrete speed supervision	intermittent/galvanic coil
Serbia	Indusi	discrete speed supervision	intermittent/inductive coil
Slovakia	LS	discrete speed supervision	semicontinuous/track-circuit
Slovenia	Indusi	discrete speed supervision	discontinuous/inductive coil
Spain	ASFA	discrete speed supervision	discontinous/inductive coil
	Ebicab	continuous speed supervision	discontinuous/transponder
	LZB	cab signalling	continuous/cable-loop
Sweden	Ebicab	continuous speed supervision	discontinuous/transponder
	Radioblock	continuous speed supervision	continuous/analogue radio and discontinuous/transponder
Switzerland	Signum	warning/stop	discontinuous/inductive coil
	ZUB 121	continuous speed supervision	discontinuous/transponder and optional semicontinuous/cable-loop

Table 1.6: Characteristics of the various European legacy control-command systems

old and simple. However, even in course of the last 30 years, at least three completely different systems for cab signalling in the context of high-speed train operation have been introduced. It is also remarkable that in certain countries several systems of different age, functionality and technology are in use. The table does not show to what extent two or more national systems are overlaid either on track-side or on the traction units.

There are big differences regarding the extent of the different types of legacy systems. Most widely installed are the PZB/Indusi, Crocodile and AWS/TPWS systems which are all in old conception and technology with relatively simple functionality. The systems used uniquely by smaller networks are numerous, however by their nature of limited extent (figure 1.7).

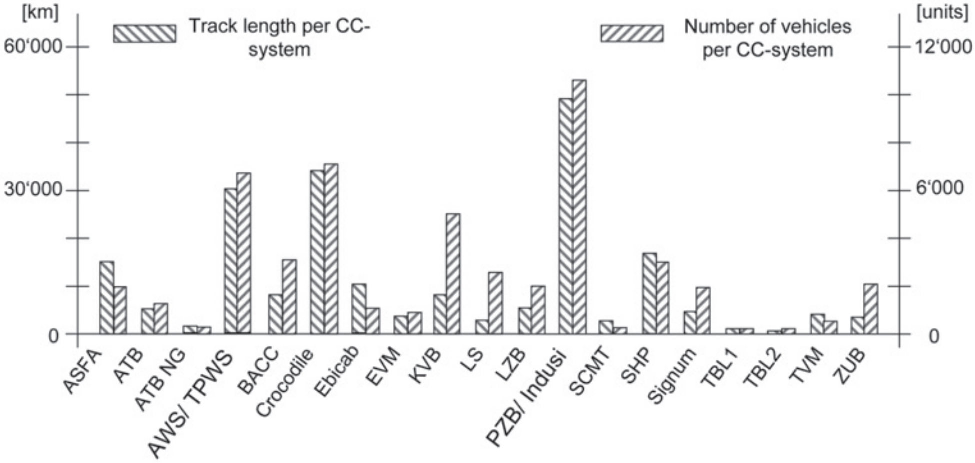

Figure 1.7: Extent of the various types of legacy control-command systems

1.1.3.2 Functionality

The functionality of the various types of control-command systems ranges from simple warning in case of transition of a warning signal, automatic stop when passing a signal at danger, discrete supervision of speed against certain maximal values at certain locations (speed traps), continuous or semi-continuous speed supervision in the background, to cab signalling with continuous indication and enforcement of the maximal allowed target speed. [1.d].

As shown in the following figure 1.8, in Europe legacy systems with discrete speed supervision (i.e. supervision of a few speed levels) are most common. The number of lines and vehicles with cab signalling functionality is relatively small. On the other hand, there is still a considerable amount of track and vehicles not equipped at all with control-command systems.

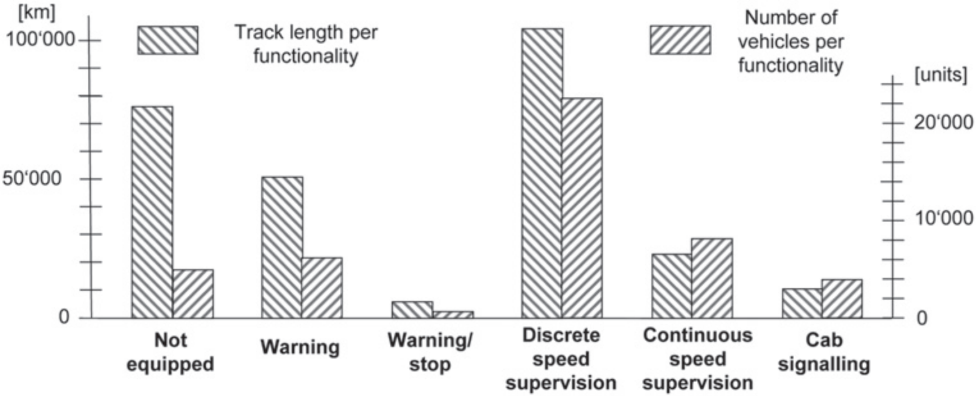

Figure 1.8: Extent of the different classes of functionality of the legacy control-command systems

1.1.3.3 Technology for track – train data transmission

For the various legacy control-command systems, there exists interdependency between the technology used for the data transmission between track and train and the functionality. In the course of years, the technological progress allowed the transmission capacity to increase from a few codes towards extended telegram messages. Thereby the geographical length of the data transmission area could be increased from originally a few decimetres (intermittent transmission) to seamless coverage of compete line sections (continuous transmission). Regarding the track to train data transmission, the following four families of legacy control-command systems can be distinguished:

– **Intermittent data transmission with galvanic contacts or inductive coils:** systems ASFA, AWS/TPWS, Crocodile, PZB/Indusi, SHP, Signum.
  Figure 1.9 illustrates the example of the AWS/TPWS system. The trackside equipment consists of a permanent AWS magnet and arming/trigger loops at the signal for the stop function as well as in warning distance before the signal for the over-speed trap function. These loops are energised by means of feeder cables from the signal control units. The loops of the over-speed sensor send pulses to the on-board receiver which measures the time delay between them and activates the brakes if this goes below a fixed critical value. The warning functionality is activated by the AWS magnet. Then a bell will sound for 1 second and a visual indicator will show a full black disk. If there is no information from the arming/trigger loop at the signal, a horn will sound continuously and – without a driver reaction – AWS will automatically stop the train. If the driver reacts by pressing a button, then the horn will stop and the on-board indicator disc will display a black-yellow aspect in order to remind the driver of the caution aspect displayed by the lineside signal. At the next signal, the first magnet restores the indicator to the all black position.

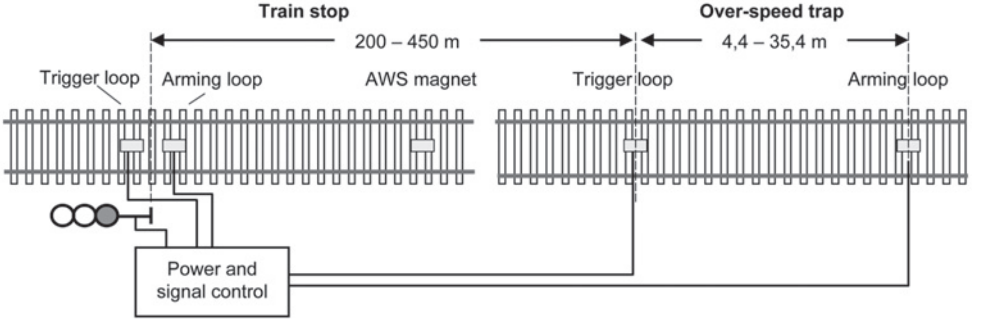

Figure 1.9: Schematic track-side layout of the AWS/TPWS system

  The functioning of the other systems in this family is similar. Over time, for some of them, the functionality has been slightly improved as a consequence of severe train accidents by making maximal use of the data transmission capability of the underlying intermittent transmission devices. For instance the AWS has been extended towards TPWS, the Crocodile towards DAAT or Memor II+, Indusi towards PZB and the original warning Signum towards warning/stop Signum. Despite of these extensions, the functionality of this oldest generation of systems remains limited compared to the newer generations of legacy control-command systems or to ETCS. As will be shown later, ETCS in level 1 with limited supervision could easily mirror the functionality of these “grandfather” systems.

– **Intermittent transmission with electronic transponder-device:** ATB New Generation, Ebicab, KVB, TBL, ZUB.

A typical representative of this family is the Ebicab system which is widely used in the Nordic countries Sweden Norway and Finland as well as in some other networks (figure 1.10). Key element is an electronic transponder data transmission system with "Balises" (or beacons) in the track, which are activated by 27 MHz radiation from the train-born balise-readers. The Ebicab collects the data from the trackside signalling equipment and transmits it to the on-board. All relevant data from trackside and from the train are processed in an on-board computer which calculates the maximal admitted speed and compares this with the real speed of the train. In case of over-speed, the driver is warned and the brakes are applied automatically if needed. On the Nordic networks, the driver receives optical information from lineside signals as well as from the system on-board. In normal train operation, the Ebicab system is considered to be fully safe and the speed displayed at the driver information panel may prevail to the indication of the lineside signals [1.e].

As will be explained in chapter 5.1.2, the intermittent data transmission by means of electronic transponder devices has become a key feature also for ETCS especially in level 1 application. Indeed, the so called KER balise used for KVB, Ebicab and RSDD (precursor system of SCMT in Italy), is the precursor of the ETCS Eurobalise and a Eurobalise reader is able to read Eurobalises as well as KER balises (see chapter 5.4.1).

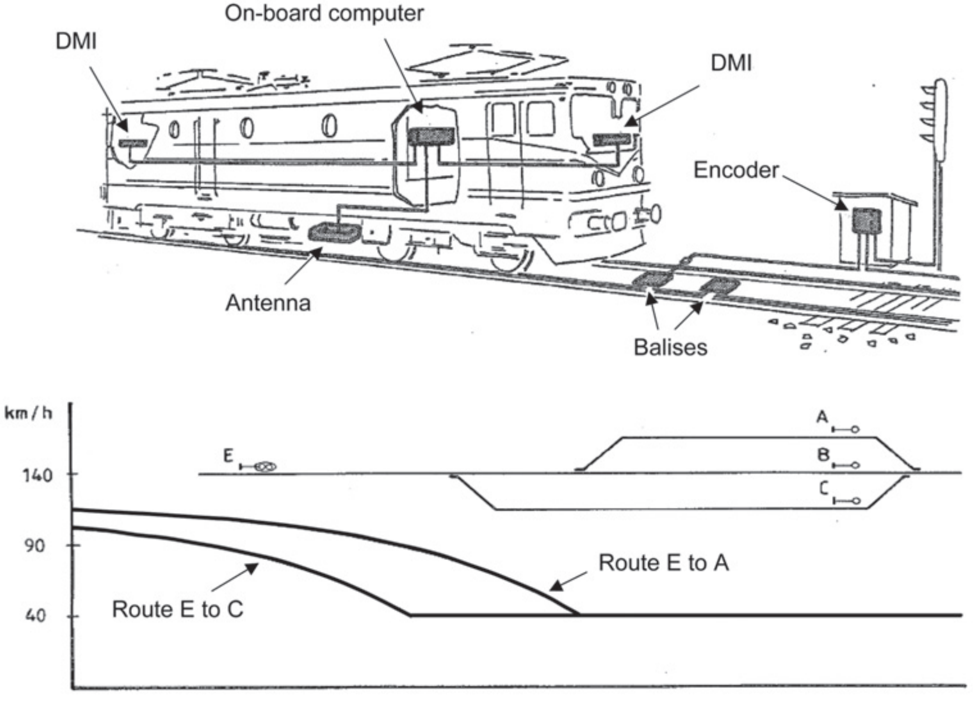

Figure 1.10: Structure and working principle of the Ebicab system

- **Track-circuit based transmission:** ATB First Generation, BACC, EVM, LS, TVM.
  This system family uses track-circuits not only for vacancy proving but also for the data transmission from track to train. The figure 1.11 illustrates the principle of track circuits and the speed supervision by means of the TVM system, which is installed mainly on high-speed lines in France, Belgium and England. The two system generations TVM 300 and TVM 430 are backwards compatible. With TVM 430, the transmission has a 27 bit capacity, 6 bits being reserved for the transmission protection by coding, 3 bits being used to define the

user network and the type of mission of the train. The remaining 18 functional bits are typically used for speed data (8 bits), distance to go (6 bits) and profile (4 bits). Over the whole line and the stations the track-circuit sections are interlinked.

The on-board equipment is structured for safety reason into two independent channels. The system compares the real and the target speed and acts on the brake if necessary. Due to the limited number of possible codes, the target speed is transmitted in relatively big steps. For the spacing between two consecutive trains, at least one complete track section is always kept free. With TVM, it has become possible for the first time to abandon the lineside signalling as it is the case for ETCS in the radio transmission based application levels 2 and 3.

Besides TVM, the other track-circuit based systems ATB, BACC, EVM and LS are used on conventional main lines and stations, whereby gaps between the different track-circuit sections may exist. For ETCS, this transmission technology has not been taken over. A similar functional behaviour may be obtained with data infill transmission devices by means of Euroloops or GSM-R radio infill (see chapter 5.4.2 and 5.6.2).

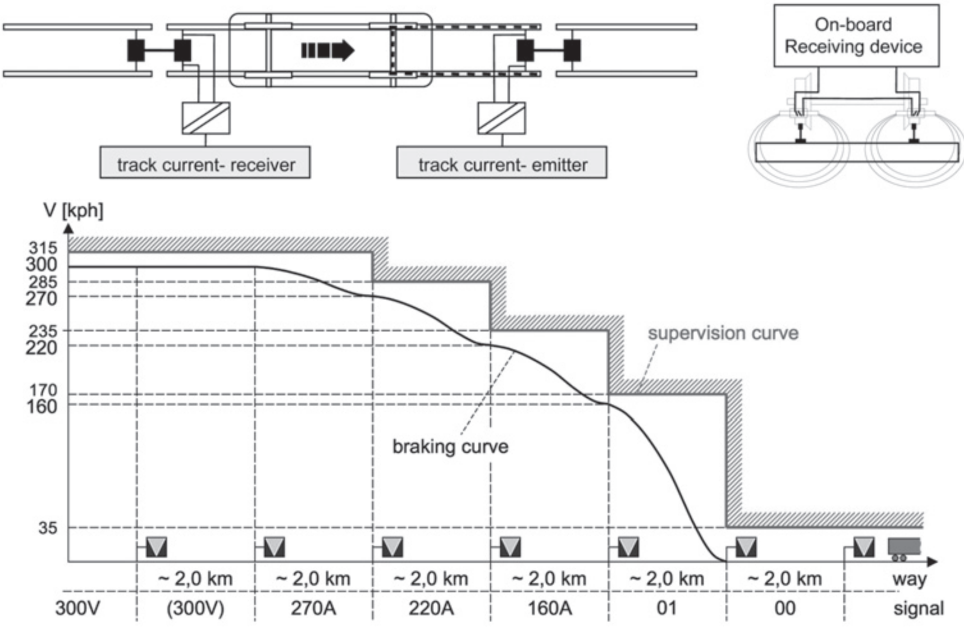

Figure 1.11: Principle of trackcircuits and speed supervision with the TVM system

– **Transmission with cable loops:** HKT, LZB, ZUB.

The most sophisticated system within this family is the LZB (figure 1.12). A bi-directional continuous data transmission is achieved by means of cable loops all along the track. The characteristics are 36 kHz and 1’200 bit/sec for track to train respectively 56 kHz and 600 bit/sec for train to track communication. The loops are crossed at regular distances what facilitates the calibration of the odometry. Unlike TVM, this system is not integrated but overlaid on the underlying signalling system with the block control. The remote feeding units are controlled by a dedicated LZB centre. The on-board equipment is engineered with two independent channels for safety reasons. The target speed is transmitted and indicated almost continuously.

The principle of bi-directional continuous data transmission between track and trains has also been adopted for ETCS, however by means of GSM-R radio transmission instead of

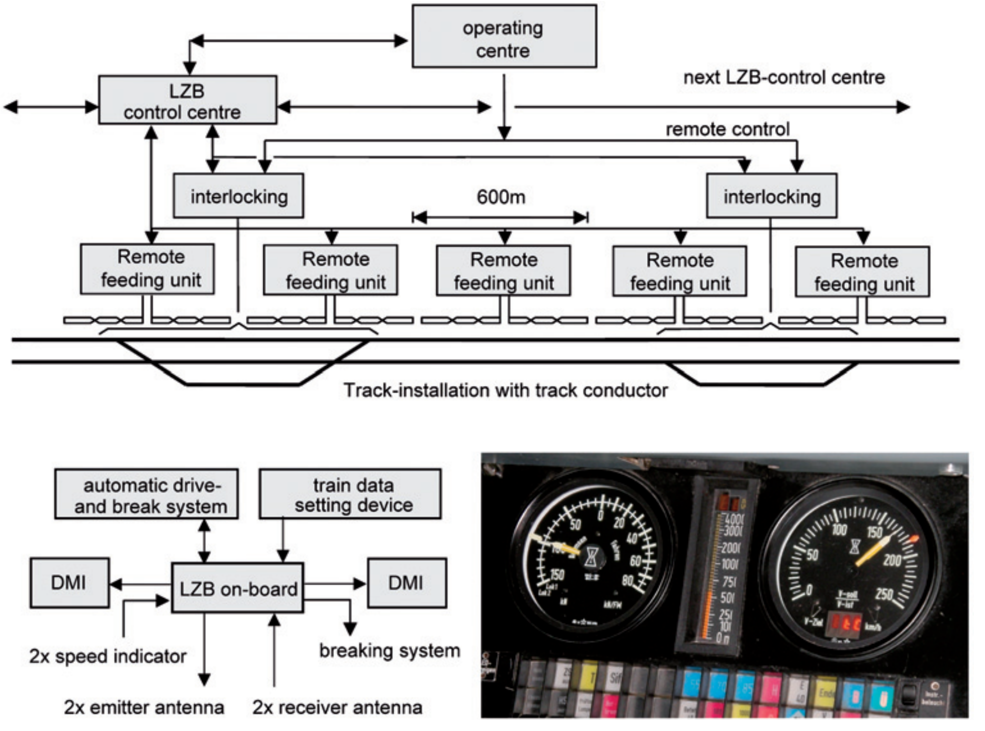

Figure 1.12: Structure and working principle of the LZB system

cable loops. Therefore the functionality of ETCS in level 2 shows many similarities with the LZB system.

1.1.4 Railway communication

Railways were the earliest users of telegraphs and telephones and all follow-up developments of wire-based communication devices.

Radio transmission has been introduced in the railway sector since the 1950s. Analogue modulation has been used first in the 4 m (around 450 MHz) and later in the 2 m band (around 160 MHz). For the latter, a certain standardisation was achieved by means of UIC codes. According to the best practice of the day, dedicated networks were used for the different applications, the most demanding being the train radio (see figure 1.13).

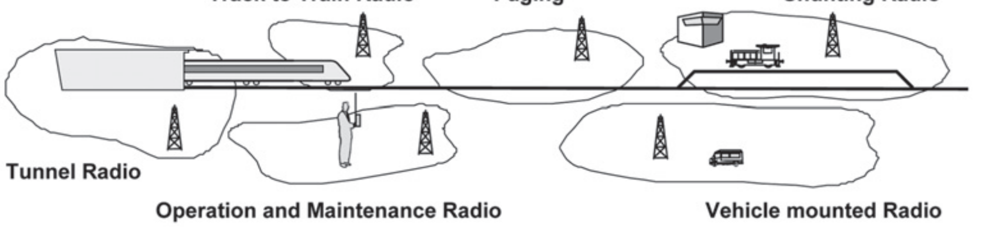

Figure 1.13: Traditional structure of railway radio communication systems

Main characteristics of the traditional systems are:
- Analogue modulation, mostly walkie-talkie, simplex system
- Range limited, continuous communications not possible
- Limited quality of communications
- Limited applications, typically voice only
- Large number of staff speaking on the same channel
- No encryptions for communication
- Different frequency spectrums allocated.

In the past, international interoperability existed only to a limited extent. The need for reforming and standardising the railway radio communication was driven mainly by the technological revolution in the sector characterised by the conversion from analogue towards digital technology with use of optical fibre cables. As will be shown in chapter 6, railways did not have to completely “re-invent the wheel” in this domain but could benefit instead from the general huge development with the public GSM system.

1.2 Driving factors for change

During the last two decades, the rail traffic management system has been confronted with legal, operational, technical and economic changes. In chapter 8, it will be outlined, to what extent these expectation have been fulfilled to date with the ERTMS developments.

1.2.1 Open procurement under competition

Procurement under open competition based on public tendering is a fundamental requirement for modern railways like for many other public sectors. In the past, this has been seriously hindered by the lack of standardised requirements and specifications especially in the signalling and control-command area. These subsystems being highly safety relevant, they are ruled by the relevant CENELEC norms in force for several years. In reality however, methods and tools for ensuring this systematically on a broad base are still missing.

1.2.2 Interoperability

As passenger and freight trains are circulating more and more through several countries over networks of different infrastructure companies, interoperability is a fundamental need of modern train operation. This term, which has been taken over from the military defence sector, postulates that complete trains including the traction units can freely circulate over the infrastructure of several networks. As will be shown later, a distinction is made between operational and technical interoperability. The latter is the pre-condition for trains being able to cross the border. It will lead after a transition period (migration phase) to a simplification for the trackside and on-board equipment. Operational interoperability facilitates from an organisational and human resource point of view the long distance train circulation over national borders. It requires in addition to the technical standardisation the harmonisation of all kind of procedures, rules and regulations for the train operation.

Of course, interoperability is not just a matter of signalling and train control. With regard to the **track gauge**, today, there are 6 major different versions in Europe (figure 1.14). The standard gauge 1435 mm is the most used – however 5 more are present. For instance, the Ibe-

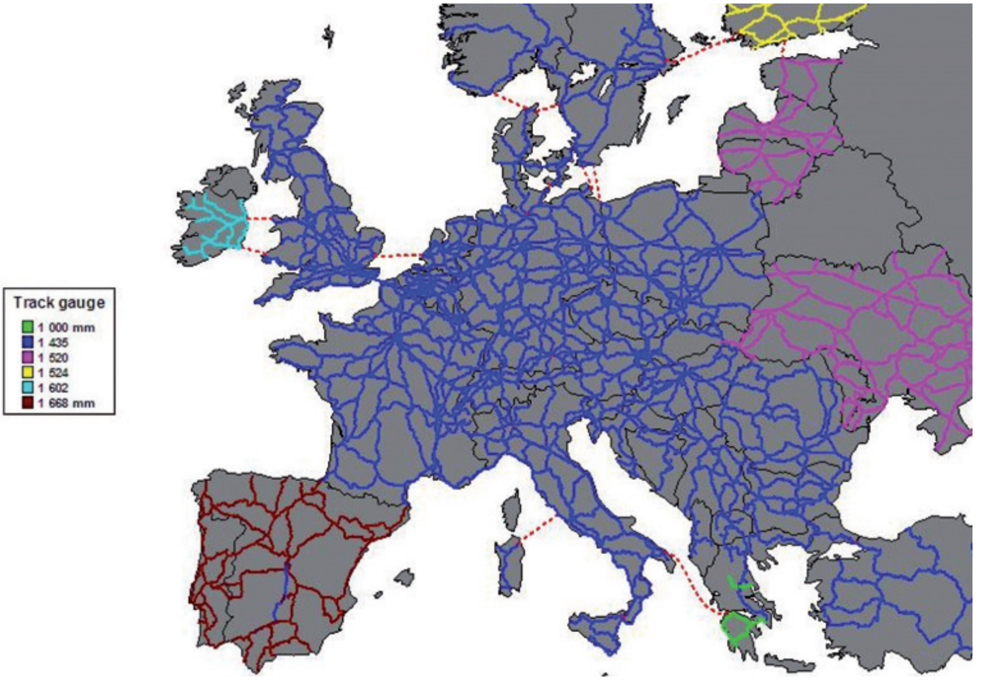

Figure 1.14: Different track gauges used in Europe

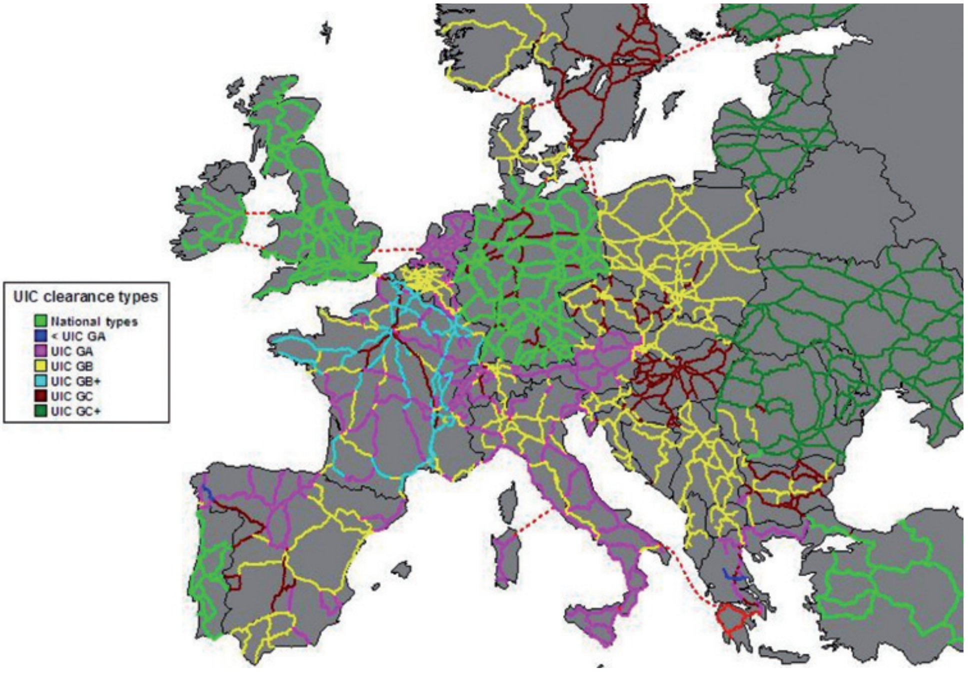

Figure 1.15: Different clearance gauges used in Europe

rian gauge is 1668 mm and there are plans to convert this whole network to standard gauge. Nowadays, interoperability is achieved via rolling stock with variable gauge. The Spanish train TALGO 250 is the latest solution. It changes gauge while running at 20 km/h.

With regard to the **clearance gauge**, today, there are 6 major different versions in Europe (figure 1.15). For commercial reasons, the trend goes towards enlarged rolling stock, which has by nature a huge impact on the infrastructure.

With regard to the **power supply systems**, today, there are 9 different kinds of electrifications in Europe (figure 1.16). As it can be seen, the 25 kV AC is the most used for high-speed lines. On conventional lines, a lot of Direct Current with 3 kV or 1.5 kV exists. The spectacular evolution in the field of traction power electronics in the last decades facilitates the construction of rolling stock able to deal with more than one power supply system (e. g. the Thalys trains operating with 4 different power supplies).

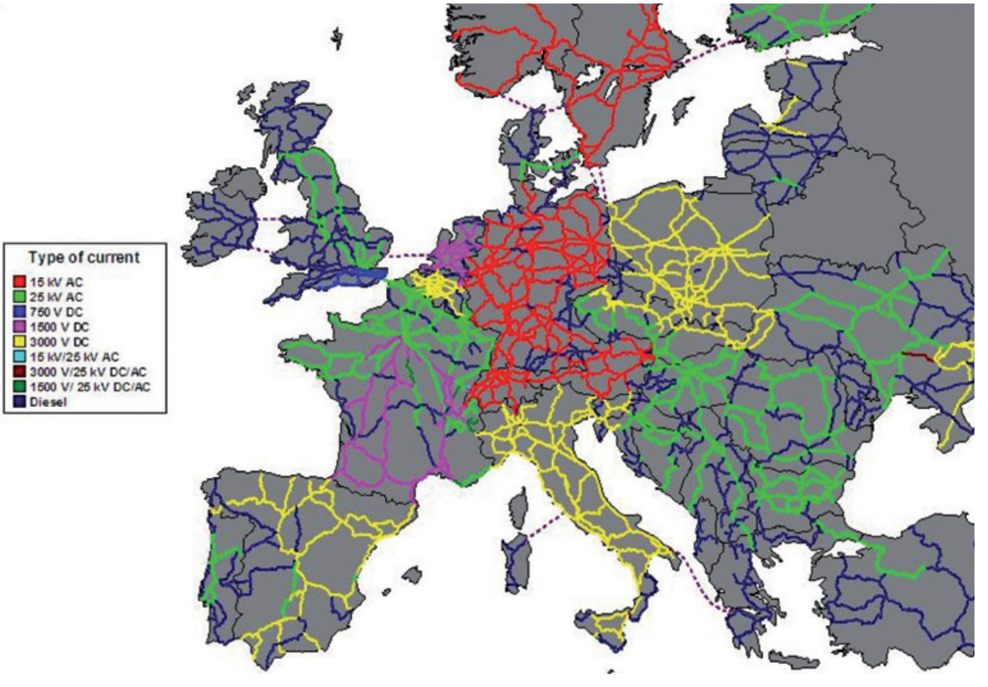

Figure 1.16: Different traction power supply systems used in Europe

From all these domains, the control-command and signalling is the most problematic, as there exist nowadays more than 20 incompatible systems as shown in table 1.6. The tradional way for ensuring interoperability in this domain consisted in equipping traction units for international lines with several legacy control-command systems in parallel. The costs for this may well reach 20–25 % of the total cost for a locomotive. Also it becomes problematic for mechanical and electromagnetic compatibility reasons to install all national control-command antennas required for longer corridor routes over several national networks (figure 1.17).

Another limiting factor is a need for many different displays for the drivers as shown with the example of the Thalys high-speed trains (figure 1.18).

ERTMS development under the patronage of the European Commission started in 1989 as part of the plans for a European high-speed railway network.

This large Europeanising process is leading to an in depth reform of the railway system. Key driving factors are interoperability in the context of open access to infrastructure, the maintenance of safety and enhancing the performance of train operators. Competition has resulted in an open multi-vendor market for procurement, requiring enhanced cost efficiency over the whole life cycle of the system. After a long history of national traditions in rail traffic management, a new harmonised European concept is becoming a reality. This combines innovative approaches in technology and processes with the underlying rules and regulations governing safety and capacity.

In this book a team of authors, all of whom have been actively involved in ERTMS development for many years, give a detailed description and analysis of the current situation. This includes consolidation with the new baselines for the ETCS and GSM-R specifications, which have now been formally decided.

This compendium is intended to guide the reader through the complex ERTMS concept by giving an overview of all relevant sub-projects. It is hoped that it will help to improve understanding of the concept and so facilitate its further implementation. This in turn will render the railway of the future more attractive and competitive.

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