Gregor Theeg | Sergej Vlasenko (Eds.)

Railway Signalling and Interlocking

International Compendium

4th edition

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Railway Signalling and Interlocking

International Compendium

4th edition

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Preface

In the era of globalisation, the future success of the railway sector depends significantly on the worldwide sharing of knowledge. Despite a strong trend to internationalisation in the scope of ERTMS, railway signalling is still one of the few sectors of technology which are still thought widely national.

For a long time, there have not even been common terms and definitions, and there is a corresponding lack of understanding of the underlying principles. In the technical literature, descriptions of railway signalling principles widely concentrate on the railways of a single country, or group of countries.

17 years ago, in 2009, the first edition of the textbook has been published with the intention to overcome this nationally limited approach, and that just to compare different national solutions is not sufficient. What is really needed is a generic description of railway signalling principles that allows the reader to look outside the national point of view. Therefore, an international team of experts analysed and compared operation and signalling principles in different parts of the world and tried to find a systematic over them.

The book became a great success, used by many universities, libraries, companies and private persons, and got a very positive reception from the readers. The demand was higher than expected, and the technical development has proceeded. This is why we decided to publish a fourth edition of the book. This new edition updates the contents from the previous editions and adds many new contents which reflect important development of the recent years. Security in railway signalling, which has become an increasingly important issue during the last years and will probably become even more important in future, has become now a new chapter of his own.

The authors wish to thank Alexandra Schöner and the whole staff of GRT Global Rail Academy and Media GmbH for their support in this book. We also thank Uwe Lehne of TU Dresden for the technical support in the production of the manuscripts and John Glover for the linguistic editing.

We also thank Aleksej Efremov, who has been editor of the Russian journal “Railways of the World” for a long time and supporter of previous editions of this book, for further upholding the spirit of international understanding in his country in these difficult times.

We also remember with gratitude two of our former co-authors who unfortunately passed away in the meantime: Giorgio Mongardi and Nino Mukhigulashvili.

We thank all readers for their support and hope that this textbook will remain a valuable resource for students at universities and colleges, and for practitioners in the railway environment alike. Comments from readers to be considered in future editions are always welcome.

Gregor Theeg and Sergej Vlasenko

October 2026

1 Introduction

Gregor Theeg, Ulrich Maschek, Sergej Vlasenko, Jochen Trinckauf

1.1 Historical Abstract

In the 1830s, Britain pioneered the main line railway. The new technology soon spread across the world, as the first means of mass transportation. In the early years, trains were kept apart by the use of the time interval system, but there was no means of knowing what might be happening once they were out of sight. If a train did not arrive at the next station when it was expected, a locomotive would be sent out to look for it. The assumption would be, probably correctly, that it had broken down.

Operational safety depended on the obedience of rules by staff, with a rather high probability of human error, while the rules themselves were imperfect. They soon became insufficient as the speed of trains increased, as did the payloads which could be carried and the density of the traffic.

Safety measures which appeared over the years were fixed signals which could be seen from a distance and by all personnel, replacing flags, the establishment of signal boxes, which were able to control points and signals over an area without staff having to walk between them, the electric telegraph which enabled communication between adjacent signal boxes, and the establishment of the block system dividing the track into sections. ‘No more than one train to be allowed in any one section (or block) at any one time’.

All these helped staff to avoid mistakes. However, accidents caused by human error still occurred, as the increasing complexity of operations could overwhelm the staff. Destructive accidents with many casualties were the result.

Learning from this, the railways searched for methods to enforce correct behaviour of the staff involved. This led to the development of rule books and other manuals, setting out what was supposed to happen and how it was to be achieved.

The first mechanical signal boxes with interlocked points and signals were introduced in the second half of the 19th century. The interlocking prevented opposing indications being given, such as points set for one direction but signals for another.

There were two major electro-technical inventions in the same period, which became decisive for further development:

– The electro-mechanical block instruments by Siemens & Halske in Germany, which enabled remote interlocking functions between different signal boxes.
– The track circuit in the USA, which enabled the tracks to be proved clear before a train was allowed to move onto them, and which also enabled the transmission of information between different trackside entities and the trains.

From the beginning of the 20th century, systems came into use to protect against the failure of drivers to stop at a signal at danger, or if the permitted speed was exceeded. These developed from simple systems which only provided an attentiveness check or enforced braking if the train had already passed a red signal. These early forms of braking supervision later progressed to advanced systems with continuous guidance of the train, which can make even trackside signals obsolete.

During the 20th century, mechanical technologies in railway signalling were replaced progressively by electricity, and later by micro-electronics. Additional and sophisticated

functions were added over time, but the principles of railway signalling and interlocking remained unchanged from those established in the early years.

1.2 Scope of this Book

The railway system, from the technical point of view, consists of three main segments (figure 1.1):

- the track infrastructure on which the rail traffic is moving
- the vehicles, which are the moving units of the railway system to carry passengers and goods
- the trackside and onboard signalling and interlocking systems, which make those movements safe

These three components make up the railway operation as a whole, together with its rules and processes.

The focus of this book is on signalling and interlocking, which have many interfaces with the other segments, but with operational rules and procedures in particular.

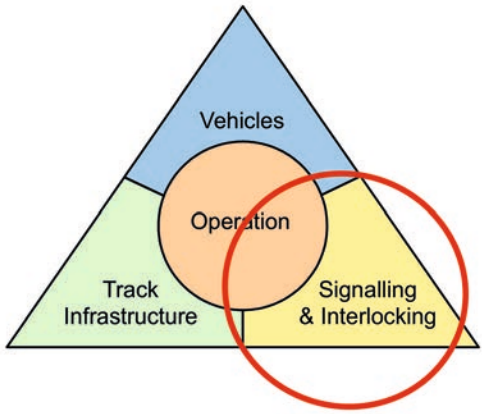

Figure 1.1: Scope of the book in the overall railway system

1.3 Characteristics of Railway Systems

Some basic characteristics of railway systems, which distinguish them from other modes of transport, are:

1. **Guidance:** The path taken by the train is determined by the mechanical guidance system of wheel and rail, and maintaining that guidance is essential for safety. Thus derailments have to be prevented, and this includes the non-continuous guideway locations at (for example) points. Also, the driver has no means of evading obstacles. The path of a train can be changed only by points. It follows that it must be possible to predetermine the route to be followed and to set the points accordingly. As the vehicle is very closely related to the guidance system, it can also be termed a linear control system.

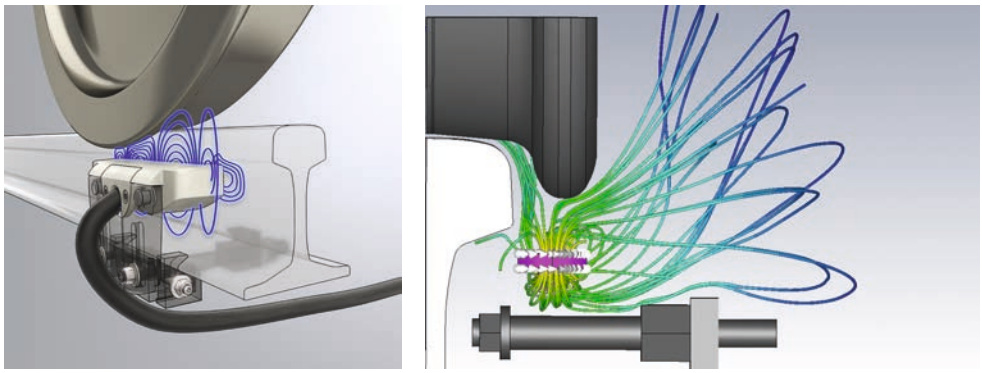

Figure 5.11: Principle of inductive detector (example RSR123)

Due to the increasing digitalisation of the whole railway sector, there is a trend towards solutions that enable an evaluation of the measured signals within the sensor. Based on the ability of providing a digital output, these sensors can be implemented in digital networks.

5.2.2.5 Fibre-optical Detectors

A recent detection principle for spot wheel detectors is based on optical sensor technology that is in use for monitoring strain inside large structures (eg bridges). They use optical fibres with so-called fibre bragg gratings (FBG) with a defined grating period Λ inscribed in their core (Heyder/Arezki 2018). Using an optical input signal and a given grating, a reflected bragg wavelength λ_B can be measured (figure 5.12). This wavelength depends on the temperature and strain changes.

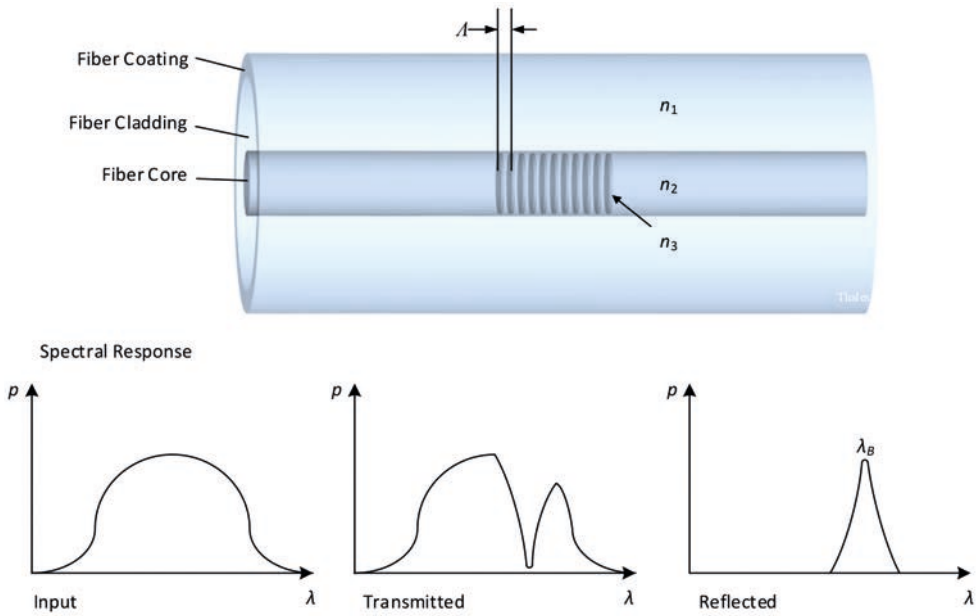

Figure 5.12: Principle of fibre bragg grating optical detection (Heyder/Arezki 2018)

The Lite4ce sensor (Thales/Hitachi) uses this principle with two FBGs placed 8 cm from each other at 45-degree angle for the detection of railway vehicles. A pre-tensioned optical fibre is first stretched (λ↑) and then compressed (λ↓) (other direction vice-versa), when a railway vehicle passes the fibre sensor. Due to the angle, the algebraic signal changes during the passing of train wheels. The sensor is installed by gluing it directly to the cleaned rail (figure 5.13). The measured data from the sensor system is used to monitor the glue joint. In addition, any breakaway of the sensor from the rail is detected by the pre-tensioned optical fibre.

Instead of induction coils, an optical laser is needed to send the signal through the sensors. This signal is permanently on and modulated in intensity. The measurement of the reflected wavelength is done by opto-electric chips, containing a photodiode and filter. The analogous optical signal is digitised, considering the temperature characteristic for each chip. Afterwards, digital signal processing is applied to generate the differential signal of the two sensors to count passing axles (section 5.4.2). Besides axle counting and detection of direction, this sensor technology allows measurement of train speeds and axle loads as well as detection of wheel flats (Heyder/Arezki 2018).

Figure 5.13: Principle of optical wheel sensor (example Lite4ce) (Heyder/Arezki 2018)

The advantages of these optical detectors are that almost no copper is needed (protection against cable thefts) and that there are no issues with electromagnetic interference/overvoltage protection in case of lightning and traction return currents. Optical and conventional inductive sensors can be combined within an interlocking area, so it is possible to extend existing interlockings with optical detectors (Heyder/Arezki 2018).

Due to gluing the sensor directly to the rail it is not possible to remove the sensor or change the sensor location. In that case, a new sensor has to be attached to the rail. This is a disadvantage, especially in the case of rail replacement.

To represent approximately the different braking performance of trains, they are distinguished into three categories. The following descriptions (figure 8.17) refer to train category 'O', which are the fastest trains with permitted speed up to 160 km/h; most passenger trains belong to it. The other groups are distinguished mainly by the speed values of the supervision curves.

The permitted speed of the vehicles (maximum 160 km/h plus a tolerance margin) is continuously supervised.

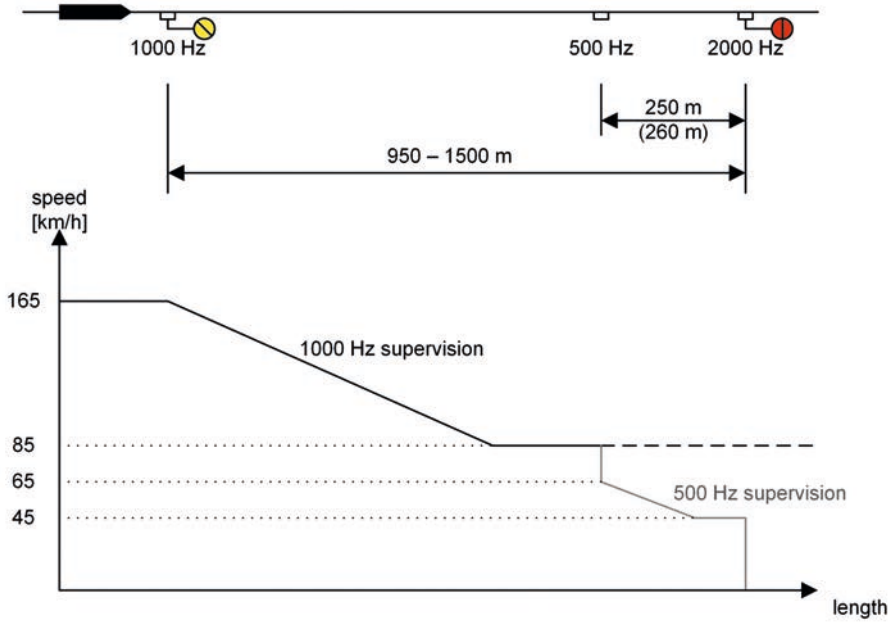

Figure 8.17: Braking supervision in PZB 90

Upon input from the 1000-Hz-magnet, the train driver has to push the acknowledgement button within four seconds. Then the supervision speed is steadily reduced from 165 to 85 km/h. As the distance from the distant to the related main signal can vary between 950 and 1500 m in Germany (normal value: 1000 m), the speed 85 km/h is supervised until 1250 m after the 1000 Hz input (latest possible position of the 500 Hz magnet). If within this distance no 500 Hz input follows, the system assumes the signal having cleared in the meantime and the supervision speed is released to the maximum of 165 km/h.

As this long speed supervision would be a great hindrance when the signal was cleared after passing the distant signal, the driver can liberate himself from the 1000 Hz supervision at the earliest 700 m after the 1000 Hz input (earliest position of the 500 Hz magnet) if he sees the 'Proceed' signal ahead.

Beginning at the 500 Hz input, a further reduction of speed from initially 65 to later 45 km/h is supervised. As the train is already close to the Stop signal, the driver has no possibility of liberation.

A 2000 Hz input results in an immediate emergency stop. As speed supervision has been reduced to maximum 45 km/h before, this is sufficient to stop the train within the overlap in most cases. To pass a red signal in degraded mode operation, the cab is equipped with an override button.

Emergency brakes are applied until stop in case of failing to push the acknowledgement button, in case of exceeding the supervision speed, passing an active 2000-Hz-magnet and in several other cases of driver's error.

In case the train has stopped or gone very slowly between distant and main signal, it cannot be assumed that the overlap is still locked. Therefore, a more restrictive supervision becomes active in this case.

More information on PZB 90 can be found in (DB Netz 2001).

8.3.3.2 Japanese ATS-P

The system was developed in the 1970s and replaced the old ATS-S system on Japanese conventional lines. Whereas the old ATS-S system provided a check of attentiveness only (see section 8.3.2), ATS-P provides advanced supervision functions including braking supervision which is even adjusted to downhill grades of the line.

Likewise in Indusi, data transmission is based on resonant circuits, but not the loss of energy is measured, but the shift of frequency in the resonant circuit on the train, caused by the trackside resonant circuit. Normally, the resonant circuit on the train oscillates at the frequency 74 kHz. When passing over an active trackside resonant circuit, this frequency increases to one out of eight defined frequencies, depending on the trackside transmitter. The frequencies are filtered by a band pass filter on the train.

The trains are divided into seven categories, according to their braking performance.

The trackside coils are positioned at a defined distance in rear of the Stop signal. Each input information initiates a related braking supervision (figure 8.18), differentiated by the train category. When the train reaches a new trackside transmitter, the previous supervision curve becomes ineffective. A fifth coil SS with another frequency marks the position of the Stop signal and causes immediate emergency stop. Block signals have no SS coil to enable permissive driving.

Other frequencies are used for following purposes:

- Braking towards a speed restriction of 50, 85 or 90 km/h. Different speed restrictions are identified by a sequence of two trackside coils with two frequencies.
- Cancellation of brake patterns and speed restrictions.

The system provides the possibility of adjustment to downhill slopes. In this case, the coils initiating the brake patterns are situated further in advance to compensate the lower deceleration (figure 8.19).

More information on ATS-P can be found in (Kondo 1980).

10.6 Centralised Systems for Safety on Open Lines

10.6.1 Overview

In centralised block systems, the detection and train position data is sent to a central controller, locking functions are performed there and the block signals are controlled from the centre, too. This block centre can be an interlocking of a neighbouring station or a separate block centre.

system	main disadvantages
token block (section 10.3)	slow processes; necessity to stop in each station
decentralised manual tokenless block (section 10.4)	slow processes; high efforts for staff
decentralised automatic tokenless block (section 10.5)	high effort for decentralised maintenance
centralised block systems (section 10.6)	high effort for communication (cables or radio)

Table 10.4: Economic disadvantages of different kinds of block systems

These systems were developed historically from different origins in order to avoid certain economic disadvantages of the decentralised block systems (table 10.4). However, the more complicated communication between the centre and the trains emerged as a new disadvantage of centralised systems. The historical origins of the systems are:

- extension of the interlocking areas and usage of route locking functions also on the open line (eg Germany)
- concentration of the evaluation units of block points in a central place (eg French high speed lines, Russia)
- replacement of tokens by electronic information and their central processing (eg Britain on secondary lines)
- improvement of safety overlay systems for unsignalled operation (section 10.2) to a full interlocking system (eg Germany)
- development of new high speed systems with particular block systems (several European countries)

Based on these different origins, the locking functions are solved logically in different ways (compare sections 4.1.2 and 10.1; figure 10.15):

- token logic: Virtual tokens are generated and exchanged with the train to permit entry of a particular section.
- tokenless block logic: Within the central controller, block information is generated and exchanged as in a tokenless block system.
- route logic: The open line sections are controlled like station areas with route locking. This is possible because all safety functions of block information can also be performed by routes, and because with the presence of continuous track clear detection, the reasons for sharp distinction of interlocking areas and open lines become obsolete (section 4.1.2). Besides, using the route logic on open lines can imply a gain of safety in certain cases of technical failure. Some countries (eg China and Russia) which are not using the route logic on open lines are starting the implementation of a sequence check principle into their autoblock logic after train accidents on high speed line in China (Wenzhou 2011).

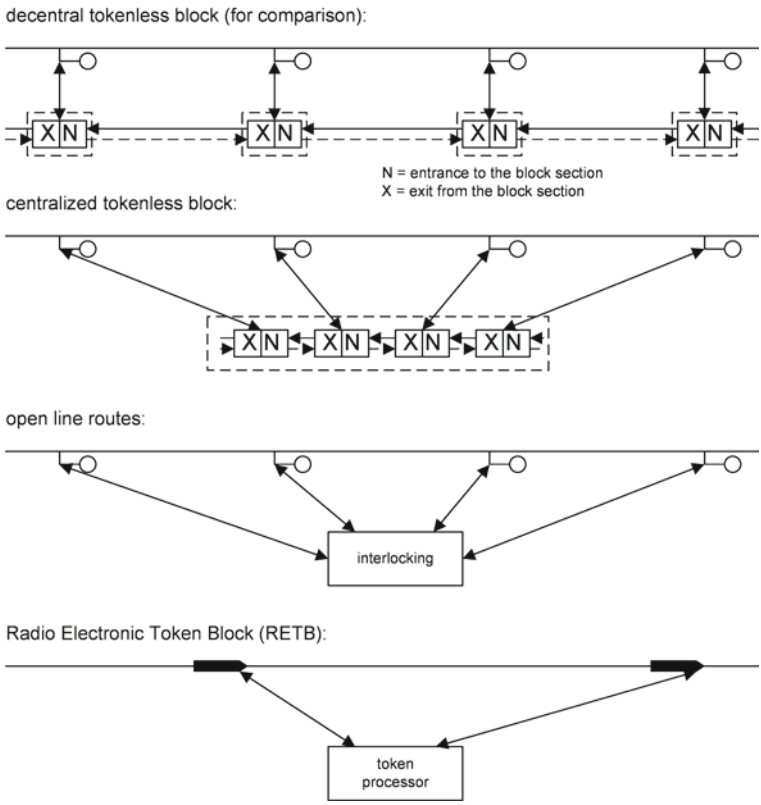

Figure 10.15: Different forms of centralisation of block systems

When using route logic on the open line, the block signals are red in normal position (if all sections are clear), whereas with block logic with automatic block, they are mostly at green in normal position. As operational decisions are not necessary before route selection on open lines, routes are usually set automatically when a train is approaching, or after an exit route has been selected. Due to improved communication possibilities in the case of technical failure, absolute instead of permissive stop signals are often used on the open line.

10.6.2 Centralised Block Systems for Secondary Lines

More recently, several centralised systems have been developed for secondary lines. The approach was to reduce costs by implementing simplified functions and cheaper technologies. One solution is so-called 'Signalised Track Warrant Control' (**'Signalisierter Zugleitbetrieb' SZB**) in Europe, which originated as a further development of safety overlay systems (section 10.2) and has now become a full electronic interlocking with route logic on the open line (section 10.6.4).

Following each Shared Security Service (SCS) is briefly introduced.

15.4.4.1 STS: Secure Time Synchronisation

Via STS a time synchronisation is provided. A standardised time source is required to check the expiry time of a certificate, among other use cases. STS uses NTS based on RFC 8915. NTS is based on NTP and backwards compatible to the NTP protocol (used in earlier EULYNX versions).

15.4.4.2 PKI: Public Key Infrastructure

A Public Key Infrastructure (PKI) is a set of processes, policies, and technology for associating certificates with the entity to whom the corresponding cryptographic keys were issued. It is a standardised method providing the certificates used for authentication, integrity protection and encryption to confirm the identity of communicating parties as well as validate information being shared.

The certificates are managed via the Certificate Management Protocol (CMP). This interface enables the systems to request and receive a certificate, among other things. The private key required to request the certificate remains on the system itself. In addition, the PKI provides the current status of the certificate via Certificate Revocation Lists (CRL). The certificates shall comply to X.509 v3 as defined in RFC 5280.

15.4.4.3 IAM: Identity and Access Management

SSI-IAM is an interface for managing digital identities (human users, software processes or devices) and corresponding permissions. The IAM acts as a single source of truth for authorisation in OPC-UA (SDI/SMI) connections and provides authorisation data to SCS-UAS, which is used to authenticate and authorise human users. This service is connected to an asset inventory and user inventory connected.

15.4.4.4 NAC: Network Access Control

The purpose of the SSI Network Access Control (SSI-NAC) interface is to prevent unauthorised access to the network. The NAC system shall identify, authenticate, and authorize the entity attempting to access the network. IEEE 802.1X and EAP-TLS is used as basis for the Network Access Control solution.

15.4.4.5 LOG: Security Logging

The Security Logging Interface enables the transmission of security-related logs from devices via relays to a central service. Logs are used to detect attacks on the system and to initiate mitigations. In contrast, Security Diagnostic contains the current state of the Secure Component, based on a diagnostics model. Security Logging is using Syslog over TLS based on RFC 5424. The evaluation is performed in the Security Incident and Event Management (SIEM) system.

15.4.4.6 UAS: User Authentication Service

The UAS allows authentication of human users with multi factor capability and configurable methods. The service also provides single sign on functionality. The UAS is connected to SSI-IAM as basis of the identity management.

15.4.4.7 BKP: Backup and Restore

The backup service is required to ensure availability of operational data which is required to operate. These are typically the software and configuration. Most secure components will not need to be connected to SSI-BKP as the data is provided centrally via a central data management service (eg MDM).

15.4.4.8 MNT: Security Maintenance

The security maintenance service is required to evaluate the security state of the secure component and to allow access to the amongst others the following functions:

- Certificate Maintenance
- Log Maintenance
- Configuration Management
- Factory Reset
- Security Function Verification

15.4.4.9 DNS: Domain Name System

The usage of DNS is not specified in EULYNX but might be an option to resolve the addresses of the Maintenance and Data Management (MDM) as well as other Shared Cybersecurity Services. The interface provides DNS via TLS based on RFC 7858.

15.4.5 Security Testing

The required updates of security and foreseeable updates of functionality supported by modularity of the systems will require regular testing of the systems. Today's test procedures for safety-related systems are usually very manual. This is because changes over time have not been expected to happen regularly.

EULYNX now provides interface and security test cases which allow standardised and comparable testing. More important it allows test automation based on these test cases.

The need for tests is not only present for suppliers but also for railways. In telecommunication systems, like GSM-R this is state of the art already. Software updates, new configurations, features etc. are tested in a test environment of the railway before they are rolled out. This allows railways to perform independent updates of sub-systems, prove the fulfilment of quality agreed in contracts, the actual implementation of required standard interfaces and additional knowledge relevant for fast incident and failure management.

15.5 Migration

Migration describes the change to a system landscape. In the context of railways, it describes in particular the change and integration into existing, older versions of this landscape.

Cybersecurity is an additional function within the CCS TSI specification since TSI 2023. All previous versions and content can be regarded as purely safety-related. In EULYNX cybersecurity is present since Baseline 4 Release 1.

In principle, the migration in security is similar to the migration in safety. Downward compatibility exists as long as the previous capabilities and versions continue to be supported. The difference, however, lies in the impact of this downward compatibility. In the example of

In the era of globalisation, the future success of the railway sector depends significantly on the worldwide sharing of knowledge. However, railway signalling is still one of the few sectors of technology in which national solutions differ substantially. This leads to descriptions of railway signalling principles concentrating on the railways of a single country or only a group of countries. In this international compendium **Railway Signalling and Interlocking**, generic description of the principles is put together in a systematic overview by an international team of experts, allowing the reader to look outside the national viewpoint.

For this revised 4th edition, almost all chapters have been updated to reflect new developments in fields such as ETCS, PTC, train integrity monitoring, digital automatic coupling or wayside train monitoring, for example. And for the first time, a separate chapter about cybersecurity in railway signalling has been added, a topic which becomes more and more important nowadays. Altogether, the book contains the following principal topics:

- safety
- railway operation processes
- interlocking principles
- train and obstacle detection, points and signals
- interlocking and line block systems
- remote control and operation technology, as well as the organisation of operational control centres
- safety and control of shunting and marshalling
- level crossings
- wayside train monitoring systems
- products and solutions for security in railway operations

The book combines the knowledge and experience of more than 20 international experts from universities, railway services and the industry. It offers basic knowledge and practical help for railway signalling technicians, operators and manufacturers, as well as for students, lecturers and scientists at universities. It is also a useful source of reference for everyday work.

Bonus for free: The e-book-PDF of this book is available upon registration. Users of devices with a PDF reader can also access all content electronically and with a search function.

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