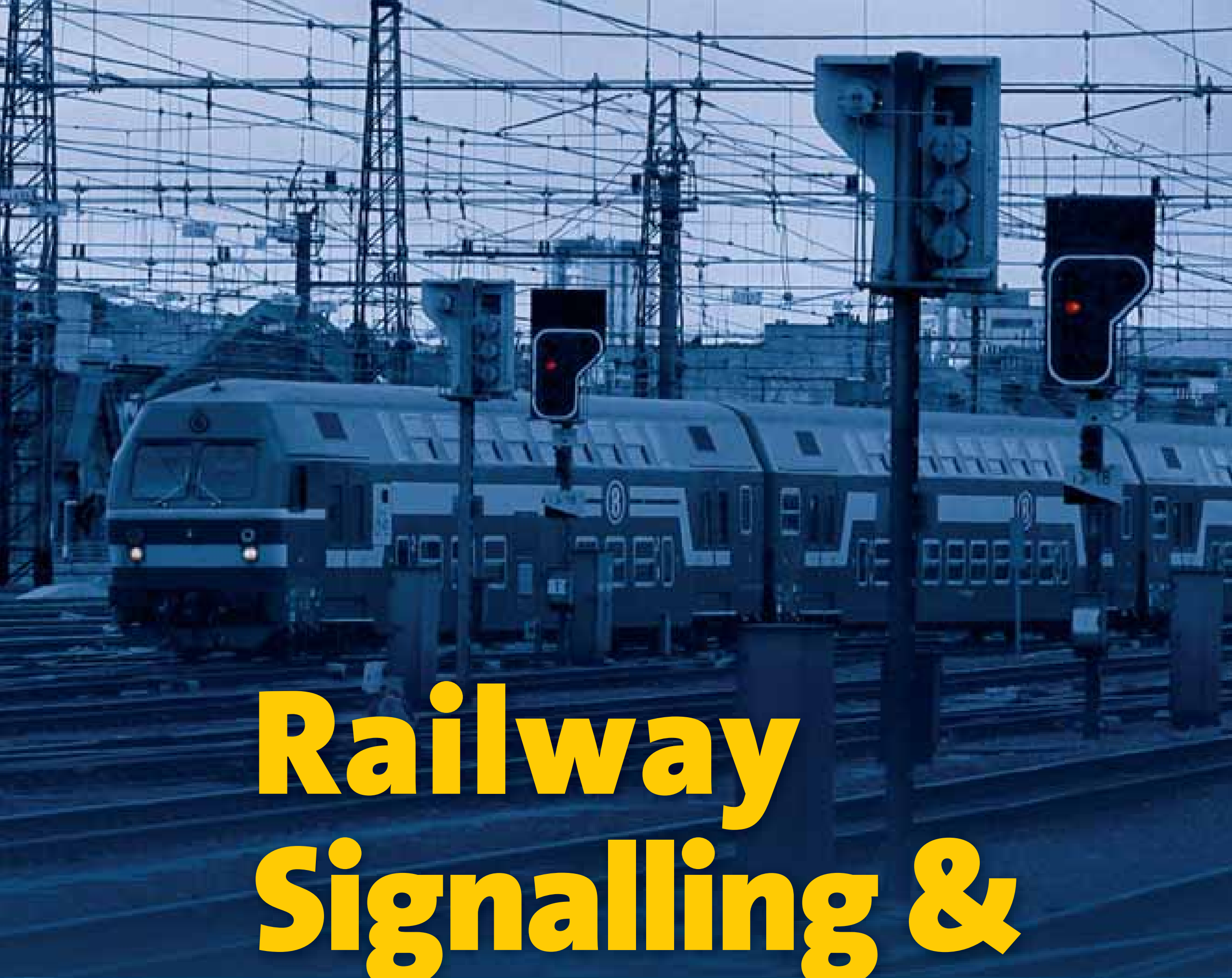

Railway Signalling & Interlocking

International Compendium

2nd Edition

Editors: **Gregor Theeg · Sergej Vlasenko**

EDITION
Eurail press

eBOOK INSIDE

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Editors:
Dr.-Ing. Gregor Theeg, Germany
Dr. Sergej Vlasenko, Russia/Germany

Authors:
Dr.-Ing. Enrico Anders, Germany
Prof. Dr.-Ing. Thomas Berndt, Germany
Prof. Dr. Igor Dolgij, Russia
Prof. Dr. Vladimir Ivančenko, Russia
Dr. Andrej Lykov, Russia
Doc. Ing. Peter Márton, PhD., Slovakia
Dr.-Ing. habil. Ulrich Maschek, Germany
Ing. Giorgio Mongardi, Italy
Dr. Oleg Nasedkin, Russia
Prof. Dr. Aleksandr Nikitin, Russia
Prof. Dr.-Ing. Jörn Pachl, Germany
Prof. Dr. Valerij Sapožnikov, Russia
Prof. Dr. Vladimir Sapožnikov, Russia
Dr. Andreas Schöbel, Austria
Dr.-Ing. Eric Schöne, Germany
Dr. Dmitrij Švalov, Russia
David Stratton MA CEng MIRSE, UK
Dr.-Ing. Gregor Theeg, Germany
Dipl.-Inform. Heinz Tillmanns, Germany
Prof. Dr.-Ing. Jochen Trinckauf, Germany
Dr. Sergej Vlasenko, Russia/Germany
Dipl.-Ing. Carsten Weber, Germany
Thomas White, USA

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Managing Directors:	Detlev K. Suchanek, Antonio Intini
Editorial Office:	Dr. Bettina Guiot, Ulrike Schüring
Distribution/Book Service:	Sabine Braun
Advertisements:	Dirk Bogisch
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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. That exchange is the only way to find the most effective solutions and to avoid unnecessary parallel developments. Railway signalling is still one of the very few sectors of technology in which national solutions differ substantially.

There have been no common terms and definitions, and there is a corresponding lack of understanding of the underlying principles. Also, adapting new technologies to different national practices is very costly. In the technical literature, descriptions of railway signalling principles widely concentrate on the railways of a single country, or group of countries.

Eight years ago, the first edition of the textbook has been published with the intention in mind 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, this is why we decided to publish a second edition to keep the book available.

As the basic principles in signalling remained very stable over the years, large parts of the contents of the book remained valid until today. Therefore we decided to do only minor updates and corrections in this second edition. However, some new developments have been addressed, too.

One new part has been added as Annex to the book, which can be considered as part of chapter 3. Keeping railway operation available and safe also in degraded situations is a topic which gains more and more importance today, this is why we added an Annex about degraded mode operation.

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.

The authors wish to thank the editorial staff of PMC Media for their support in this venture. We also thank Mr. Aleksej Efremov, editor of the journal Rail International, for supporting this book with many advices and pictures from different parts of the world and for successfully publishing the Russian edition of this book.

The authors
October 2017

1 Basic Characteristics of Railway Systems and the Requirements for Signalling

Jochen Trinckauf

1.1 Introduction

The railway was the first means of mass mechanised movement. Over time the speed of the trains increased, as did the payloads which could be carried, and the length of the trains themselves. Railway development began in the early years of the nineteenth century, and it became the backbone of transportation systems in many countries. Of course, after World War 1 the use of mechanised road transport started to rise, and after World War 2 this became a real competitor.

Nowadays we have railway systems with multiple variations around the world. They can be classified as follows:

1. by rolling stock
   - Trains consisting of one (or more) locomotive(s) and a number of cars for passenger or freight
   - Self contained passenger trains, including multiple units, without a separate locomotive

   Either type may be powered by diesel or electric traction
2. by traffic characteristics
   - long distance
   - regional service
   - urban transport (mass transit)
3. by operation, for example:
   - centralised control
   - fully signalled operation
   - drive on sight
   - driverless automated

There are several other classifications, for instance by public or private ownership, separation of infrastructure and operating companies, main line/secondary line, single track/double track and so on. But all are variations of 'the railway' because they are similar in their principal characteristics and hence their requirements for signalling.

During a long period of gestation, many techniques, technologies and components were developed. The basic characteristics of the railway are described here to help understand the requirements of signalling.

1.2 Specific of Railway Systems

All railway systems have these two identifying features:

1. The path taken by the train is determined by the mechanical guidance system of wheel and rail, and this can be changed only by points. On a single track railway, trains can only pass each other at particular locations, such as loops. Therefore it has to be possible to predetermine the route to be followed and to set the points accordingly. As the vehicle is very closely connected to the guidance system, it can also be termed a linear control system.
2. The steel wheel has a relatively poor braking response on the steel rail, but there is a relatively high running speed. Depending on the braking system, braking distances at as little as 50 to 70 km/h are often longer than the visible and clear route in front of the driver.

Therefore the sight on the route has to be supplemented by other precautions in order to indicate to the driver in good time a clear route or a need to stop. This applies to both an actual stop and a requirement to reduce speed.

These technical problems had to be solved. Consequently, procedures and techniques have been developed to ensure a safe, reliable and effective railway operation.

Starting from the days of simple information transmission, the railway operation and control system has been developed and over generations adapted to the state of the art. These principles generally have been proven and the partial techniques of control systems of the earlier generations are still in use today. The principles are also being put to use in innovative railway systems, where for instance the steel wheel on steel rail is replaced by other guidance systems, or by doing without a driver.

1.3 Railway Signalling and Control

1.3.1 Definitions

The **Railway Signalling and Control System** is needed for the safe control of transport processes in rail traffic.

The objectives and tasks of signalling and control can be defined as follows:

Signalling system
The signalling system ensures the safe control of transport processes. The safety aspect is stressed.

Operation control system
The operation control system ensures optimal control of the sequences of main and auxiliary processes in a traffic system.

Looking at the control loop of the process (see figure 1.1), it has to be ascertained that processes in the sector of the signalling system are triggered by internal events. These events can occur both theoretically and practically at any time. In the sector of the operation control system, railway operation processes are triggered by external influences, such as time-related schedules, response to traffic demands and so on.

Both systems use the means and methods of **information transmission** and **information processing**. Considerations of safety, reliability and availability are important in both systems, even though they serve different purposes:

Signalling systems involve the regulation of traffic and the prevention of accidents, whereas operation control systems have to prevent effective failures.

The technical components of control and signalling systems are similar (industrial computers, electronic controls etc.) but any considerations of safety and availability have to be general considerations that take the entire situation into account.

The subject matter of this book is the railway signalling system.

1.3.2 The Safety-related Railway Theory

The safety related railway theory has been developed to gather the variety of technical solutions in the railway control system. This theory can be demonstrated by means of a control loop, which is also known from the control theory (figure 1.1).

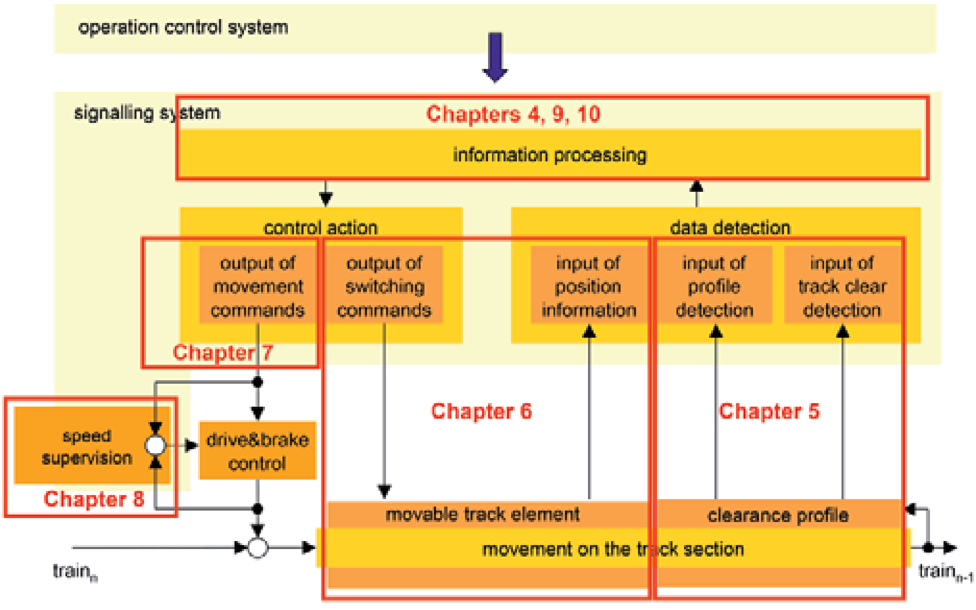

Figure 1.1: Control loop of the railway signalling system

The **train** is defined as all the movements of railway vehicles under local supervision.

The controlled element is 'movement on the track section', which is monitored. A track section is characterised by two significant features, the position of the movable track elements and the state of the clearance profile.

For this theoretical consideration the track sections themselves do not need to be further specified. For instance it could be single track sections within the railway station, entire routes or block sections.

Movable track elements are mainly points. However, there are further movable track elements, which are considered in chapter 6. The control loop is applicable even if the train moves in a track section without movable track elements.

The clearance profile is the space surrounding the rails and of course has to be clear before it can be used by a train. The clearance profile may be or may have been occupied by a train, which has used the same track section immediately before the monitored train, or by an off-track obstruction, for instance road vehicles at a level-crossing. Details are discussed in chapter 5.

A measured value detection takes place in the control loop, in the course of which the following are registrated:

- position information of the movable track elements
- present state information of the track clear detection (clear or occupied)
- information on other obstacles (technically or organisationally, if possible)

The measurement values are safely and logically processed. This is the core of such systems, whose logical principles are discussed further in chapter 4 and the technical solutions in chapters 9 and 10.

Finally, control values are issued. They refer to the movable track elements, which have to be positioned as required by the trains. However, they also have to be locked into this position before a corresponding movement authority can be issued to the train (chapter 7).

It is now up to the train driver to execute these movement authorities. However, these movement authorities are not just restricted to the commands 'Proceed and 'Stop'. They can also be specified by information on the speed-limit. The stop signal can be interpreted as 'speed limit zero'.

Due to the dynamic driving behaviour of trains, restrictions have to be received in time to be actioned effectively. This concerns lower speed limits in particular.

There are means for monitoring the train speed and acting on the train in case a maximum speed is exceeded. These may be simple train stops, highly complex automatic train protection systems, or the driverless systems, as dealt with in chapter 8.

The control loop is valid for the highly complex systems of control technology as well as for simple solutions, which are merely based on organisational procedures. This applies to all combined forms of organisational and technical processes, at the highest and lowest levels.

Within every control loop the previously described processes are sequences, which depend on each other in a strictly deterministic way. The trigger for the self-controlling system is external (figure 1.2), because the time or occasion for undertaking the control function is determined by operating conditions. Practically speaking, the dispatcher gives the driver a movement authority with the help of the control loop, which is described in the following section 1.3.3.

In summary, the safety-related railway theory results in the following technological basic railway control requirements. They apply generally and are independent from the particular technical solutions. Furthermore they are independent of local peculiarities, which are country-specific and/or related to historical experiences.

1. All track sections in front of the train have to be clear and kept clear, until they have been completely passed by that train.
2. All movable route elements in front of the train have to be held in their correct positions and kept there, until they have been completely passed by that train.

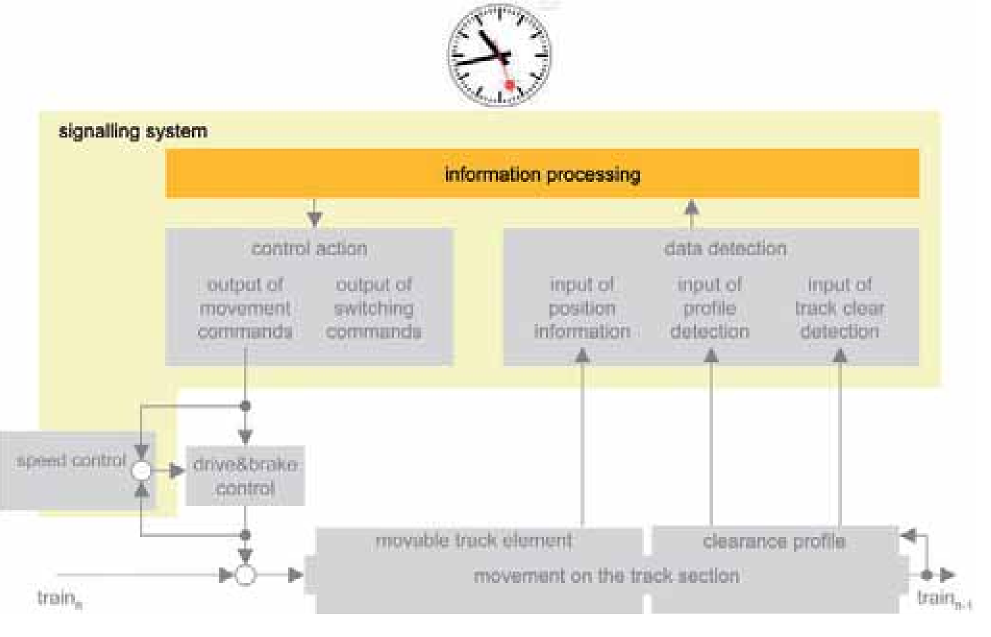

Figure 1.2: Establishing time context

3. Speed changes of the train have to be begun in sufficient time in order to reach the permitted speed at the target speed point.

1.3.3 Functional Structure

Figure 1.3 shows the functional structure of the railway control system, as it has been developed and practically proved over the years. In the course of this development numerous specific solutions have been determined and are discussed later.

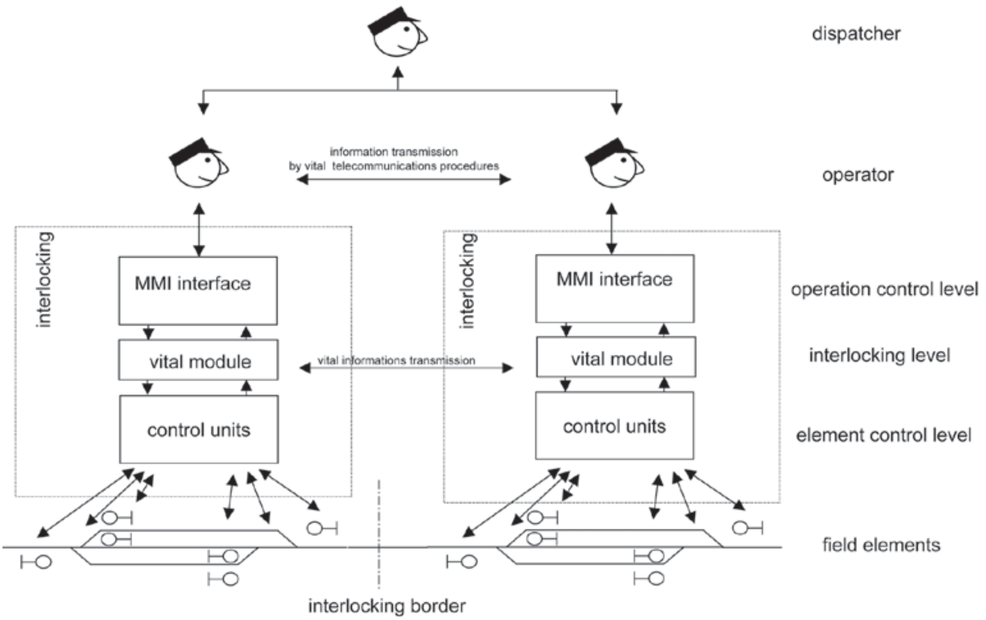

Figure 1.3: Functional structure of the railway control system

Field Elements

Basic field elements are:

- points
- signals
- track clear detection systems
- train activated systems (such as treadles or track circuits)
- automatic train protection systems

These installations are connected to the controlling and monitoring units of the local interlocking station.

Element Control Level

Controlling and monitoring units are arranged on the element control level, defined as that which operates the basic components of the system such as points and signals. From here the components of the field elements are triggered and monitored with regards to their current operating state.

Signaller and Operation Control Level (Man-Machine Interface)

The signaller is the person who directly induces the train movement. However, there is a preceding planning stage with regard to the railway operation requirements. The signaller makes the decision on the basis of the corresponding timetable documents, the correct time at which each movement should occur, and with consideration of the current operating situation. He thus has an element of discretion at his disposal. The ease and effectiveness with which he can use this can be very different. It depends on the technical generation of information by the system in general and on the type of the system used in particular.

The standard of the status signals, which informs the signaller about the current state of operation, is also system-dependent.

Interlocking Level

The task of the central vital safety module is to transform the signaller inputs into control commands that are supposed to lead to a proceed signal. It is important that conflicting movements are excluded and route elements for one's own movement (such as points) are locked before the proceed signal is displayed.

Those are the ultimate vital tasks, which are discussed in the immediately following chapters of the book. Basically, it is about the prevention of inadvertent wrong signaller inputs that might lead to dangerous situations.

Interlocking Station

These structural elements are technically and organisationally pooled in an interlocking station. The control distance of an interlocking was in the past limited by technology, such as the

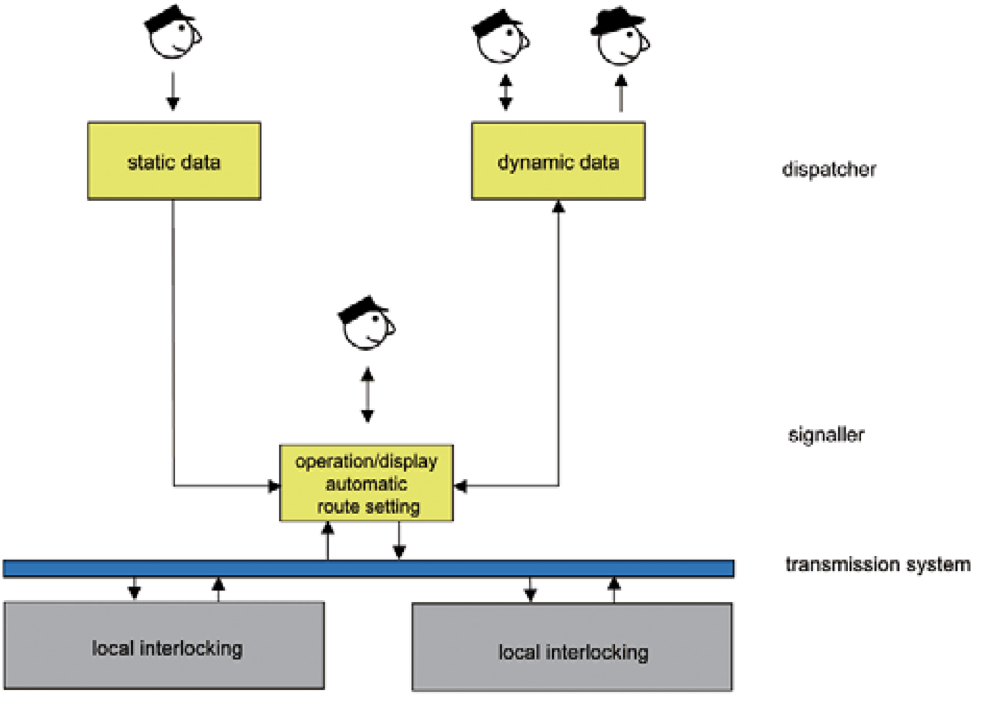

Figure 1.4: System solution centralisation

maximum distance at which a signaller could operate a semaphore signal. For many reasons, control distances have often not been extended beyond the borders of railway stations[1]. In many countries the organisational classification of railway stations and open lines is still held today. However, the technical control distance of modern electronic interfaces are theoretically and practically unlimited and are defined in terms of expedience.

Dispatcher

Basically, the railway operation is communicated to signallers by means of a timetable. However, there are numerous reasons to have a dispatcher level above that of the signallers, which fulfils central and overlapping tasks (figure 1.4). Accordingly, these tasks are supported by railway operation control facilities. There are systems in which interlockings are connected to operation control systems. At the interlocking level, operation then occurs without the local signaller. The operator gets both the signaller and the dispatcher tasks. As a necessary consequence, control processes are strongly automated.

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[1] Railway stations, as meant here, are railway facilities with at least one set of points, where trains are allowed to start, terminate, cross, pass or reverse by changing tracks (back shunt). Home signals mark the border between open line and stations.

2 Safety and Reliability in Signalling Systems

Valerij Sapožnikov, Vladimir Sapožnikov, Enrico Anders, Jochen Trinckauf

2.1 Safety Basics

2.1.1 What is RAMS(S)?

The rail related norm EN 50126 (CENELEC 1999) carries the term RAMS in its name: Railway Applications – The specification and demonstration of reliability, availability, maintainability and safety (RAMS). This norm defines procedures for railway companies, the rail industry and its suppliers in the European Union, to implement a management system for reliability, availability, maintainability and safety. This management is to be applied during the complete life cycle of a system (figure 2.1) and to permit harmonisation of the technical level of safety. Through this, national restrictions are avoided and competition and interoperability are therefore strengthened.

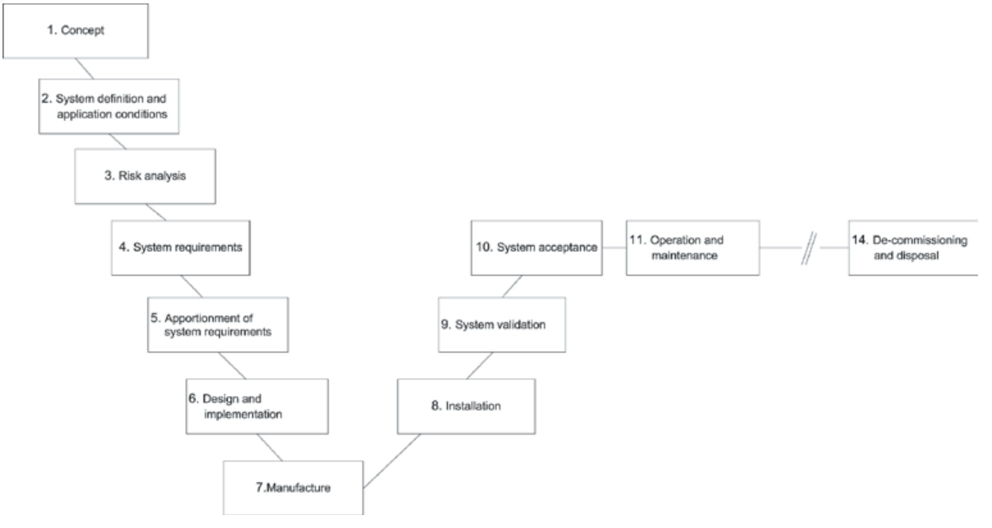

Figure 2.1: Phases in the life cycle of systems in the so-called V-diagram, according to EN 50126

2.1.2 Safety/Security

Frequently, the abbreviations 'RAMSS' or 'RAMS(S)' are used. The two words safety and security need to be defined.

Safety means the functional safety within the system and protection against hazardous consequences caused by technical failure and unintended human mistakes. **Security**, by contrast, protects against hazardous consequences caused by wilful and unreasonable human actions.

A simple example is an emergency exit door. To ensure that it can be released from the inside in an emergency, the door has to be opened by a simple handle with no lock. That is a matter of safety. But to stop intruders, the door has to be locked from the outside. That is a matter of security.

The majority of components in railway signalling, e.g. track clear detection, interlockings, point switching, signals and level crossings, are safety related. But measures to protect buildings containing interlocking equipment from unauthorised intrusion are security related.

2.1.3 Availability, Reliability und Maintainability

This section describes the meaning of 'RAM'. Reliability, availability and maintainability. These interact with each other as shown in figure 2.2.

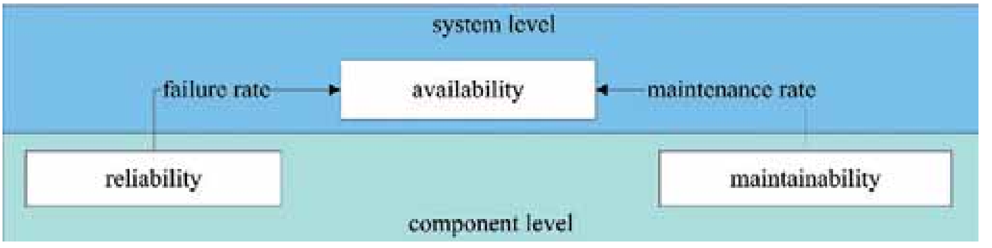

Figure 2.2: Interference in 'RAM'

The term **availability**, according to EN 50126 (CENELEC 1999), is defined as:

The ability of a product to be in a state to perform a required function under given conditions at a given instant of time, or over a given time interval, assuming that the required external sources of help are provided. This means that the system (here called 'product') will fulfil the required tasks (here called 'functions') under the defined framework conditions.

An important function of the railway system is the safe transport of persons and goods. The preconditions to fulfil these functions are the *required external sources of help*. In the case of the railway system, these are reliable functioning technical components such as interlocking between points and signals, the track clear detection and the avoidance of following or crossing trains in one block section, but also reliable performance of railway staff in undertaking their tasks. Therefore, **reliability** is an important factor for availability. Reliability is defined in IEC 61508 (IEC 2001) as follows:

The probability that an item can perform a required function under given conditions for a given time interval (t1, t2).

The phrase *required function* means that a component here referred to as an item works in conformance with its specifications under the precondition that it has done so on entering service and that no maintenance has since been necessary. This results in the requirement of failure-free working of the component during a specified time period.

Therefore, besides reliability, **maintainability** of the used components is an important factor for availability of the system. This term is defined as follows in EN 50126 (CENELEC 1999):

The probability that a given active maintenance action, for an item under given conditions of use, can be carried out within a stated time interval when the maintenance is performed under stated conditions and using stated procedures and resources.

Reliability and maintainability are both probability values which lead to failure rates and maintenance rates respectively, related to a defined time period.

An important requirement of the railway system is high availability. In particular, this is a result of its strong link with safety: The more available a technical system is, the longer it can be operated regularly and the lower is the ratio where it is operated in degraded mode. As systems work on a lower level of safety in degraded mode, high availability reduces the probability of a dangerous error in degraded mode operation.

From the requirement of high availability, two requirements result regarding reliability and maintainability:

- low failure rates
- high maintenance rates

2.1.4 Role of the RAMS Components in the Railway System

What are the practical consequences of the RAMS components in a railway system? In a common public opinion the railway counts as ‘safe’ or in other words the public acceptance of railway hazards is extremely low in comparison with other transportation systems like roads. To fulfil these expectations, the railway system has to achieve a high level of safety through the strategy of avoiding accidents. As risk can never be zero, safety can never be perfect. By definition, *safety is the absence of an inadmissible risk*. The railway system has to run in the zone of safety but a certain level of remaining risk cannot be avoided. But it is self-evident that this remaining risk must be low and so the resulting safety as high as necessary.

As shown in figure 2.3, the **risk** is defined as the *product of hazard rate multiplied by damage*. Damage in a railway accident will count as ‘high’ in most cases so that risk can only be decreased by lowering the hazard rate. This again will be achieved by high availability. As shown in chapter 2.1.3 above both the components of the reliability of system design and maintenance during its operation are able to influence the availability. This is mainly responsible for the safety of a railway system.

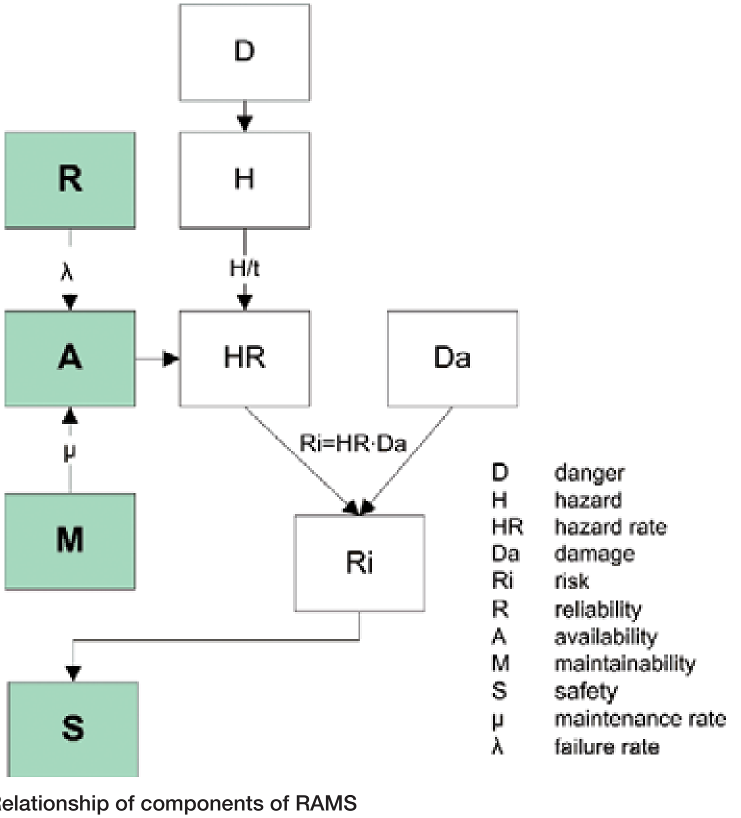

Figure 2.3: Relationship of components of RAMS

Railway signalling is one of the few technical fields which are still mainly oriented nationally. However, the international aspect becomes more and more important. The purpose of this book is to give a summary and comparison of railway signalling and interlocking methods at the international level.

The contents cover the whole range of signalling equipment and methodology. They include:

- basics of safety
- operational basics of signalling
- principles of interlocking
- technical interlocking and block systems
- systems for centralised operational control
- shunting control systems
- movable track elements such as points
- detection
- signals
- train protection systems
- level crossings
- hazard alert systems

The book follows a generic approach and sets out the basic principles, giving the reader a better understanding of the solutions applied in different countries. It is intended for experienced railway signalling experts and railway operators, as well as for students who want to extend their signalling knowledge to an international level. More than 20 authors from universities and practitioners from various countries have contributed, and much literature has been used to gain the information.

The authors have also discussed the topics of the book widely, to develop an international understanding. The result is a book which records the principles and the present situation on railway signalling throughout the world.

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