3rd Edition

Gregor Theeg | Sergej Vlasenko (Eds.)

Railway Signalling and Interlocking

International Compendium

EDITION Eurail press

eBOOK INSIDE

Railway Signalling and Interlocking

International Compendium

3rd Edition

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

Authors:
Dr.-Ing. Enrico Anders, Germany
Jelena Arndt, MA, Serbia/Austria/Germany
Prof. Dr.-Ing. Thomas Berndt, Germany
Prof. Dr. rer. nat. Jens Braband, Germany
Dipl.-Ing. Dmitriy Chelobanov, Russia/Kazakhstan/USA
Dipl.-Ing. Artem Glybovskii, Russia/Germany
Dipl.-Math. Stephan Griebel, Germany
Dipl.-Ing. Thomas Heinig, Germany
Dr.-Ing. Michael Dieter Kunze, Germany
Dr. Eng. Andrej Lykov, Russia
Doc. Ing. Peter Márton, PhD., Slovakia
PD Dr.-Ing. habil. Ulrich Maschek, Germany
Dr.-Ing. Daria Menzel, Russia/Germany
Dr. Eng. Nino Mukhigulashvili, Georgia
Rolf Natterer, Germany
Prof. Dr.-Ing. Jörn Pachl, Germany
Dipl.-Ing. (FH) Martin Rosenberger, MSc, Austria
Dipl.-Phys. Carsten Sattler, Germany
PD Dr. Andreas Schöbel, Austria
Dr.-Ing. Eric Schöne, Germany
Dipl.-Ing. Max Schubert, Germany
Dr. Eng. Dmitrij Shvalov, Russia
Dipl.-Ing. Martin Sommer, Germany
Dr.-Ing. Gregor Theeg, Germany
Prof. Dr.-Ing. Jochen Trinckauf, Germany
Dr.-Ing. Sergej Vlasenko, Russia/Kazakhstan/Germany
Dipl.-Ing. Dirk Zimmermann, Germany

EDITION
Eurail press

German National Library bibliographic information
The German National Library catalogues this publication in the German National Bibliography; detailed bibliographic information can be found on http://dnb.de.

Publishing House:	PMC Media House GmbH Werkstättenstraße 18 D-51379 Leverkusen
Office Hamburg:	Frankenstraße 29 D-20097 Hamburg Phone: +49 (0)40 228679-506 Fax: +49 (0)40 228679-503 Web: www.pmcmedia.com E-Mail: office@pmcmedia.com
Managing Directors:	Detlev K. Suchanek, Antonio Intini
Editorial Office:	Dr. Bettina Guiot, Alexandra Schöner
Distribution/Book Service:	Sabine Braun
Cover Design:	Pierpaolo Cuozzo (TZ-Verlag & Print GmbH, Roßdorf)
Typesetting and Printing:	TZ-Verlag & Print GmbH, Roßdorf

3rd Edition 2020

ISBN 978-3-96245-169-1

A publication by

PMCMedia
International Publishing

Contents

Preface

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.

For a long time, there were no common terms and definitions, and there was a corresponding lack of understanding of the underlying principles. In the technical literature, descriptions of railway signalling principles tended to concentrate on the railways of a single country, or group of countries.

Ten years ago, the first edition of the textbook was published, with the intention that merely comparing different national solutions was not sufficient. What was really needed was a generic description of the principles that allowed the reader to look outside the national viewpoint. The result was that an international team of experts analysed and compared operation and signalling principles in different parts of the world, with the aim of putting together a systematic overview.

The book became a great success, used by many universities, libraries, companies and private individuals, and was very well received by readers. The demand was higher than expected, and technical developments have continued to advance. The result has been the publication of the second and now this third updated edition. This new edition builds upon its predecessors and adds much new content to reflect subsequent important developments.

We would like to express our gratitude to all readers for their support. We 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 for future editions are always welcome.

We wish to thank Alexandra Schöner, Dr Bettina Guiot and the whole staff of PMC Media House for their support in this venture. We also thank Uwe Lehne of TU Dresden for technical support in the production of the manuscripts and railway author John Glover for the linguistic editing. We also thank Aleksej Efremov, editor of the journal *Railways of the World*, for his advice and supply of a variety of illustrations, and for the successfully publishing of a Russian edition.

Gregor Theeg and Sergej Vlasenko

October 2019

General note: For better readability, when talking about persons and functions (such as signallers, train drivers etc.), the pronoun "he" is usually used in this book. However, also female persons are equally meant.

PMC Rail
International Academy

Our knowledge for your success

PMC Rail International Academy stands for instruction and further training in the rail industry, independent of the manufacturer and meeting the customers‘ needs. The offer we provide appeals to members of staff on all levels of the company hierarchy – from track workers to managers. Our aim is to develop a training programme covering all activities required for the operation and maintenance of rail infrastructure.

The team of PMC Rail, particularly the competent and practically experienced trainers, is looking forward to sharing its knowledge in an ideal balance of theory and practice. State-of-the-art simulation technology allows training under realistic conditions but without track damage entailing costs in case of errors.

“PMC Rail International Academy is fully committed to the railway system. This commitment is an integral part of our identity. Our aim is to strengthen the railway sustainably and to contribute to its positive development with our offer. We want our knowledge to help optimise the success of the railway system and our customers.”

Antonio Intini,
Managing Director, PMC Rail

PMC Rail International Academy
T +49 (0) 2171 58088-10
E office@pmcrail.com
www.pmcrail.com

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.

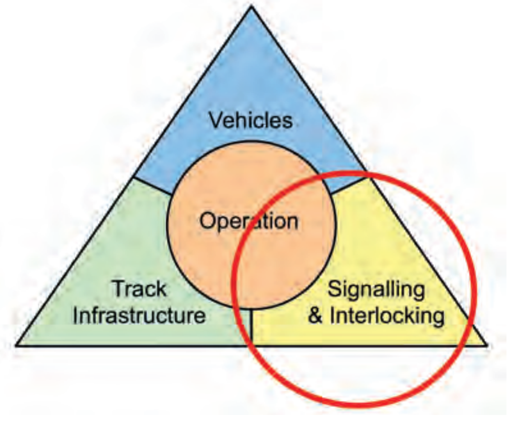

Figure 1.1: Scope of the book in the overall railway system

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.
2. **Long braking distance**: The steel wheel has relatively poor braking performance 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, and braking from 160 km/h to zero needs one kilometre or more. Braking distances increase in some weather conditions, especially when icy or during the leaf fall season. The sighting distances are insufficient for the driver to decide when to reduce speed or stop. The driver has very limited means of avoiding collisions, but has to rely on the technical systems and his own route knowledge to decide when to brake.

The procedure of Timetable & Train Order was even used on most lines with automatic block signals. Although time spacing was replaced by fixed block operation, the traffic was still controlled by train orders. This allowed the railway to have non-interlocked hand-operated points on automatic block lines. A signal-controlled operation in which trains are governed directly by signal indications can only be found on lines with Centralised Traffic Control (CTC). Although CTC is normally associated with remote control of interlocking stations, the basic definition of CTC is that trains are governed by signal indication. This is a frequent cause of misunderstandings between North American and European railway experts, since governing trains by signal indication is the standard form on all European mainlines. This applies even on lines controlled by old mechanical interlocking systems. Formally though, any European line controlled by local mechanical interlocking stations meets the North American definition of CTC.

3.2 Classification of Tracks, Stations and Signals

3.2.1 Classification of Tracks

In signalling and operating rules of many railways, a track is often referred to as a line. A route consisting of just one track is called a single line, while a route with double track operation, i. e., two parallel tracks and a specified direction for normal moves on both tracks is called a double line. In North America, this use of term line is not so common. For operational purposes, tracks are divided in two main classes, which have different descriptions in the rule books of several railways. However, the basic idea is always the same. First, there are tracks that can be used for regular train movements (for the classification of movements with railway vehicles see chapter 3.4). Here, these tracks are called main tracks. Another term mainly used in the British rules, is running lines (since in the British terminology in operating and signalling rules, a track is often referred to as a line). The tracks of the open line, i. e. the sections between stations and their continuation through stations and interlockings, are always main tracks. Main tracks used for passing and overtaking trains are called loops (figure 3.1).

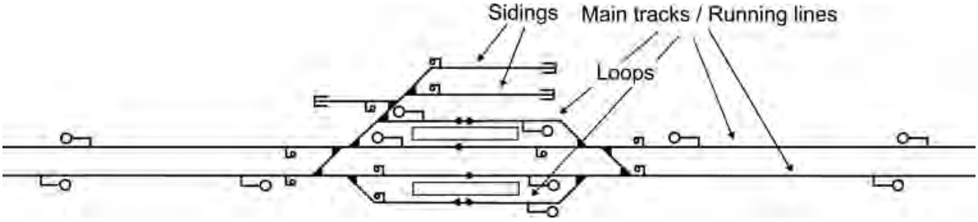

Figure 3.1: Classification of tracks

In a signalled territory, main tracks are equipped with signalling appliances for train movements. Points on main tracks are usually interlocked with signals. Sidings are all tracks that must only be used for shunting movements. In shunting areas with hand-throw points and in older interlocking systems that do not provide shunt routes, points in sidings are often not interlocked. An arrangement of sidings for making up trains, storing equipment, and similar purposes, is called a yard (figure 3.2).

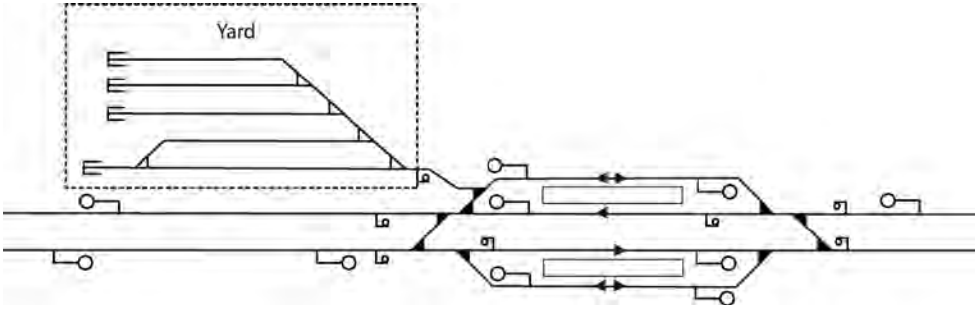

Figure 3.2: Yard

In the North American terminology, loops are called sidings. Whether or not a siding of that kind is considered as a main track depends on the operating procedure of a particular railway. Even in signalled territory, points in main tracks are not necessarily interlocked with signals (White 2003).

3.2.2 The Role of Lineside Signals

While being gradually replaced by advanced radio-based train control systems, lineside signals are still the most common technology for controlling train movements. Concerning the control philosophy, there are two different control principles to be found on individual railways:

a) railways on which signals just indicate if and under what conditions a movement may enter the section beyond the signal independently from the kind of movement to be made

b) railways on which the signal aspects authorise a specific kind of movement

The principle a) is to be found on North American railways but also on some railways outside North America (e.g., on the Dutch railways). The principle b) is the dominating principle outside North America. It is typical for most railways where train movements are strongly separated from shunting movements (see chapter 3.4). On these railways, there are two basic kinds of lineside signals:

– main signals
– shunting signals

Main signals authorise a train movement to enter a track section. This is typical for almost all railways outside North America. In a fixed block territory with a signal-controlled operation, train movements are authorised by signal indications. Apart from when the approach line has a low maximum speed, a signal that authorises a train movement requires an approach aspect (also called 'warning aspect' or 'caution aspect') at the braking distance. This is because the stopping distance is generally greater than the distance the driver can see ahead. The approach aspect is necessary for safe braking when approaching a stop signal.

In a territory where the distance between signals does not much exceed the braking distance, the approach aspect is usually provided by the signal in rear. In a territory with very long distances between main signals, distant signals are placed at the braking distance in approach to a main signal (chapter 7.3.3). A distant signal warns; it can only provide an approach aspect for the signal ahead. It cannot show a stop aspect.

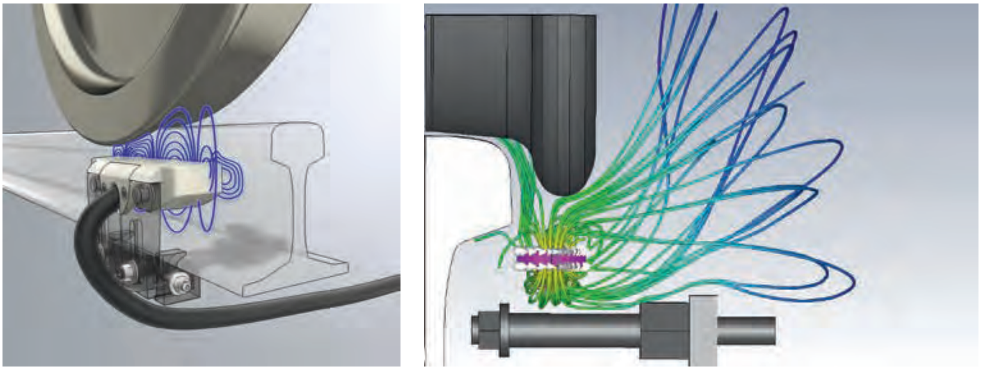

Figure 5.11: Principle of inductive detector (example RSR123)

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 (e.g. bridges, aircraft wings). 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 λB can be measured (figure 5.12). This wavelength depends on the temperature and strain changes.

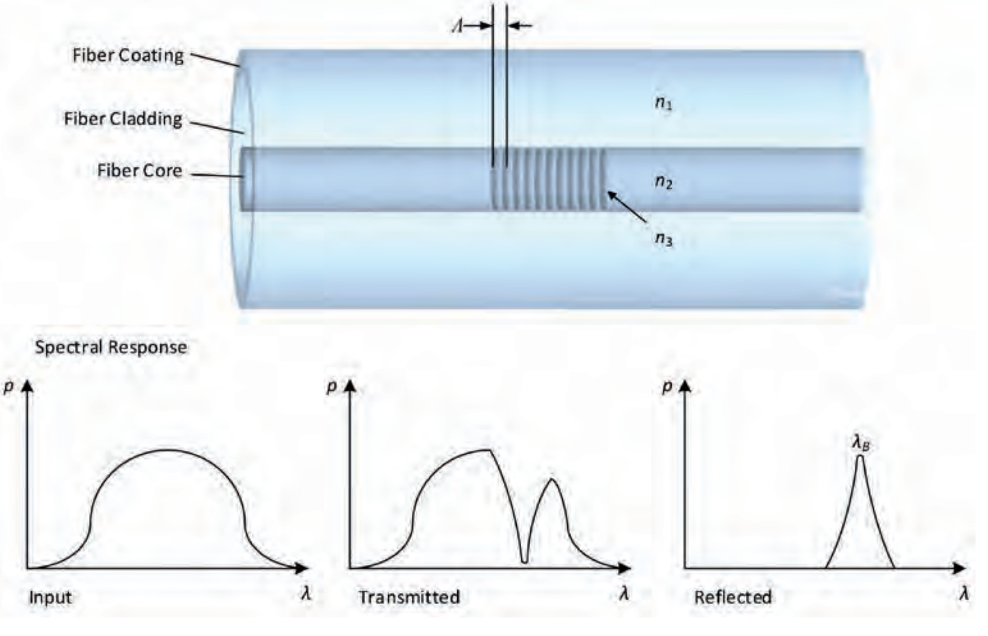

Figure 5.12: Principle of fibre bragg grating optical detection (Heyder/Arezki 2018)

The Lite4ce sensor (*Thales*) uses this principle with two FBG-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 (chapter 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 de-install 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.

14.1 Hazard in Railway Systems

According to an ontology based approach, there are a number of dependencies between different fault states within the railway system. Generally, one fault state can lead to another fault state, usually being much worse than the one before. Thus, in an abstract view, fault states can be interpreted as causes and the resulting fault states can be interpreted as consequences (figure 14.1).

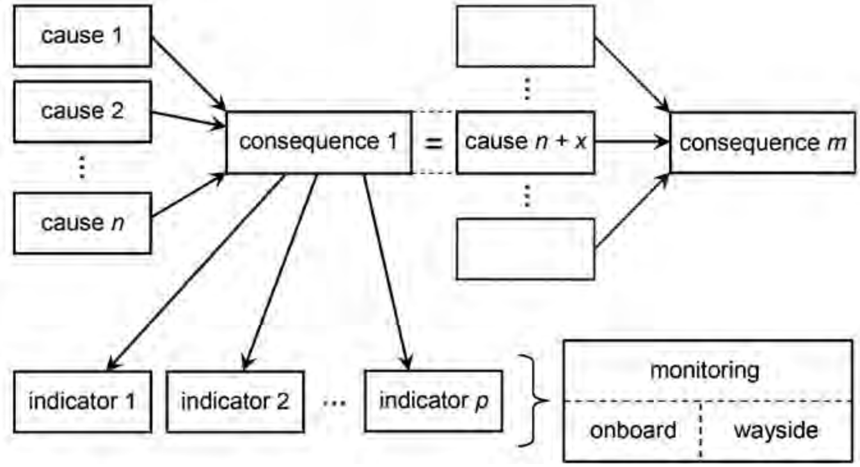

Figure 14.1: Cause-consequence-chain

If there are no means of monitoring to recognise them, the final consequence of many fault states is a derailment. Therefore, it is necessary to prevent the long-lasting occurrences of all critical fault states. The majority of relevant fault states cannot be directly observed due to trains running at speed. Thus, on-board or wayside monitoring systems can provide a number of measurements that can indicate a fault state (Schöbel/Maly 2012).

Generally the estimation of risk is a difficult task, because an accident data base only provides indicators. Dangerous situations during operations which did not lead to an accident are normally not stored in an accident data base, although these situations are important for the risk estimation. To compensate for this missing information, the judgement of operational experts is very important. Of course, the first task is always to have a closer look at the accident data base if there are reliable values available for the risk estimation. Therefore it is necessary to know details about the history of an accident. Sometimes a predefined categorisation is not suitable for a specific accident. On the other hand, the accident data base gives a first indicator of the potential risk. The specific view on the accident data base is given by this aspect if it is possible to recognise one fault state by some wayside monitoring system. So the fault states which are in the focus of such an analysis must be vehicle related and appear for a certain time to be measured by some detector.

The calibrated risk matrix can be used to put in the vehicle related fault states which may seriously damage the infrastructure. Therefore it is necessary to check that all well-known fault states have been considered. For each fault state, an analysis based upon the national accident data base can be carried out for the infrastructure manager to estimate the risk caused by each fault state. Risk is always defined as a product of probability and severity.

The usage of the risk matrix in signalling issues is state-of-the-art. For the operational application, the qualitative descriptions of probability and severity must be quantified. The calibrated matrix must cover the range of operational scope (Schöbel/Vek 2012).

Weekly	0,48	4,8	48,0	480,0
Monthly	0,12	1,2	12,0	120,0
Quarterly	0,04	0,4	4,0	40,0
Annually	0,01	0,1	1,0	10,0
Once in 10 years	0,001	0,01	0,1	1,0
Once in 100 years	0,0001	0,001	0,01	0,1
	10.000 €	**100.000 €**	**1.000.000 €**	**10.000.000 €**

Figure 14.2: Risk matrix for demand analysis of hazard monitoring in million € per year

14.1.1 Safety Related Hazards

In terms of derailment prevention, the following causes are be observed:

- blocked brakes or wheels
  Continuous braking may lead to a derailment of a wheelset due to additional longitudinal forces resulting from certain non-ideal movements of the train, such as acceleration, movement around curves, or an unsuitable combination of wagons by their relative weights. Moreover, the thermal stress on the wheels and axles may lead to the displacement of one or both wheels on the axle and thus causing an increased derailment risk. Furthermore, due to the massive frictional heat generated, blocked brakes can lead to temperature increase of axle boxes. Finally, they can cause fires in the bogie construction, the sparks which might cause lineside fires.
- broken axle shaft
  If the rigid link between left and right wheel is missing, each of the wheels will be guided by only one axle box, which can again lead to derailment.
- broken axle stub
  In case of a broken stub shaft, the vertical forces cannot be contained by the axle box. This can lead to the wheel being displaced from the axle, leading to a derailment.
- broken wheel
  A broken wheel cannot guide the train, resulting in a high possibility of derailment.
- faulty flange of wheel and flat spots
  In case of the increased wear of the wheel flange the rail-wheel interaction will be more intensive, which may lead to a derailment under special operational conditions. If parts of the wheel flange are broken, the guidance will be missed completely and the wagon could derail.

- faulty suspension
  A faulty suspension may cause a loss of contact between wheel and rail. Furthermore, due to the reduced absorption capability of faulty suspensions, the vehicle body may oscillate. Both may lead to a possible derailment.
- faulty frame
  Unbalanced wheel loads can be a result of a faulty frame. The reduced lateral guidance of unloaded wheels might lead under certain non-ideal running conditions (curves, etc.) to a derailment.
- imbalance (in motion)
  Unloaded wheels do not provide lateral guidance. This might lead to a derailment under certain non-ideal conditions (curve, etc.).
- violation of clearance gauge
  If the vehicle fouls the structure gauge, contact with wayside assets (e.g. signal masts, power supply masts) can occur. In extreme cases, this might lead to a derailment. Also loose load fastening straps might reach the contact wire, resulting in a flashover or fire.
- faulty buffer
  If there are cracks on the buffer head, their ability to slide against other buffers will be hindered. This can cause derailments or overriding buffers. If the buffer head fails, one buffer might break off and fall on the track.
- overriding of buffers
  Due to an overriding of buffers it is not possible for buffer discs to slide causing an axle to be pressed out of the track.
- objects within the clearance gauge
  If external objects protrude into the clearance profile, a collision with parts of a moving vehicle might occur. Depending on the object, such events might lead to a derailment. This applies also to objects lying on the infrastructure.
- variation of width of the track gauge
  The width of the track gauge, being either too large or too small, by distortion or otherwise, can be the cause of a derailment.
- track distortion
  Too large track gauge might lead to a derailment.
- broken rail
  A breakage with a damaged rail head might cause a loss of the guidance, leading to a derailment. If there is a vertical rail break, the rail will move laterally under stress, also causing a derailment.
- insufficient track bed
  Wear of ballast causes subsidence which can result in failures of the track. Therefore, the proportion of Y and Q forces might be higher, causing a derailment. Moreover, a reduced edge of ballast might reduce the lateral resistance and track distortion might be the consequence.

If these causes are not recognised in time, a derailment will result. Additionally, the following hazards need to be monitored:

- hot (damaged) boxes
  The dangers caused by hot axle boxes are well known, especially derailment, and usually in conjunction with the irregular distributions of loads within vehicles. The best indicator for damaged boxes is the temperature of the box itself. Monitoring of the axle box temperature can prevent breakage of the axle shaft or axle stub.
- displaced cargo
  If loads are inadequately or incorrectly secured, they may foul the clearance gauge or even completely displaced from the wagon.

As a standard work on **Railway Signalling and Interlocking**, this book documents the principles and current situation of international signalling technology.

This 3rd edition of this work contains some fundamental extensions and the latest findings on the following topics:

- Innovations in train control systems (ETCS, CBTC, PTC)
- Improved descriptions for RAMS (Reliability, Availability, Maintainability, Safety)
- Innovative methods for train detection and hazard alert systems
- Modern diagnostic solutions
- Innovations in electronic interlocking and communication networks

This book combines the knowledge and experience of more than 20 renowned international authors from universities and the railway industry. It offers practical help for railway signal technicians, operators and manufacturers as well as teachers, scientists and students 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 (PC, tablet, smartphone) will have electronic access to all the terms and references through a search function.

ISBN 978-3-96245-169-1