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COMPENDIUM

Railway Vehicle Maintenance

EDITION
Eurail press

eBOOK INSIDE

Bibliographic information published by the Deutsche Nationalbibliothek:
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
Translation/Proofreading:	Notburga Preining
Distribution/Book Service:	Sabine Braun
Cover Design:	Pierpaolo Cuozzo (TZ-Verlag & Print GmbH, Roßdorf)
Typesetting and Printing:	TZ-Verlag & Print GmbH, Roßdorf

1st edition 2020

ISBN 978-3-96245-203-2

A publication by

PMCMedia
International Publishing

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Preface

Just as with any maintenance activity, the maintenance of railway vehicles has as its aim to maintain or re-establish the safe, reliable and economical function of the "railway vehicle". However, two characteristics of rail vehicle maintenance are of special significance.

First of all, the safety aspect. The maintenance of railway vehicles plays a crucial role in safeguarding the high level of safety that is expected by society in railway traffic. A crack in supporting elements that has not been detected, a screw that has not been tightened properly or a failure of the electronic brake control system can have devastating consequences. Therefore, the people working in rail vehicle maintenance have a particular personal responsibility to be aware of and be proficient in the technical rules and standards as well as the corresponding procedures, to develop them further if weaknesses have come to light and to monitor their consistent application. Targeted safety, quality assurance, environmental and occupational safety management form part of their toolkit.

The second aspect is the exceptionally high technical complexity of rail vehicle maintenance. Contemporary railway vehicles contain mechanical components such as diesel engines, hydraulic transmissions, gear drives, high-performance rolling contact bearings and structures made of light metal, special steels and plastics. They contain electrical, power electronic and telecoms electronic components as well as computer systems, just to name a few. In addition, appropriate processes such as measuring processes, materials testing processes, manufacturing processes and joining processes have to be mastered. A knowledge of the relevant rules and standards is a prerequisite, as is keeping accurate maintenance documentation. Where rail vehicle manufacturers usually have specialist departments, the rail vehicle maintenance company will have be knowledgeable about all of these areas of expertise and continuously keep updated on new developments.

The demands mentioned will require solid training and continuous professional development that keeps pace with the rapid technological developments in all areas. The aim of this compendium is to provide a brief overview of the essential requirements that have to be met by the people working in rail vehicle maintenance on a day-to-day basis. In addition, it shall serve as a toolkit for students to introduce them to this complex and interesting subject matter.

Reinheim, February 2020
Prof. Dr.-Ing. Wolfgang Rösch

1 Basic principles of maintenance

1.1 Terminology

The maintenance of railway vehicles is essentially the means of maintaining or re-establishing the target condition of vehicles during their entire service lives. The target condition is defined as the entirety of possible conditions, between factory limit state (new condition) to serviceability limit state in all relevant feature values, cp. DIN 27200:2011 [1] and EN 17018:2019 [2]. The serviceability limit state is the condition where the accepted risk of operational safety or reliability has been reached and would be exceeded if operation was continued, which means that the vehicle must no longer be operated. It may well be that the vehicle is still capable of operation.

When in operation, vehicles are exposed to various influences and loads that change their condition. These include friction, impact loading, pulsating, vibrating and thermal stresses and ageing. These influences will result in material degradation, rolling contact fatigue, fatigue failure, overload breakage and changes in material structures or properties.

The vehicles as technical systems are highly complex, equipped with mechanical, electrical, electronic, pneumatic, hydraulic and software components. Just as complex are the maintenance processes, procedures and methods and the equipment and tools required. Extensive terminology has developed from this. It contains some general terminology relating to the maintenance of technical systems, as laid down in standards DIN 31051 [3] and EN 13306 [4], but also railway-specific terminology, as laid down, for instance, in the standard series 27200 ff. for railway vehicle maintenance. Since railway vehicles are often managed in an asset management system, terminology from asset management is also used, see EN 16646:2015 [5] and DIN ISO 55000:2017 ff. [6]

The terminology associated with the preparation and changes of maintenance programmes is detailed in EN 17018:2019 [2] and in EN 17023:2019 [7] (previously DIN 27200:2011 and DIN 27201-1:2006). In some parts it deviates considerably from the terminology introduced in practice and which was used until the new standard was published. However, as it forms the basis for the use of terminology in all further rules and standards on railway vehicle technology, for example in the Technical Specifications for Interoperability (TSI), which are currently revised, there is no alternative but to adapt to the changes in terminology quickly.

Therefore, a few basic terms are listed below:

- **Maintenance system:** complete set of technical, organisational and other specifications for fulfilment of the vehicle maintenance to ensure that the vehicles which are maintained are in a safe state for running
- **Maintenance manual:** compiled set of information for the maintenance of the entity to be treated (vehicle or component)
- **Maintenance plan:** railway vehicle or component based structured document containing a set of planned maintenance activities (in practice also referred to as maintenance steps or periodicity steps) and their maintenance interval limits based on performance parameters, e.g. vehicle mileage, operating hours of the vehicle or component, operating cycles etc.
- **Step frequency table:** document, as part of a maintenance plan, assigning maintenance interval limits and their sequence to planned maintenance activities (previously the register of maintenance activities)
- **Inspection:** determination of the current condition of components or the vehicle
- **Maintenance:** maintaining the target condition of components or the vehicle

- **Repair:** restoring the target condition of components or the vehicle
- **Elimination of weaknesses:** Improvement of target condition by elimination of recognised weaknesses without functional expansion or upgrade

1.2 Development of railway vehicle maintenance

The historical development of rail vehicle maintenance is characterised on the one hand by the development of railway vehicle technology and on the other hand by the state of the art in measuring, testing, diagnostics engineering, handling and lifting technology, supply and disposal technology, i.e. areas outside the realms of rail vehicles that are nonetheless necessary to determine the current condition or maintain or re-establish the target condition of a vehicle.

The introduction of the railways also created the requirement to maintain the rolling stock. In the beginning, maintenance work was carried out in the locomotive shed or depot. The work was carried out by the drivers. Not long after, as a result of the rapid growth of the railways, special workshops with their own staff sprang up that were responsible for the maintenance. By the middle of the 19th century, a distinction was made between depots that would ensure the daily availability and central workshops, later repair workshops, that would carry out major repair work. With growing expertise, companies set periodic work tasks at regular intervals, initially for safety-relevant components, e.g. steam boilers. This should prevent the dangerous boiler explosions, which in those days would be a frequent occurrence due to material fatigue. Other parts of the locomotives and wagons, too, were highly maintenance-intensive taking into consideration the state of the art of the time. For instance, moving parts were guided by plain bearings, which meant that mechanical wear was the main concern of maintenance. As this sector of the industry was only just evolving, the railway workshops were often left to their own devices to solve a wide range of issues. This resulted in a high level of vertical integration. For instance, repair workshops would have foundries, blacksmith's shops, presses, mechanical workshops for machining procedures, welding shops, and later on electrical workshops and chemistry laboratories. This production depth was also necessary because standardisation and interchangeable parts production were in their infancy. The parts that had to be reconditioned had to be refitted into the same vehicle from which they were removed.

Even depots had many individual workshops, such as bearing foundries, upholstery workshops for passenger trains, joineries for all the wooden parts of wagons as well as extensive hoisting gear for lifting the vehicles or dismantling the wheelsets. By the end of the 19th century, the maintenance tasks had been developed such that it was possible for the railway to become the safest means of transport, thanks to the high quality of maintenance. The Prussian-Hessian Workshop Regulation of 1880 was the first binding maintenance regulation. Around 1895, scheduled preventive maintenance was introduced and consisted of a time-limited system of periodic inspection and repair work.

As part of the industrial development in the early 20th century, standardisation and interchangeable parts production started to flourish so that on-site maintenance evolved more and more into a parts replacement activity. The replaced parts would then be reconditioned in specialist workshops. This considerably increased the availability of the vehicles and the economic efficiency of maintenance. More and more, maintenance had to deal with new vehicle technologies. The breakthrough of the diesel and electric locomotives in the middle of the 20th century brought a considerable change to the requirements for workshops. Completely new qualifications and equipment were necessary to be able to maintain these vehicles. At the same time, the developments in standardisation and interchangeable parts production had brought about new forms in the division and organisation of labour.

Maintenance was more and more split into the replacement of worn or defective parts on the vehicle on the one hand and in their reconditioning on the other hand. At the end of the 20th century the term "light" or on-site maintenance was coined for the former. It is usually carried out during stoppages and does not result in prolonged vehicle downtimes. On the other hand, larger reconditioning work on the vehicle, which requires it to be taken out of operation for a longer period of time, and the reconditioning of dismantled components were called "heavy" maintenance. Since determining the condition of the vehicle during that period would usually require comprehensive dismantling into its component parts, the term "overhaul" was created. This describes an extensive activity which includes both the "recurrent examination" required by law, i.e. a regular inspection to determine the current condition of the vehicle and its components, and preventive scheduled measures to maintain or re-establish the target condition and to ensure sufficient wear until the next overhaul.

Fig. 1-1: Modern railway vehicle workshop

With the emergence of power and electronics communications in rail vehicle construction at the end of the last century, rail vehicle maintenance was once again faced with huge challenges. It was not only the technological change that yet again required new qualifications and equipment. The different failure behaviour of electronic assemblies compared to the measurable wear of mechanical parts also had an impact on maintenance strategies. In turn, this resulted in the development of complex diagnostic tools for fault recognition in electronic assemblies. This and the increasingly modular structure of the vehicles, that facilitates component replacement as part of the on-site ("light") maintenance, gave way to the classic vehicle overhauls with complete dismantling being replaced more and more with modular maintenance plans that facilitate condition-based maintenance at component level. This development also had an impact on the development of rail vehicle workshops. Modern workshops have all the equipment available that is required for a short workshop downtime and good working ergonomics (Fig. 1-1).

The liberalisation of the transport market and the ensuing competition that is primarily price-driven also created new economic pressures for maintenance (Fig. 1-2).

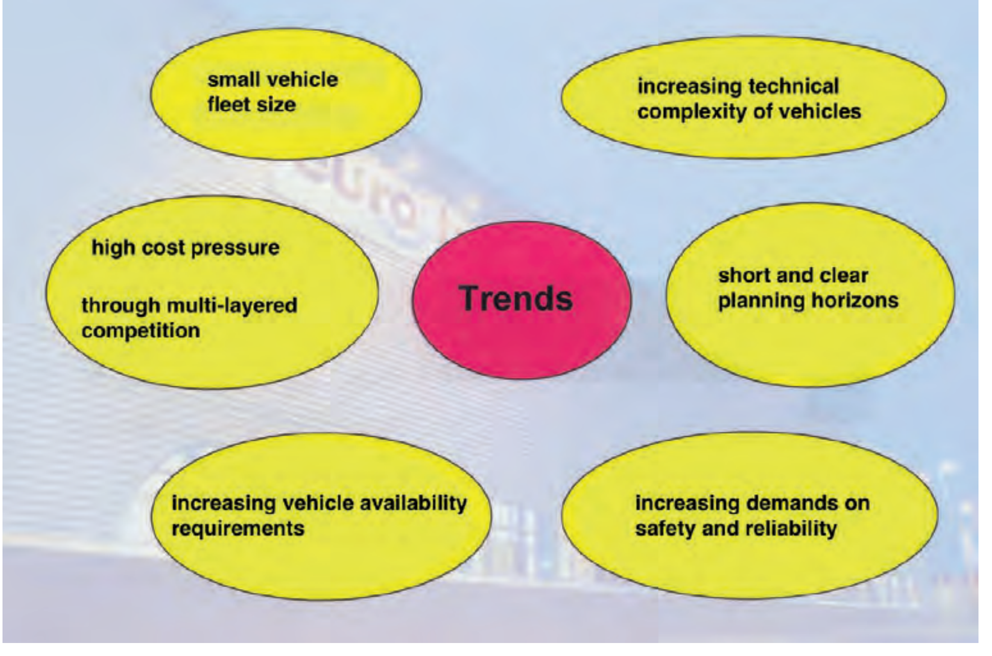

Fig. 1-2: Development trends in rail vehicle maintenance

One thing has remained constant throughout the history of the railway: Railway vehicle maintenance reflects the status of railway vehicle technology as it has to deal with all the technological disciplines combined in a railway vehicle out of necessity. Furthermore, establishing the condition of parameters that cannot always be measured directly and the knowledge about the expected wear, failure and ageing behaviour depending on planned operation and its stresses become more and more important for estimating the residual service life of components. In future, this will increasingly facilitate a predictive maintenance that will better utilise the residual wear and service life of components. For the maintenance companies this requires risk assessments based on fault and failure probabilities for which they need statistically robust data. Therefore, data collection and evaluation will become increasingly important for maintenance. Following a general trend in engineering, railway vehicle engineering is gradually moving from designing for fatigue strength to designing for a defined service life. This will reduce the manufacturing, operating and maintenance costs to a minimum.

3 Processes

3.1 Vehicle-related process

The vehicle-related process of maintenance describes the type, sequence and contents of the maintenance activities that are carried out on a railway vehicle either in a workshop or a depot. Here, the maintenance process will usually be integrated into the depot's vehicle work processes. Figure 3-1 shows such a vehicle-related throughput process in a depot.

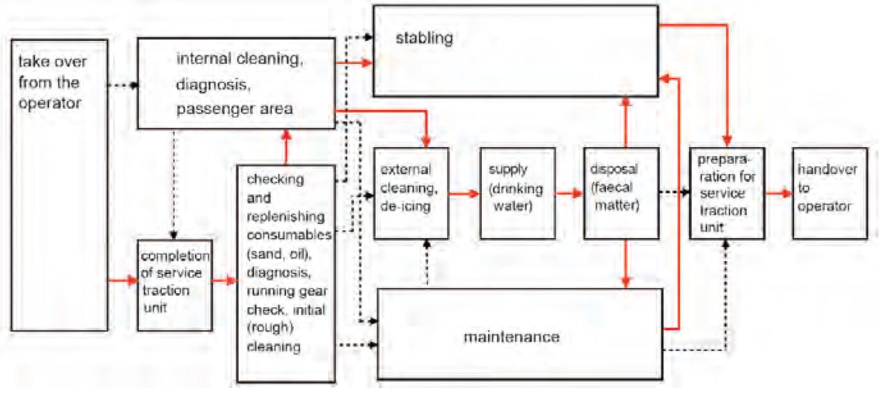

Fig. 3-1: Work and maintenance process

The maintenance process includes scheduled (preventive) activities based on the maintenance plan and non-scheduled (corrective) activities based on findings or results of on-board diagnostic systems or diagnostic systems operated by the workshop. While the maintenance plan determines the maintenance activities and the contents of the activities together with procedure and work instructions and the register of maintenance intervals determines the due dates and sequences, any processes going beyond this need to be determined by the ECM as part of its MMS. These may range from the point of receiving the vehicle and maintenance order through to the release of the vehicle back into railway operation.

Here, several sub-processes that occur in certain phases have to be taken into consideration. The sub-processes and procedures can be divided into maintenance technical performance processes that are described in the technical regulations including the technical procedure and work instructions, and into maintenance management processes that are to be specified by the ECM in its MMS.

In the maintenance planning phase, a maintenance order is generated that is derived from the maintenance programme for scheduled maintenance activities. Insofar as the required corrective maintenance activities are known at this point, they are included in the worklist for the specific vehicle and integrated in the works order after they have been given the relevant priority. In addition, this includes the scheduling of the vehicle throughput through the factory sidings and the maintenance stations, which needs to be coordinated with the throughput process in the depot.

Once the vehicle has been delivered to the workshop for maintenance, the maintenance control phase will begin. The aim here is to keep the workshop standing time of the vehicle as low as possible while making the most economical use of resources and meeting the requirement to return an operationally safe vehicle for railway operations on time.

Due to the increasingly modular design of vehicles with component diagnostic and replacement options becoming easier and easier, preference is increasingly given to diagnostics and the replacement of components, if necessary, over repairing the component in the vehicle. This means that diagnostic, disassembly and assembly activities in maintenance are becoming more important. The control of the vehicle maintenance process is also geared towards this. Thus, the usual service interruptions during the day for freight traffic and during the night for passenger traffic will be sufficient to carry out due replacements of components and therefore maintain the vehicle without affecting its operational availability. The control phase ends with the release of the vehicle into service following maintenance and the return of the vehicle to railway operation that will be defined by time, place and content.

The documentation phase needs to be carried out during and after maintenance and includes the maintenance activities performed, the findings identified and the associated component stress data. On the one hand, this will provide the maintenance company with legally robust documentation as evidence towards the client and towards supervisory bodies and for the exclusion of any liability claims of third parties. On the other hand, based on this data, it will be possible to develop the maintenance programme further or to validate any further developments that have already been implemented.

To be able to execute all three phases safely and efficiently, it is recommended that a computer-based Maintenance Planning, Control and Documentation System (MPCDS) is set up. The system to be used needs to meet all documentation requirements specified in the applicable rules and standards.

3.2 Component-related process

The component-related process starts with dismantling a component from a vehicle and comprises diagnostics, reconditioning, handling and transport, storage and provision of the component for reassembly in the vehicle. The reconditioning of components, in particular, requires specialist resources and particular know-how the provision of which can only be presented economically for larger volumes. This will result in the component reconditioning being organisationally and spatially separated from vehicle maintenance.

Components are increasingly reconditioned by specialist reconditioning companies, often by the manufacturers themselves, in a factory environment. It should be noted that these processes, too, form part of the service chain of maintenance and are the responsibility of the ECM and as such are not only subject to the applicable technical rules but also to the specifications of the ECM’s MMS. Particularly relevant are the specifications of the technical rules and standards with regard to the interfaces between vehicle- and component-related processes that also include the handling, transport and storage of components.

Furthermore, depots will be equipped with standard machine tools, such as universal lathes, milling machines, drilling machines, grinding machines, presses etc.

Component reconditioning workshops will have machinery geared towards the production requirements for the respective components. These can include heavy-duty lathes, straightening and balancing machines, testing and measuring machines, washing machines, paint removal, blasting and painting plants, heat treatment plants, foundry machinery etc. Fig. 5-11 shows a wheelset press, Fig. 5-12 a wheelset lathe.

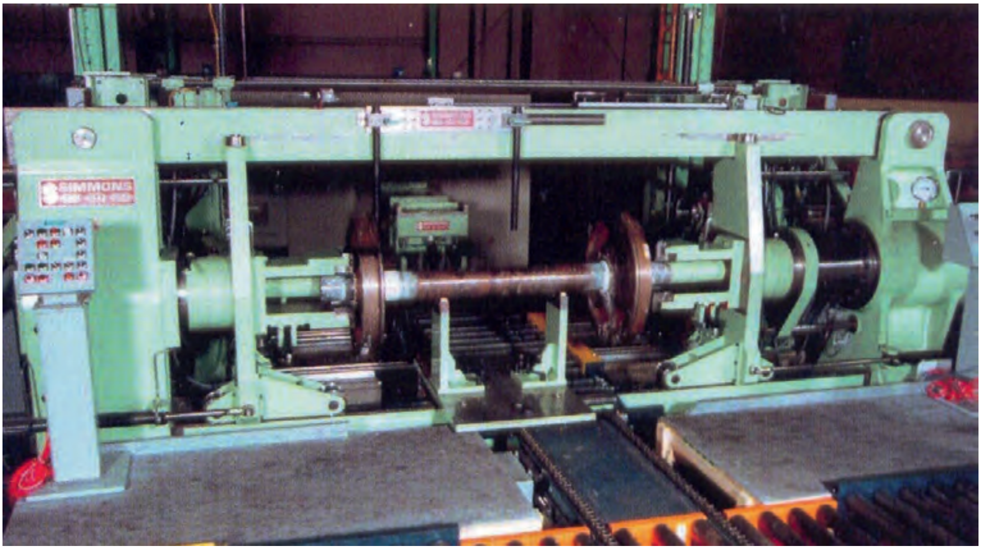

Fig. 5-11: Wheelset press

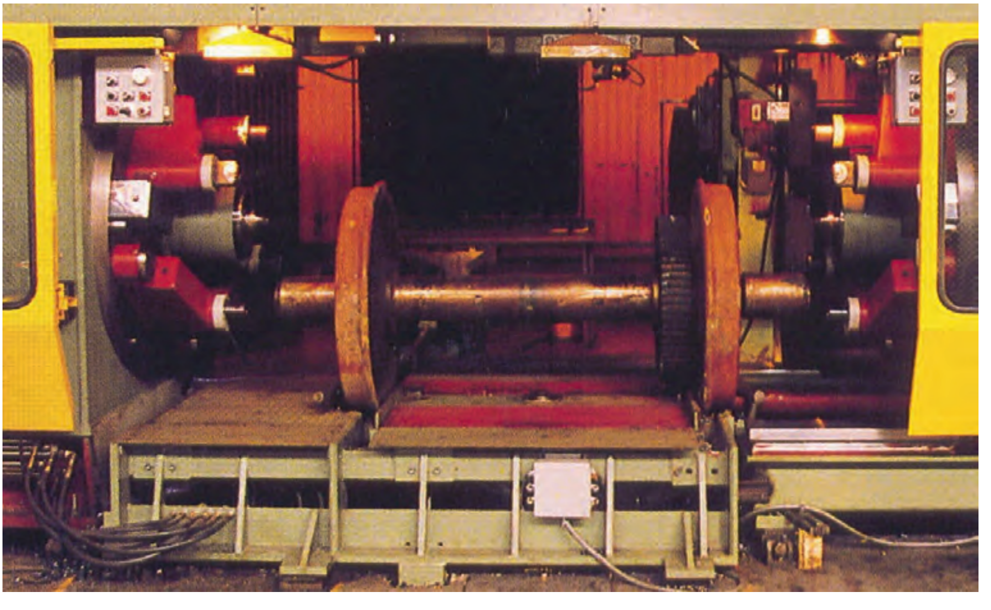

Fig. 5-12: Wheelset lathe

5.2.5 Logistic and handling technology, working levels

For many safety-related components of rail vehicles, special regulations apply for their handling and logistics, e.g. for the transport and storage of wheelsets, the storage of brake sand or electronic components. In addition to the standard equipment of forklift trucks, pallet trucks, overhead gantries and pillar-mounted cranes, other facilities include paternoster storage racks that allow for efficient and automatic space-saving storage of large parts in the workshop or heated sand hoppers for brake sand with pneumatic sand delivery to the point of use. They also include excrement disposal systems with tapping points at the vehicle treatment and disposal locations in the depot.

Fixed or mobile equipment for setting up different working levels is important for safe working and ergonomics. Fig. 5-13 shows a moving roof platform and Fig. 5-14 mobile steps.

Fig. 5-13: Mobile roof platform

This **compendium** describes the technologies, methods, processes and systems of modern maintenance of railway vehicles.

Ever since the beginning of the railway era, the maintenance of railway vehicles has been an indispensable function for a safe and economically efficient railway system. The vehicle design as well as the workshop equipment and qualifications of the staff have to be geared towards this objective.

Modern railway vehicles are technically highly complex mechatronics systems that combine mechanical, hydraulic, pneumatic, electric and electronic components. With the hardware and software of vehicle control systems, the automatic train protection system ETCS and many other components, cutting-edge technology has arrived on the market and must be mastered by maintenance companies. This has also fundamentally changed the technical requirements of maintenance. In addition, rapid developments in market conditions have resulted in reforms of the legal principles for the integration of maintenance providers and their various functions into the whole railway system and its organisation. This compendium contributes to highlighting these changes.

It is primarily aimed at experts working in railway vehicle maintenance, who want to refresh or consolidate their knowledge about the subject, and at students of railway and railway vehicle engineering.

Extra: Free e-book included. Users who have a PDF reader installed on their device (PC, tablet, smartphone) can access the content of the book electronically including a search function.

ISBN 978-3-96245-203-2

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