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ROLLING STOCK

IN THE RAILWAY SYSTEM

EDITION 2020

Edited by
Éric Fontanel and Reinhard Christeller
with the support of François Lacôte

EUROPEAN UNION AGENCY FOR RAILWAYS
INTERNATIONAL UNION OF RAILWAYS
UITP ADVANCING PUBLIC TRANSPORT
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IMPRINT

ROLLING STOCK IN THE RAILWAY SYSTEM (work in three volumes)

edited by Éric Fontanel and Reinhard Christeller, representing the author's association "Association des auteurs de l'ouvrage 'Rolling stock in the railway system'" (non-profit association under the French law "loi de 1901")

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Freight and passenger trains crossing at Muttenz station in Switzerland (Reinhard Christeller)

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Chapter 13: Outlook

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Foreword

By Josef Doppelbauer
Executive Director of the European Union Agency for Railways

The European railway system is very complex – both from a technical and from an organisational perspective. There are various types of rolling stock that interact with regionally specific trackside infrastructure, controlled by national signalling systems, following rules that have developed over more than 150 years, individually in each country of Europe. Written by engineers from several European companies, representing seven different nationalities, the present book on "rolling stock in the railway system" can be seen as a symbol of a new era of the European railways, resulting from more than twenty years of experts' collaboration in the working parties of the European standardisation bodies, of the former AEIF and of the European Rail Agency.

Indeed such a project would never have materialised if the experts of the European industry had not learned to work together, forgetting during the time of a meeting in Brussels or in Lille that they would be again harsh competitors when going out of the meeting room.

But furthermore it is probably partly thanks to the enormous work done to achieve the interoperability of the European rail system that experts became really aware of what is the key thread of this book: the design of a railway vehicle can only be considered in relation with the system within which it is operated, always having the needs of the end customer in mind as the principal requirement.

The long history of the European railways has shaped a system of which the sub-systems, rolling stock and fixed installations, as well as communications, operations, and maintenance are interfaced in a complex way, which has to be understood in all details before being able to make any tentative of harmonisation.

Even though their scope is limited to the sole objective of achieving the necessary harmonisation, the European *Technical Specifications for Interoperability* offer a unique and coherent tool for the description of the railway system, and notably of the interfaces between rolling stock and the other sub-systems. This is why, after a historical analysis of the construction of the railway systems through almost two centuries, the authors have spent significant time to describe in this first volume, as an introduction to the more technical chapters, this regulatory package of directives, regulations and standards, which allows for identification of the major interfaces and of the constraints and services exchanged through them.

The book shows all the diversity of the European railway vehicles, resulting from the complexity and variety of a system environment inherited from history, associated with a wide range of different transport services provided.

This diversity can be seen as a wealth of the European railway sector - but the lack of standardisation and the consequential higher cost of equipment and operation can represent a weakness in the competition of rail against other modes of transportation, as well as in the competition between the European manufacturing industry and its challengers from other regions of the world, able to offer better standardised solutions produced in large volumes.

This book shows the technical and historical origins of the diversity in rolling stock solutions, but it also offers a vision of the future in which higher standardisation leading to higher volumes will be obtained through a systematic use of platform solutions, of which the design will be facilitated by the standardisation of basic parameters and interfaces, as well as by the use of common safety methods provided by the European Railway Agency though its mandate from the interoperability and railway safety directives.

At the end of the book, a vision of this hopefully near future will be provided, elaborated on the basis of the preliminary works of the Shift^{2}Rail joint undertaking, which is gathering all the European industry together with the European Commission, for a seven years collaboration program aiming at significant progress towards the objectives for European rail set by the White Paper on transport. These objectives in terms of shifting transport volume from other transport modes to sustainable modes such as rail have just been re-confirmed in its mid-term review in summer 2015.

Published in two different languages, first in French and now in English, this book can be considered as the first European book of its kind and I wish it the largest possible success for the education of the next generation of European railway engineers – building upon the fundament of a deep understanding of the history, but oriented towards the future, solidly embedding all concepts from the unique framework of European standardisation.

Foreword

By François Lacôte

Who knows rail? Who knows the railway system and its many paradoxes?

The oldest of the current transport modes, this system has certainly become the most modern, the best accepted and probably the most promising of all.

It is the safest (on a par with air travel), yet the number, importance and criticality of interfaces between subsystems probably make it more vulnerable than other modes. Thus security is always at the heart of the concerns of engineers and operators of rail transport systems.

In the operation of the train itself, the paradox seems to transform into magic:

The heaviest per linear meter of all mobile land transport means, its contact area with the infrastructure by which it is carried is by far the lowest (a few square centimetres to carry more than ten tonnes);

Its power consumption is by far the lowest (less than one litre per 100 kilometres per passenger for a train traveling at over 300 km / h).

The "electric socket" (contact between the bow of the pantograph and the overhead contact line) has a contact area barely larger than the connection of an electric car, and yet the power transferred through this contact is hundreds of times higher.

How is it possible that a system dating back over two hundred years, is now capable of speeds of 575 km / h, with an energy cost of just 1 euro cent per passenger per kilometre transported, with 100 kilometres travelled in less than fifteen minutes with 200 people on board?

The answers to these questions, and to many others, are in this book.

This book gathers and presents all the disciplines that control these phenomena, the result of intelligence and know-how of engineers who are all working to create a system which is increasingly safe, more reliable, efficient, environmentally friendly and closer to its customers than ever before.

I was happy and proud to participate in and contribute to this great endeavour that brings together the best specialists in their discipline: to produce a reference book presenting the latest achievements and the state of the art in the science of railway rolling stock within the wheel-rail system.

I hope that it will be an invitation for young engineers to share the passion and enthusiasm of its authors, an invitation to you, dear reader, to participate in this great adventure of the progress of a system that will continue to surprise us, bringing progress to a transportation mode ever closer to the mobility needs of citizens, within a community driven by development in harmony with its environment.

Notice to readers

By Eric Fontanel and Reinhard Christeller, editors of the book

Designed not only for all railway professionals, but also for all those interested in railway history and technologies, the book was initiated by the need to have a support and an in-depth tool for the “Advance masters Railway Engineering and Urban Transport systems” of the Ecole des Ponts ParisTec and Ensiame (University of Valenciennes), the title of this book is the thread that has guided us throughout these coordination and writing work: “Rolling Stock in the Railway System."

Even more than in the case of all other modes, rail, as a guided means of transportation, is a system in which all elements are in constant interaction.

The rolling stock interacts strongly with all other physical components of the rail system: tracks, tunnels and station platforms, catenaries of the power supply system, control, signalling and communication systems, but also with the operation and maintenance management systems.

The train must be designed to pass through the limited space allowed by tunnels while ensuring a comfortable access to passengers, including those with reduced mobility, and it must provide them a comfortable and reliable journey. The level of safety of rail transport, higher than in any other land transport mode and at least equal to that of air transport, must be at least maintained and as far as possible improved. The technologies for control-command, signalling and braking, the mastering of the wheel-rail dynamics and of aerodynamics, the design of the structures and the protection against fire or electric shocks contribute to this guarantee.

These technical aspects, the foundations of which have not significantly changed for more than two centuries, are however only part of the constraints to which this transport system is subjected, as it must as well meet political and economic objectives, cope with the constraints of a competitive environment and comply with laws, standards and best practice recommendations at transcontinental, international, national or local level, depending on types of operations ranging from heavy and long distance freight , via very high speed for passengers, up to small tram networks operating in numerous cities around the world.

It is therefore all interfaces between rolling stock and other systems, technical, operational, regulatory, economic, all constraints sustained through these interfaces, as well as the quality, reliability and safety of the services provided in this very particular environment, that determine the design of the rolling stock and that make the job of the mechanical or electronics engineer and of the IT specialist so different from those of their colleagues working for other industries.

It is also what explains the existence of a multitude of different types of railway rolling stock, unparalleled in other transport modes, in contrast to the simple basic technical characteristics standardized for nearly two centuries: those of the steel wheel rolling on a steel rail.

This book of which you have the first volume in your hands, aims at facilitating the understanding of the design and functioning of the rolling stock in this complex and interconnected system, which allows for this wide variety of applications.

It is aimed at the connoisseur wishing to deepen his knowledge of the railway transport system, as well as at technical specialists, who will probably learn little in their own field, but will better understand the craft and skills of their colleagues in other fields, and will better understand their own systems as parts of a larger one.

By directing the writing of this book, the point that has most struck us is indeed the impossibility to separate the different components of the systems, speaking of the rail transport system as a whole or simply of the system constituted by the rolling stock.

You will see that when reading this first volume in which we will help you to become familiar with the world of railways and rolling stock by an historical approach, followed by a description of the railway system, particularly based on the analysis of European directives for interoperability and security and their associated technical documents, regulations and standards, then by a technical description of two key interfaces between rolling stock and infrastructure, and finally by a presentation on the mastering of the life cycle.

The second volume will be devoted to the typical architectures of all categories of trains, tramways, metros, suburban trains, conventional and high speed inter-city trains, and freight trains. It will also address the technologies of construction of vehicle bodies and running gears and deal with passenger comfort and the management of it.

The third volume will describe the essential embedded subsystems to guide and move the trains, to control them and to stop them safely and we will conclude the technical systems analysis with a chapter on locomotives, which accommodate all these embedded systems at their highest level of power and complexity. And finally, we will attempt to turn our gaze to the future.

This book has the ambition to present the state of the art of European rolling stock design and provide guidance on the different variants that can be found around the world. So we wanted to form a team comprising some of the best European specialists in different disciplines and we are pleased to have been able to gather for the three volumes a team of twenty authors belonging to many different companies, and representing seven European nationalities. It is also in this spirit and in order to make it a European reference that this book, originally written in French or English depending on the nationality of the authors, will be published in two languages, the English version following the French version by a few months.

It is obvious also that despite the high quality of the professionals who participated in creating this book, it can only summarize in the best possible way the state of the art at the date of its publication, and it is not either a substitute for standards and regulations in force, which remain the only reference for industry professionals.

It was for us, editors of this book, a great pleasure to work with all our colleagues each specialists in their different fields and to exchange and learn from them. We also had the pleasure and honour to be supported in our efforts by François Lacôte, one of the great contemporary specialists of rolling stock and high-speed transport systems, who gave us the benefit of his very valuable advice.

This volume is the updated English version of the first volume of “Matériel roulant dans le système ferroviaire”, published by Les Editions la Vie du Rail, Paris 2015. Chapter 3 in particular has been largely rewritten to fully take into account the publication of the European “Fourth Railway Package” in 2016 and the big changes that it introduced in the processes of authorisation to put rolling stock on the market and in service. As such this chapter is the best possible guide for those who need to understand these complex European processes.

1.7.5 André Chapelon (1892 – 1978)

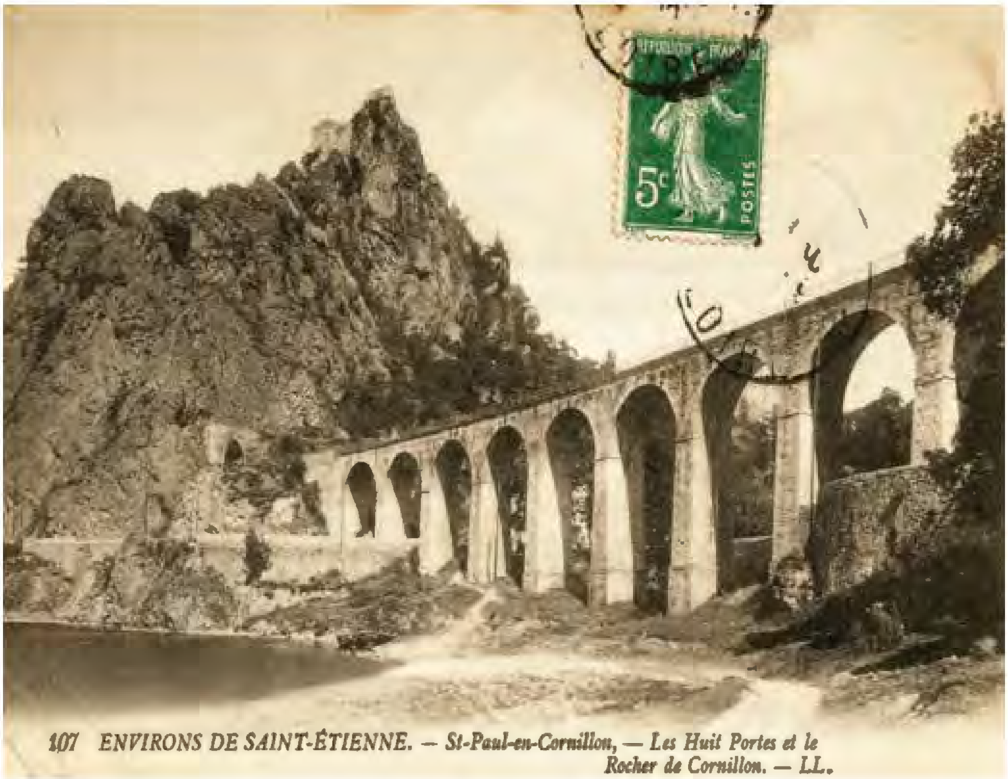

Fig. 105: The "Les huit portes" (the eight doors) viaduct and the Cornillon rock from where André Chapelon observed the passing steam locomotives. (Archive JP Rigouard)

Looking at the high viaduct that spans between steep rocks in a loop of the Loire river in the little village of Saint-Paul-en-Cornillon near Saint-Etienne, on the line to Le-Puy-en-Velay, one can understand that young André Chapelon [13] fell in love with steam locomotives when he observed them thundering over it. André Chapelon, son of the ancient Chapellon family of the neighbouring village of Firminy, was born in Saint-Paul on 26 October 1892 and spent his youth there. As a very small boy, he was already observing the galloping steam engines. His enthusiasm for this machine never left him until his death in Paris on 29 June 1978.

Fig. 106: André Chapelon in 1937 with one of his Pacific Île de France (Photo Félix Fenino / Photorail / La Vie du Rail)

At the age of 17, he had already sketched out a new locomotive, the "Mastodon", in all its details, and he had established its main characteristics. In 1913, he entered the Ecole Centrale des Arts et Manufactures in Paris to learn the science, in particular the "Réflexions sur la puissance motrice du feu" (Reflections on the driving power of fire) of Sadi Carnot. He later applied this knowledge to his locomotives. His strength was putting theoretical knowledge in practice and integrating several scientific spheres in order to arrive at a successful technical solution. Nevertheless, he remained humble, not seeking any glory or wealth for himself.

After his army service, he entered the services of the PLM (Paris-Lyon-Méditerranée) railway but soon discovered that his ideas and suggestions were not appreciated. In 1925 he joined the R&D department of the PO (Paris-Orléans) railway. It was there, and later at SNCF when it was created in 1938, that he would develop his many improvements. First, the exhaust system had to be improved. Increasing the draught of the fire by injecting exhaust steam from the cylinders into the chimney had been known for more than hundred years, but it had to be optimised by minimising the performance losses in the cylinders due to counter-pressure and by perfecting the smoke and steam ejector device. Chapelon had discovered an ejector system that achieved a reduction of coal consumption of between 6 and 28 %, patented in 1919 by the Finnish locomotive driver Kylälä[89].

Chapelon developed this system to perfection by combining several Kylälä elements and nozzles, and named it Kylchap. He anticipated coal consumption could be reduced by 16 %, 25 % more power could be generated and a further 10 % would be available thanks to the addition of improved steam pipes. Raising the temperature of the steam superheating should add a further 19 %. In total, the power of the locomotive should almost double. Although these calculations were considered to be crazy, the PO converted a "Pacific" (2'C1') locomotive 3566, and tests carried out in 1929 confirmed the calculations. The drawbar power of the series 3500 locomotive was almost doubled, it increased from 1450 hp (1070 kW) to 2700 hp (1990 kW) while coal consumption, adjusted to 1450 hp decreased by 54 %. Other improvements and changes were introduced to French locomotives and Chapelon also started advising foreign railway companies. He considered the 240 P (2'D) locomotives as "probably the most successful ever built". In 1932, the French Etat network had ordered 241 type "Mountain" (2'D1') locomotives from Fives-Lille, but they delivered such poor performance that it was decided to call on Chapelon to improve them. He converted one into the most magnificent of all steam locomotives, like his other machines, a "Compound" with two steam expansion stages, this made it heavier, and so it was converted into a 242 "Niagara" (2'D2'), it subsequently delivered 5500 hp (4050 kW) at the cylinders against 2800 hp in its original state.

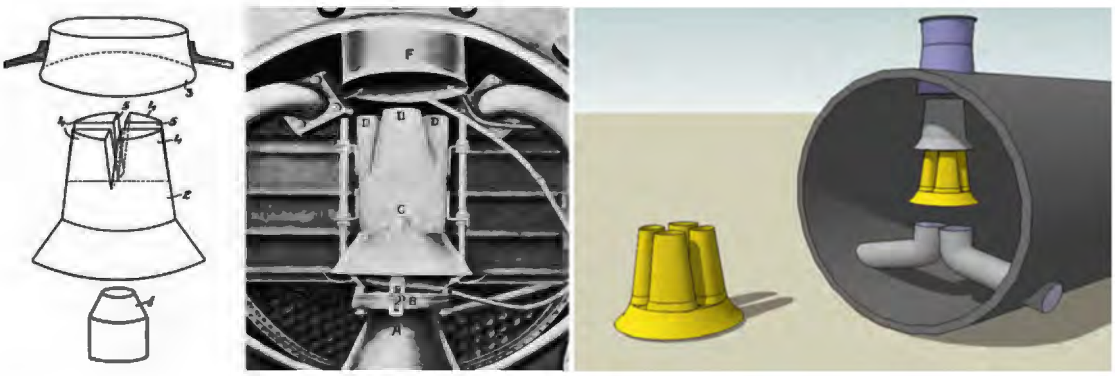

Fig. 107: Left: Kylälä exhaust system. Steam enters by the lower large diameter blast-pipe, draws the exhaust gases from below, divides the mixture into 4 or 6 and draws in more exhaust gases at the upper level before the whole lot is discharged to the atmosphere (Source: Brochure O.Y. Inventor) Right: André Chapelon's Kylchap superposed several stages of Kylälä blastpipes (Wikipedia)

The Second World War stopped further development. In 1945, the French steam locomotive fleet had an average age of 34 years. Electric traction had progressed but diesel still did not perform as well as steam. Studies on fleet replacement showed the need for 2000 to 3000 new locomotives. Chapelon, now at the SNCF, had suggested a range of six types of locomotives as early as in 1942 – based on a modular system having three to five driving wheelsets, one of these locomotives would have had a v_{max} of 200 km/h. This idea was taken up after the war, but in 1946 the Government stopped all steam locomotive construction. For all his genius, Chapelon had improved a multitude of locomotives but he had never built a new one for his country.

In 1952, the performance of the 242 was demonstrated to a Brazilian delegation that changed its mind and ordered steam locomotives instead of the 100 diesel locomotives that were initially planned. Chapelon had previously undertaken a locomotive export mission to Brazil and Argentina in 1950. Brazil ordered 84 locomotives and in Argentina the very brilliant engineer Livio Dante Porta used Chapelon's methodology to modernise many locomotives in his country. André Chapelon retired from SNCF in 1953 but he continued to work as a consultant. His biography was written by H.C.B. Rogers after intensive meetings in the early 1970's. It appeared in 1972 in English and was translated to French in 2001. At the beginning of Chapelon's career, steam locomotives had an overall efficiency of 8 %, in 1950 they achieved double that. Chapelon looked into the future and from his knowledge of what had been achieved by 1950 he calculated that 20 % might be possible in 1990. If their technical development had continued, would we now have completely automatic and even more efficient steam locomotives? Their power rating was already close to that of their electric competitors and at the same level as diesel when they disappeared.

Was Chapelon born too early or too late?

89 Brochure of O.Y. Inventor, Patented Locomotive Plast Pipe, System Kylälä, Helsinki, 1920

The current list of registers is as follows:

- The European Vehicle Register (EVR).
- The European register of authorised vehicle types.
- The register of the 'EC' declarations of verification of subsystems.
- The register of the 'EC' declarations of conformity of interoperability constituents and 'EC' declarations of suitability of use of interoperability constituents.
- The register of train driver licences issued.
- The register of the single safety certificates issued.
- The register of the (accident) investigation reports sent to the Agency.
- The register of the national rules notified to the European Commission.
- The national vehicle registers and links between them (until the European Vehicle Register is in place).
- The national infrastructure registers, including via the links to relevant national registers.
- The registers relating to entities in charge of maintenance and their certification bodies.
- The register of requests for changes and planned changes to the ERTMS specifications, in accordance with article 28 (2) of this Regulation.
- The register of requests for changes and planned changes to the TSIs for telematics applications for passengers ('TAPs') and telematics applications for freight ('TAFs').
- The register of vehicle keeper markings kept by the Agency in accordance with the TSI on operation and traffic management.
- The quality reports issued in accordance with article 28(2) of Regulation (EC) No 1371/2007 of the European Parliament and of the Council (1).

The development and on-going maintenance of these registers is essential for the completion of railway interoperability.

3.6.5.5 (Formal) opinions

The Agency may be required to issue formal opinions as follows:

- At the request of one or more national regulatory bodies referred to in SERA Directive in particular concerning safety-related and interoperability-related aspects of matters drawn to their attention.
- At the request of the European Commission on amendments to any act adopted on the basis of the Interoperability and Safety Directives especially where any alleged deficiency is signalled.

All opinions of the Agency must be issued by the Agency as soon as possible and at the latest within 2 months of receipt of the request, unless otherwise agreed with the requesting party. Those opinions shall be made public by the Agency within one month after they are issued, in a version from which all commercially confidential material has been removed.

The Agency is also frequently called upon by the European Commission on an ad-hoc basis to offer its assistance including its (informal) advice on matters within its area of competence. This includes "*examining, from the point of view of railway safety and interoperability, any project involving the design, construction, renewal or upgrading of any subsystem in respect of which an application for Union financial support has been submitted*"[84].

3.6.6 EU railway research

Over the years the European Commission has invested a significant amount in railway research however in the early days there was some concern at the low "market uptake" in that around only 30% of outputs were taken up and used by the rail sector. The situation has substantially improved in two ways as a result of a concerted effort by all parties. Firstly, research effort was focussed on closing Open Points in the TSIs. An example of this is the "TRIOTRAIN" series of projects that looked at vehicle - track interaction, aerodynamics and pantograph - overheard line interaction. Whilst it can take time for research output to find its way into standards, thanks to good co-operation with the Agency outputs relevant to TSIs were introduced rapidly into the TSIs, in some cases before the final report was published. The second and most significant step forward has been the setting up of the "Shift2Rail" joint undertaking. This entity jointly funded and managed by a Board comprising the European Commission and key railway manufacturers and Infrastructure Managers is charged with implementing a one billion euro programme of research over the 7 years of the present "Horizon 2020" European research framework program.

[84] Article 42 of the Agency regulation.

Its activities cover Innovation Programmes on specific subjects all linked by a set of overarching cross-cutting activities. The diagram below illustrates this.

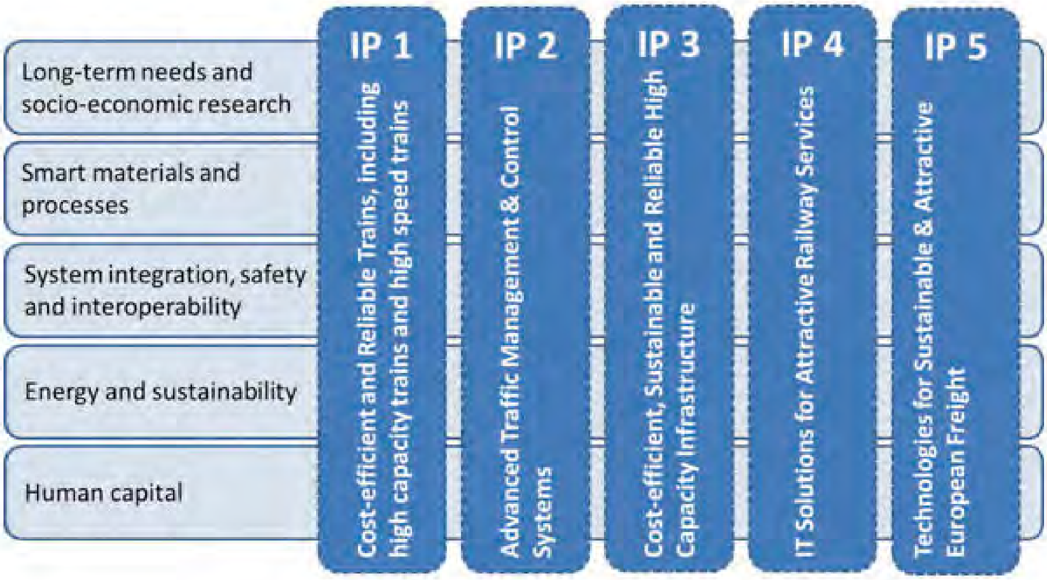

Fig. 16: Shift2Rail scope (from the Shift2Rail website).

Whilst Shift2Rail's role is to coordinate and deliver rail research over its seven year life-span, the Agency has a role in defining and acting as independent expert railway advisor to the European Commission on research and also a specific role in respect of Shift2Rail by:

- proposing possible amendments to the S2R Master Plan and to the annual work plans, in particular to ensure that research needs relating to the realisation of the Single European Railway Area are covered;
- proposing guidelines for research and development activities leading to technical standards with a view to guaranteeing the interoperability and safety of results;
- reviewing the common developments for the future system and contributing to defining target systems in regulatory requirements;
- reviewing project activities and results with a view to ascertaining their relevance to the objectives of the Joint Undertaking and to guaranteeing the interoperability and safety of research results.

It is hoped that the present Shift2Rail program will be followed by another programme of seven years. This is, presently under investigation, under the next European research framework program starting in 2021.

More information on Shift2Rail can be found on their website[85].

3.6.7 Railway standards

Whereas legislative and regulatory documents, national laws, Directives and regulations, decrees etc., with which conformity is a legal obligation, are public by nature, Standards, on the other hand are documents of a private nature, with which conformity is voluntary and the rights of reproduction belong to the organisations that publish them and they are written by the actors of the sector without the intervention of public authorities. Standards are generally intended to facilitate a more competitive economy for the benefit of all stakeholders.

Nevertheless, although standards are generally documents of voluntary application, a standard or part thereof may be called up in legislation making it mandatory. They are also frequently applied by contract.

Where standards are called up by legislation, in order to ensure that the standards content meets the need of the legislator, there is normally an arrangement mandated on, or agreed between, the entity in charge of drafting the legislation and the standardisation body.

In the European case, CEN, CENELEC and ETSI publish the EN set of standards. The first two organisations are the European associations of the different national standards organisations accredited by each of the Member States (e.g. AFNOR and UTE in France or DIN and VDE in Germany, BSI in UK etc.) and ETSI is the standardisation body of the European telecommunications industry.

[85] www.Shift2Rail.org

3.6.7.1 The "new approach"

As explained earlier the European Commission gives mandates to CEN / CENELEC and ETSI to draft standards, in particular the so-called "harmonised“ standards in relation to a particular “new approach” Directive. Compliance with these harmonised standards gives "presumption of conformity" with the requirements of the relevant Directive, provided that the compliance is verified by an organisation notified in respect of the Directive by one of the Member States to the European Commission (a Notified Body). These Directives of the "new approach" category, include for example those on ski-lifts, on electromagnetic compatibility (EMC), toys, machinery etc. They contain no detailed technical requirements, but only essential requirements and high-level functionality related to safety or compatibility.

Harmonised standards are never explicitly mentioned in the Directives, as the demonstration of conformity to the Directives can be done by any means, not necessarily by application of harmonised standards. It is the harmonised standards themselves that provide the information regarding compliance with a Directive in an appropriate annex (such an annex that we find incidentally in the harmonised standards linked to the Interoperability Directive).

This information allows manufacturers and / or importers to Europe to place their products on the European market on the basis of a declaration of conformity, accompanied by a CE marking, confirming verification by a Notified Body.

European standards generally define a scope, technical parameters associated with compliance requirements and methods for demonstrating conformity.

3.6.7.2 Special case of the railway sector

It may be noted that the vocabulary of the Interoperability Directive, although it does not strictly belong to this category, is inspired by that of the "new approach" as it includes a number of basic principles such as Notified Bodies, Harmonised Standards and verification of conformity on the basis of similar “modules” made available to the NoBos.

However, the Interoperability Directive differs significantly from the “pure” new approach directives in two key areas:

- In order to ensure the functioning of the shared system the technical requirements that all actors must comply with to meet the objectives of the Directive (Market Opening, Interoperability and International operation) are explicitly laid down and mandated in a regulation (the TSI).
- An authorisation to place equipment on the market or in service must to be granted by the Agency or an NSA.

Notwithstanding the above, the technical requirements of the TSI, the Basic Parameters and their values, are often expressed in the Directives through an explicit reference to EN harmonised standards, the application of which, at least the paragraphs to which the reference is made, becomes de-facto mandatory by law. In addition voluntary detailed measures for compliance with the essential requirements and the TSI are often also to be found in the relevant harmonised standard, without this being explicitly mentioned. Thus we see the principle of the harmonised standard of the “new approach” Directives being applied to the Union rail system, and the applicant being free to use any other means to demonstrate compliance with the essential requirements of the Directive, as specified by the Basic Parameters of the TSIs.

This is the case for example with the standard EN 45545, regarding fire safety. Only one part, the part 2 on the choice of materials, is explicitly mentioned in (and therefore mandated by) the LOC & PAS TSI and the selection must be done strictly according to this method. The other parts of the standard, concerning construction requirements of the rolling stock are not mentioned. However, the EN 45545 is a standard harmonised under the Interoperability Directive and in its Annex ZA the standard indicates the correspondence between its requirements, the relevant parameters of the TSI and the Essential Requirements of the Directive. Compliance of railway vehicles to the standard then grants a presumption of conformity with the fire protection requirements of the TSI.

However, applicants should have the freedom to use technical solutions of their own choice to meet the essential requirements provided that the specifications of these technical solutions comply with the TSIs and other applicable legislation.

The guide for application of the TSIs[86], published by the Agency, gives the list of standards harmonised under the Railway Interoperability Directive and specifies how they should be used for the satisfaction of the TSI requirements, putting together the basic requirements of the TSI and the relevant clauses of the standard. The mandatory use of standards is listed in the annex to the TSI itself.

[86] To be found on the Agency website.

- *The support of computing resources***.** The systems are equipped more and more with complex software. The operator is confronted with a need for software evolution (equipment changes, software "bugs", desirability of new functions, etc.). Computing support covers all of the resources necessary to produce the changes and re-integration of the modified components and associated software into the original environment.
- *The means for the monitoring and management of the equipment.* These are necessary for controlling the system, its components and all the components of the support system (place, configuration, availability, etc.). CMMS enters into this framework.
- *The technical assistance by the suppliers* covers all of the actions of the supplier to benefit the client, whether performed at the latter's premises (assistance with set-up, trouble shooting etc.) or at the supplier's premises (repairs).

5.7.2 General principles for integrated logistics support

5.7.2.1 Origin

Structuring the information necessary for defining the support system requires both method and tools. Integrated Logistics Support (ILS) has emerged as the proven methodology with the final goal of overall optimisation of maintenance. ILS is a standardised management and engineering method for support systems of the major industries (transport, nuclear and energy, weapons, aerospace, telecommunications, offshore, etc.). By the structured approach that it proposes, this method produces transverse consistency for maintenance activities and processes in complex organisations. Integrated Logistics Support has been the object, firstly in the United States and then in Europe, of a standardised reference system, notably the military standard MIL STD 1388 2B, and more recently the family of aeronautical standards S3000L (logistical support), S2000M (supply data) and S1000D (documentation). This reference system is regularly updated to integrate the experience acquired as well as technical and methodological progress.

While formalising the method, the standards leave much latitude for "tailoring" to needs. This flexibility authorises the use of ILS in contexts different from the initial military or aeronautics ones, while setting minimal inescapable rules. Thus programmes for the development of new railway rolling stock and its commissioning and operation have progressively implemented ILS since its conception, structuring new approaches for the improvement of the operational and economic performance".

5.7.2.2 Objective

The approach only makes sense if it is permanent. Thus it brings an ability for prediction and continuous correction. The design, acquisition and operation of the whole complex system must be performed by permanently evaluating the proper compromise between efficiency and operational performance and the overall lifecycle cost. The objective of this arbitration is:

- in the design or acquisition phase, as we have seen, to integrate as closely as possible, the study of the system and that of the support system, with the goal of defining it by optimised and coherent "support elements". Design and acquisition are global. They concern not only the railway rolling stock but also simultaneously the whole necessary environment necessary for operations and maintenance during the projected lifecycle,
- in the operating phase of the system, to optimise the behaviour of the overall system, by integrating feedback from the analysis of intervention files managed by the CMMS system. Including that from the dismantling phase, the support system must be managed as a whole, consistent with and adapted to operating needs.

Each of these stages will be described later.

This approach to management activities and technical activities is therefore iterative by nature. It is a permanent process and not a one-time activity. It progresses throughout the stages of the lifecycle of the rolling stock as defined at the beginning of this chapter. These stages are the design, acquisition, organisation of support established before commissioning, then the operations until end-of- life dismantlement.

- Taking into account from conception the objectives and the constraints of users relative to operations, maintenance, support and cost. These must be systematically and rigorously integrated into the specification of the support system and its organisation.
- Conducting a programme of acquisition, dimensioning an appropriate support system and controlling the lifecycle cost. The support system must be studied from the initial phases of the programme and be interactive with the design itself. This allows, on the one hand, for the design of the system to achieve the objectives of optimal

"supportability" and on the other, for a support system to be developed consistent with the technical configuration of the system.

- Harmonising the support elements between each other and with regard to the design. The support system must be managed, developed and delivered in a consistent manner by basing it on the data coming from studies. It means that the support system must be taken fully into account at the programme management level (single logistics manager, monitoring of logistics tasks, reviews) and in relation to other disciplines.
- Ensuring the necessary support during the operations phase, at a cost controlled in function of the operational need. The support system must be managed as a consistent whole. It must be adjusted if need be by capitalising on the experience acquired from measured data on the operational behaviour of the systems.

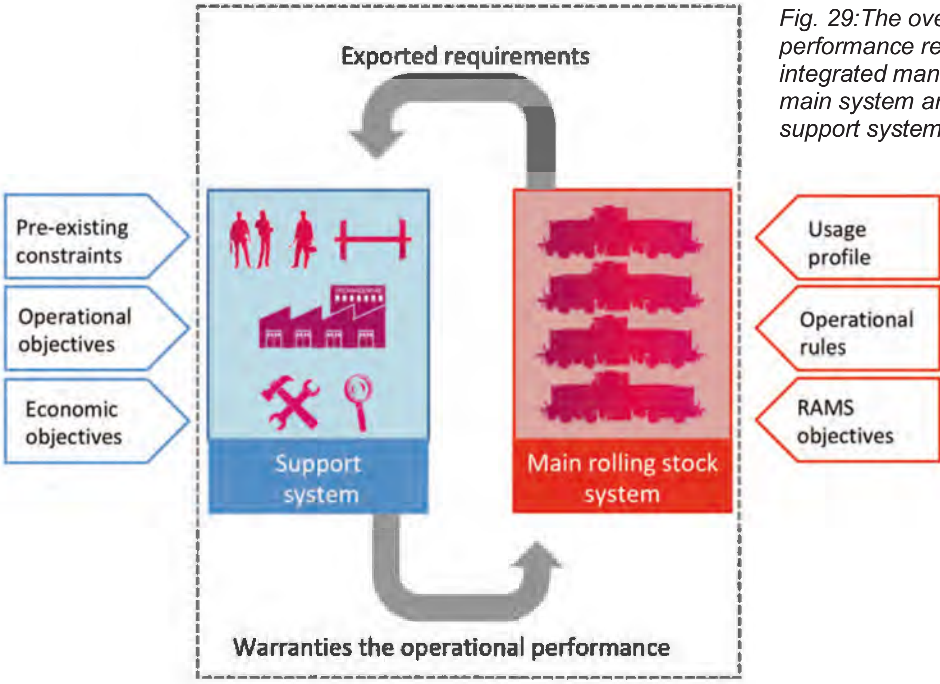

Fig. 29:The overall performance results from an integrated management of the main system and of the support system.

5.7.3 Process components

The ILS process components are:

- The Logistics Support Analysis or LSA,
- The management of data and the logistics support data base (or logistic support analysis record: LSAR),
- the management of data, which ensures the sustainability and the updating of analyses and allows improvement decisions to be taken.

5.7.3.1 Logistics Support Analysis

Integrated Logistics Support is based on the engineering method bearing the name of Logistics Support Analysis (LSA). The LSA principle is that no control of the support system is possible without measuring all the determining factors. Its objective is to collect data to characterise the support system, to explain the links between this data, and to control its consistency and therefore the cost, while guaranteeing that the fixed performance objectives will be attained for the fleet.

LSA is achieved by carrying out a precise sequencing of tasks, which allow the support system to be precisely described jointly with the manufacturer.

- Analysing and formulating the operating and support needs in the form of objectives, hypotheses and associated constraints, for example, the objectives of maintenance operation cycles, maximum time for these operations, constraints related to workshops and tools, availability objectives etc.
- Describing and modelling the main system, in this particular case, the rolling stock, conforming to a logistics tree structure. This latter is a hierarchical representation both functional and material of the equipment, which identifies each element vis-a-vis the end purpose of its maintenance. This tree-structure is one of the tools linking the main

system and the support system, in the sense that it identifies in particular the elements that can be removed on the line or in a specialised workshop, and sets out the sequencing of all the necessary information for this maintenance.

- Identifying the different downstream tasks (operations, maintenance, support) that are to be performed on the system or on one of the constituents. This relies notably on the input data coming from RAMS analyses, maintenance recommendations coming from manufacturer's data, or maintenance choices retained (preventive, curative, at the element, etc.),
- Formulating a maintenance plan, i.e. for maintenance tasks, their periodicity, their groupings and their organisation at the levels of maintenance (cf. box). For technical interventions, the choice of support elements is based on the analysis of levels of maintenance, which allow resources and maintenance sites to be optimised.
- Describing very accurately each of these tasks by its support needs (personnel, means, packaging, documentation, etc.).

Figure 30 gives an essential overview and summarises the whole process described in the chapter.

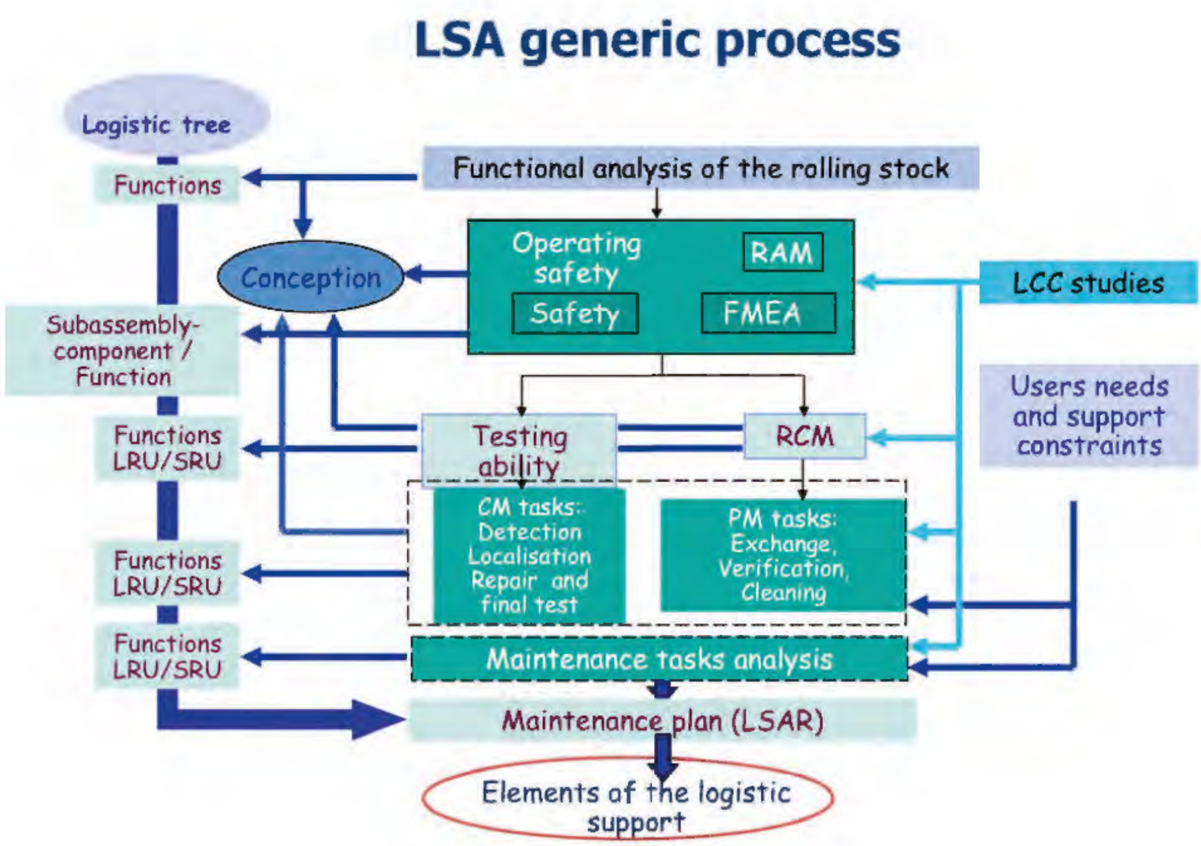

Fig. 30: General process of the logistic support analysis (LSA). (Mohammed Hosni)

The analysis of data provided by this approach allows different steps of arbitration to be performed:

- imagining diverse solutions for the support system, evaluating one against the other taking into account technical, economic and organisational criteria,
- potentially intervening in the design of the main system itself, in order to improve the ability to support or to reduce the lifecycle cost, in all the scenarios treated above,
- choosing the "best" solution (or the best compromise) main system + support solution with regard to fixed objectives,
- evaluating full-scale the pertinence of the solution retained.

2

ROLLING STOCK

IN THE RAILWAY SYSTEM

EDITION 2020

Edited by

Éric Fontanel and Reinhard Christeller

with the support of François Lacôte

EUROPEAN UNION AGENCY FOR RAILWAYS

INTERNATIONAL UNION OF RAILWAYS

UITP ADVANCING PUBLIC TRANSPORT

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Industrial design cannot do it alone, but it gives the 'finish coats' to the train proposition. However, it only represents the tip of the iceberg in the process. Industrial design is at the crossroads of distinct technical disciplines sometimes pursuing antagonistic goals: engineering, marketing, branding, ergonomics, etc. The industrial designer strives to orchestrate and package these various options into the most attractive ' layered' proposition to be superimposed on bones, muscles and nerves, as artful flesh and skin padding. His/her talent literally "transfigures " an initial set of input functions into a creative precipitate that will generate impressions, feelings, emotions. At arm's length with categorical logic, industrial design has the outstanding ability to touch our sensitivity channels: the intensity of our passions always overrides reason...

For their artistic deliverables, industrial designers have developed proven work methodologies. Traditionally, there are four major steps to be reckoned with, each one being subdivided into more or less numerous phases depending on project scope and extent.

Impregnation stage

This corresponds to a technical and marketing data collection to understand in depth all the specifications. This data collection is followed by a benchmarking initiative with the review of competing offers and by investigations documenting local culture, needs and behaviours and also by existing trend analyses in the train industrial design field and other related fields.

The rendering of this gestation period takes the form of a 'target-market positioning' often represented by boards of style trends, and diagrams mapping the product design intentions relative to competition or specifying product design territories to be explored. The combination of all these elements is the product design strategy to be adopted throughout the study

Creative stage

It is the key period of the study, because it marks the genesis of the future product design. It is usually a two-act 'play' consisting of :

• Creative investigations as such, leading to several product design proposals meeting the objectives assigned. Basically, investigations are centred on the principal trainset components : exteriors and livery, main interior fittings, design or even re-design of seat diagrams. All the elements are then submitted, reviewed and jointly assessed by decision-makers for engineering, marketing, business and sometimes PR people.

• A synthetic phase further to the decisions and comments made in the previous phase, giving rise to an original product design proposition reflecting expectations. That is the moment when the train exhibits its nearly final shape and sees the light of day

The rendering usually takes the form of a Product Design Book presenting the stated objectives and the product design proposition in the form of diagrams, 3D photo-realistic images, presentation videos and sometimes a reduced-scale model or a scale 1 model.

Fig. 16: CAD and the 3D imagery accuracy make possible the display of the product's final appearance- Synthetic image on the left hand and true-to-life rolling stock on the right hand side.

Development stage

The industrial design options, after the creative phase, are then finalised in each and every technical and visual detail for train exteriors and interiors and are benchmarked on a continuous basis with the currently-emerging industrial developments. It is the right time for the industrial designer to demonstrate that his/her work meets all the constraints, like aerodynamics, drivers' sighting criteria, detailed dimensional and ergonomic specifications, illuminance, accessibility and maintainability criteria.

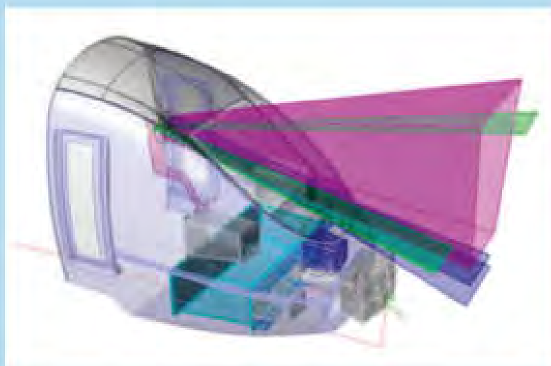

Fig. 17 (left): Ergonomics cannot be dissociated from industrial design in the transport industry, passengers and train crews come together, ergonomics and industrial design are all in one (MBD Design). Fig. 18 (right): Industrial designers know how to take into account the fucntionnal specifications in their developments and how to interact with them, for instance to meet sighting requirements. (MBD Design).

Fig. 19: Scale one mock-up for Reims tramway: the real-size representation remains the most reliable method for validation of rolling stock industrial design. (MBD Design)

It is also during this stage that the product design's detailed concepts will be extended very precisely over all the train areas : bar or catering coach, access vestibule, toilets, luggage area, driver's cab, etc...

Always based on CAD, this phase will be include a rendering in 3D files, reference boards for colours and materials, an executive document for graphic elements. In a few cases, this stage will also lead to the development of scale 1 mock-ups, but if not, in the remainder of cases, photorealistic images will always be presented.

Industrial follow-up stage

Industrial development and sometimes its unfortunate side effects – require detail modifications not caught in the net of the previous development stage. However minor these changes may seem, they may downgrade significantly the final development quality outturn. The product designer monitors all the industrial cycle to keep up with the original product design policy injunctions. All the changes are made consistent with this policy. The product designer also checks and validates the production of early specimens in terms of quality of appearance and assembly, due compliance of materials and colours, etc. His assigment really terminates when the first trainset enters revenue service...

After partnering for decades, industrial designers and railway suppliers have developed an unshakeable bond and despite their different backgrounds, the gaps between them have been bridged due to their complementary stances. Now, industrial designers and railway suppliers look as though they intend to live up to the promise of "Beauty and the Beast".

6.2.2.3.2 Design drivers

Generally the goal of the design of a multiple unit is to get as much space as possible for the passengers at the required comfort level and to fulfil the other constraints that are given by the infrastructure.

The design drivers are the mission requirements and the constraints from the infrastructure.

The following table shows their influence on the design characteristics as described in 6.2.2.3.1 above, classified in 3 categories: high, medium and none.

Examples to explain and illustrate the issues with high influence on the design characteristics are given below.

			Design Characteristics					
		Influence	Single deck/double deck	Entrance and interior floor / steps / ramps	Propulsion diesel / electric AC / DC	Power distribution / arrangement	Articulated or standard design	Tilting
Design drivers	**Mission requirements, service performances**	Type of operation	medium	**high**	**high**	medium	medium	**high**
		Capacity, seats/standees ratio	**high**	none	medium	medium	medium	medium
		Capacity during day	none	none	medium	medium	medium	none
		Comfort level	**high**	medium	medium	medium	medium	medium
		Running performance	none	none	**high**	**high**	medium	**high**
		Passenger exchange time	**high**	**high**	none	medium	medium	none
		RAM *)	medium	none	**high**	**high**	**high**	**high**
		PRM **)	**high**	**high**	medium	medium	medium	medium
		Fire safety level	none	none	medium	medium	medium	none
		Environmental sustainability	**high**	none	**high**	medium	medium	medium
	Constraints	Loading gauge	**high**	medium	none	none	medium	medium
		Maximum axle load	medium	medium	medium	**high**	medium	**high**
		Track gauge	medium	none	none	none	medium	medium
		Platform heights	**high**	**high**	medium	medium	medium	none
		Platform length	**high**	none	medium	medium	medium	none
		Maximum speed	none	none	**high**	**high**	none	none
		Catenary existing	none	none	**high**	none	none	none

*) RAM = Reliability, availability, maintainability **) PRM = Passengers with reduced mobility

Tab. 10: The design drivers

Single deck or double deck: The decision for single or double deck units is mainly driven by:

- *Required capacity, seats/standees ratio.*
  Double decker units are more efficient when a high passenger capacity is needed, and especially when a high number of seats has to be offered. But if less than 200 seats are required one- or two-car double decker units are inefficient.

Fig. 48 and 49: German DB ETR 430 single deck commuter train with a continuous floor level at 1030 mm from top of rail (TOR), built by Alstom and Bombardier for 960 mm high platforms (FlughafenSTR / Wikipedia)

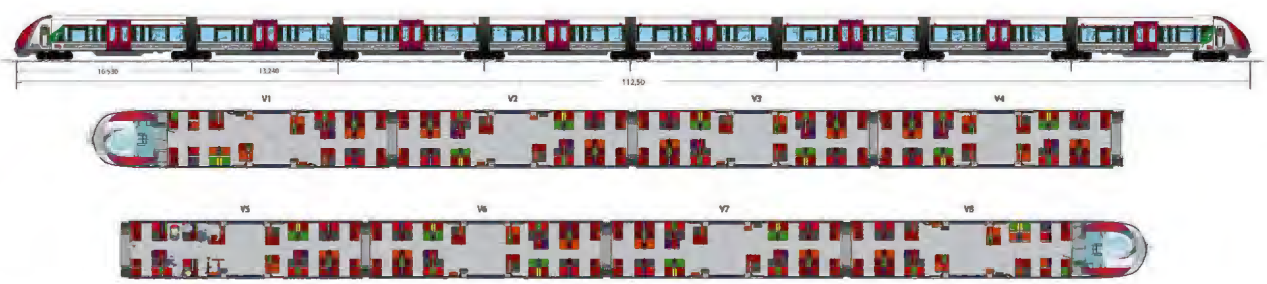

Fig. 50: French SNCF Z 50000 "Francilien" train with a continuous floor level at 985 mm from top of rail (TOR) for 920 mm high platforms. (Bombardier)

- *Passenger exchange time.*

Fig. 51: French SNCF MI2N "Eole" double decker commuter train with 3 entrance doors per car, built by Alstom and Bombardier. (Kirikou/Gonioul,Wikipedia)

Especially for commuter trains the passenger exchange time at a station is a very important factor. It depends on the number and width of the doors and the passenger flow in the adjacent part of the car. For double decker trains there is a loss of capacity in the area of the doors and the bogies, because the upper deck is restricted in the bogie area and at least partly at the entrance door. This means that the advantage of double decker units is reduced when there are many and big doors. Therefore in most units there are only one or two doors per car. An exception is the RER MI2N "Eole" Paris commuter train equipped with three doors per car, allowing for short passenger exchange times with a higher capacity per length than with a single deck unit. This performance is achieved thanks to spacious access platforms at station platform level with a high density of standing passengers between city-centre stations while passengers travelling longer distances will use the seats at both the lower and upper level.

- *Platform height and passengers with reduced mobility.*

The platform height of 550 mm is ideal for double decker units. It enables an entrance without step to doors between the bogies and a good access to the lower deck area. For single deck units the ideal platform height is about 1200 mm (which is not standardised by the TSI's). With this height a train can be accessed without steps and the floor height can be at this level along the whole train without steps or ramps.

Other platform heights require either additional steps at the entrance or inside the train. With the standardised platform heights in Europe of 550 mm and 760 mm steps and ramps are necessary either at the entrance doors or inside the unit.

The difference between single and double decker units for passengers with reduced mobility (PRM) is the accessibility of mobility impaired persons or persons in wheel chairs.

Fig. 52: Bombardier TWINDEXX double decker variants.
Top: entrance between the bogies with no step at 550 mm platforms.
Bottom: entrance over the bogie with three entrance steps (Bombardier)

Due to the stairs in double decker units for such persons there is no free access to all areas. Elevators might compensate this effect, but lost passenger space and additional cost would reduce the advantages and attractiveness of double decker units.

The arrangement of train access depends on the platform heights. There are solutions with level entrance to the lower deck of double decker units with platform heights of 550 mm as in Switzerland. This arrangement allows an access to the lower deck without steps and ensures a good accessibility for wheelchairs.

Where the platform height is different from the floor height, there is a need for steps either at the entrance or inside the train to access the compartment.

- *Environmental sustainability.*
  Several parameters of double decker units are favourable to the environmental sustainability of such trainsets: The weight per seat of a double decker unit is smaller and its usable area is bigger. So the energy consumption as well as the resources needed for the production of the trainset are lower. At the same time the necessary platform length for a given transport capacity is lower for double decker trainsets, so platforms and stations need less resources to build and maintain.

- *Loading gauge.*
  With a minimum required standing height of 1950 mm at both levels, the height of the loading gauge should be at least about 4300 mm. Bigger heights make it more comfortable.
  For this reason there are no double decker units in the UK with its restricted loading gauge height. A double decker design named "Aeroliner 3000" [34] with gangways offset between the two floors has recently been proposed but the standing height in the lower floor would still be as low as 1.85 m and 1.7 m in the upper floor.

- *Platform length.*
  If an increased passenger capacity is required for an existing platform length, such requirements can sometimes only be achieved by double decker units, because the capacity per length can be up to 50 % higher compared with a single deck unit.

Fig. 53: Proposed "Aeroliner" double decker train for the United Kingdom. (Reinhard Christeller)

34 Under the £2.2 million Future Railway Programme funded by the British Railway Standards and Safety Board (RSSB) and Network Rail, in conjunction with the Department for Transport (DfT) and the Royal Institute of British Architects (RIBA), the Munich based design office Andreas Vogler has developed the "Aeroliner 3000" concept with the scientific support of the German Aerospace Center (DLR).

Entrance and interior floor arrangement, steps and ramps
is mainly driven by:

- *Type of operation.*
  In commuter trains it is very important to have short passenger exchange times and a good passenger flow at the entrances. Therefore the goal is an entrance without steps. Also inside the train the steps, stairs, ramps and pedestals are disturbing the passenger distribution in the train. The ideal commuter trains have a continuous floor height from the entrance area that matches the platform and no or only a minimum of stairs, steps, ramps and pedestals inside the train.
  In long distance and regional trains the passenger exchange time is less important and compromises based on the existing platform heights with steps at the entrance and ramps/pedestals inside the train are acceptable.

Fig. 54 and 55: Pesa Dart train for the Polish PKP Intercity. While there are steps at the entrance the interior floor is completely level. (Reinhard Christeller)

Fig. 56: Floor area in the bogie zone of a Siemens built Austrian ÖBB cityjet regional train with two steps, a light and long ramp and pedestals to access the seats. The access to the train is at 600 mm and thus stepless for 550 mm platforms. There are sliding steps for remaining 380 mm and lower platforms in some stations. (Reinhard Christeller)

The ergonomic features of the postural support are to be taken into account. For example, the presence of a backrest significantly increases sensitivity to front-to-back vibration between 2 and 5 Hz. Other variables in the physical environment may change the way the individual responds subjectively to the vibration.

The measure of vibratory comfort

The vibratory comfort can be evaluated according to direct approaches (questionnaires of comfort for the travellers) and indirect ones (physiological indices). The passenger's dynamic environment with can also be measured using accelerometers.

Comfort Questionnaires

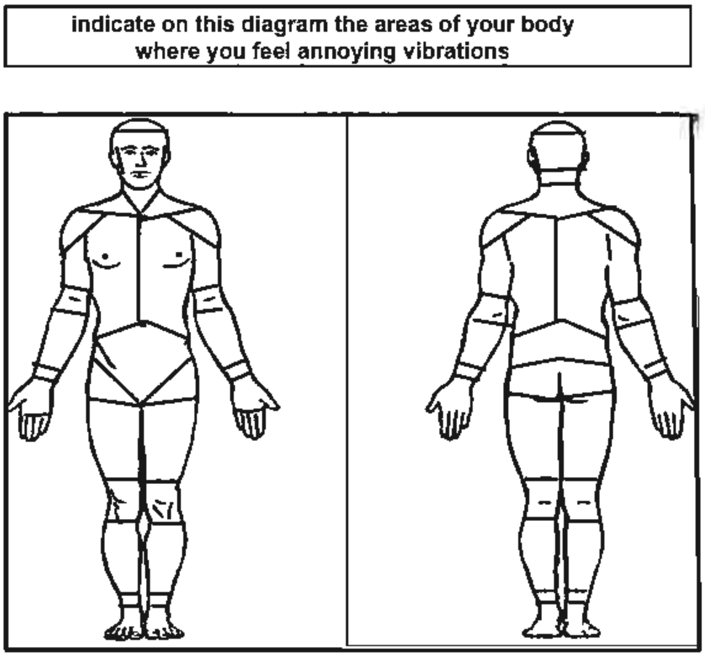

Fig. 71: Manikin test. (Louis-Marie Cléon)

Questions about vibratory comfort can be included in more general questionnaires, generally used by the operators' commercial departments, to know the wishes of the customers and to orient their commercial policy.

These very general questionnaires generally do not allow us to isolate vibratory comfort. Selected subjects are then placed under representative experimental conditions.

Specific questionnaires of vibratory comfort can be filled at closer intervals, for example one hour.

These questionnaires make it possible to evaluate the weight of the different factors and parameters of the dynamic environment. Other types of questionnaires such as that of the "manikin", also applicable for thermal comfort, make it possible to analyse body fatigue (figure 71).

This type of evaluation is very expensive in terms of experimentation and the analysis of results. Statistical sampling of subjects truly representative of the "rail passenger" population is difficult to achieve. The size of the sample is very important for the result to be reliable, considering the interaction between all the components of comfort, or even possible effects of synergy with the noise level.

Physiological measurements

Attempts at physiological measurements on a voluntary subject have been by the French national institute for transport research (IFSTTAR). They consist in continuously recording the electrical activity of the muscles particularly interested, in this case, muscles of the back and the neck. These measurements are very delicate because the treatment of these recordings must make it possible to separate spontaneous movements, due to changes of posture, from the muscular activity induced by the vibrations. The method of measurement, which involves the instrumentation of a subject, makes these physiological measures reserved for research, in particular as regards the evaluation of the phenomenon of fatigue.

Measurements of the dynamic environment

Logically, the measurement of vibrations must be done at the interface between the seat and the subject, because the vibrations perceived by the occupant are different from those received at floor level. In fact, several methods can be used.

➢ Indirect method

In-line vibration measurement at the floor level characterises the vehicle from the vibratory point of view. This method is the most widely used because it requires known and reliable testing and counting means.

The vibration measurement at the test bench at the subject/seat interface characterises the seat from the vibratory point of view.
This method can also be used when the vibratory behaviour of one of the elements (floor, seat) is known.

The test procedure is as follows:

The seat is mounted on the test platform (figure 72). Two subjects take position successively on the seat: a heavy subject of 90 kg and a light subject of 50 kg. The tests are successively carried out under pseudo-random excitation of direction x, y and z. The accelerations at the man / seat interfaces are measured using the "cupule" (a soft interface devices placed between the subject and the seat and comprising measuring accelerometers in y and z as described in figure 7, for the seat sitting, and a rigid disc equipped with an accelerometer for the backrest.

An example of results obtained in figure 73 shows the transmission ratios between the response at a given point and in a given direction, and the excitation at the level of the foot in a given direction.

In general, these curves show two types of resonance. The one marked, around 5 to 6 Hz, corresponding to the resonance of the mass of the individual on the foam of the seat sitting, and others, between 10 and 30 Hz, corresponding to the specific modes of the structure of the seat and in the specific mode of the seat screws to its elastic binding to the floor.

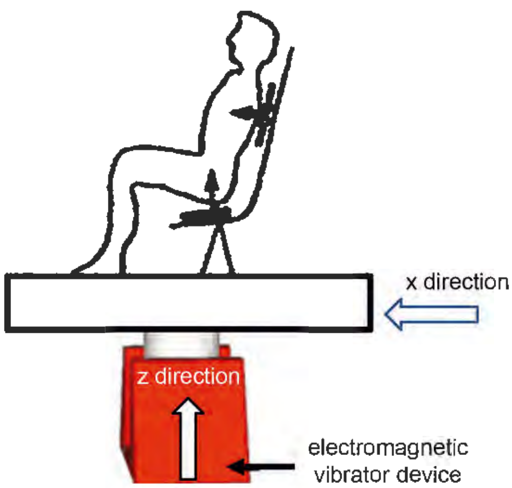

Fig. 72: Test principle on bidirectional bench.

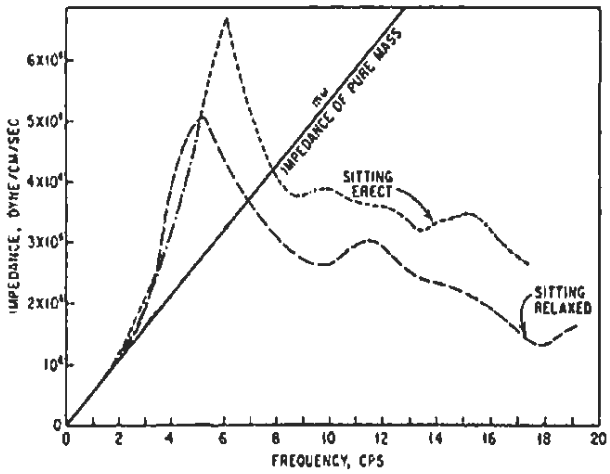

Fig. 73: Transmissibility of a seated subject [25].

➢ Direct measurement

In-line vibration is measured at the interface between the person and the seat. This measurement directly characterises the vibratory comfort perceived by the passenger. We use the same interfaces as those presented in the previous paragraph. The great difficulty of this type of measurement is the maintenance of a stable position of the subject relative to the seat. In the laboratory, keeping is easier to perform. Figure 74 shows a spectrum obtained in line at the interface cupule of figure 75.

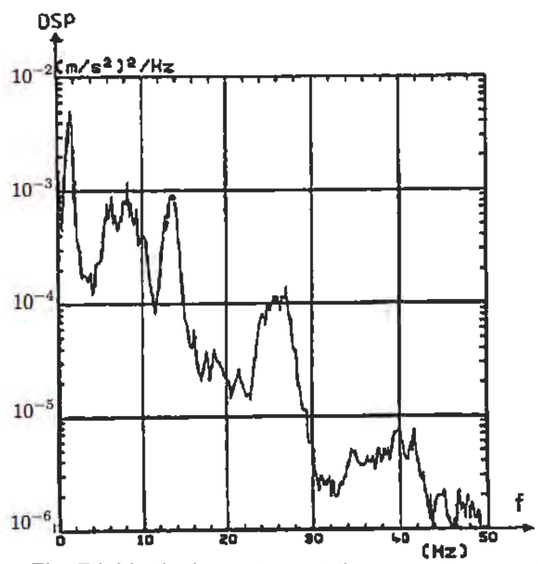

Fig. 74: Vertical spectrum at the passenger-seat interface.

7.2.7.4.1 Railway applications based on steel

Fig. 39: Examples of vehicles with steel bodies

Fig. 40: Rolled steel solebar Fig. 41: Sheeted framework (both Alstom)

Steel structures are composed of a framework made up of rolled (figure 40) or folded profiles welded together, and sheets tensioned and welded to the framework (figure 41).

Body side sheets are flattened to minimise deformations and the thickness of filler needing to be applied before the finished paintwork.

The MIG (Metal Inert Gas) welding process is most commonly used for the assembly of the different profiles and sheets, but TIG (Tungsten Inert Gas) may also be used[17].

The steel grades used for the various structural members depend on the loadings and tensions induced by the different load cases. S355 MC and S500 MC grades are mostly used, but S700 MC may be introduced locally.

Several assembly concepts may be employed.

17 See section 7.2.9.2.1

7.2.7.4.1.1 Vehicle underframe

A. Self-Supporting Underframes

Here the underframe itself can withstand the vertical loads. This is the case for freight vehicles (Figs. 42 and 43) and most often also for locomotives.

Fig. 42: Self-supporting wagon underframe

Fig. 43: Wagon with self-supporting underframe (Reinhard Christeller)

B. Semi self-supporting underframes

Here the underframe cannot alone withstand all the applied loads. It contributes to vertical body stiffness in combination with the other body shell elements (body side walls, roof etc.). Among semi self-supporting underframe designs, there are:

- underframes with solebars (figure 44).
- underframes with a central beam used particularly for low floor applications, where the solebars are ‘cut’ by access doors, as shown in figure 45.

Fig. 44: Underframe with solebars (both Alstom)

Fig. 45: Underframe with a central beam

3 ROLLING STOCK
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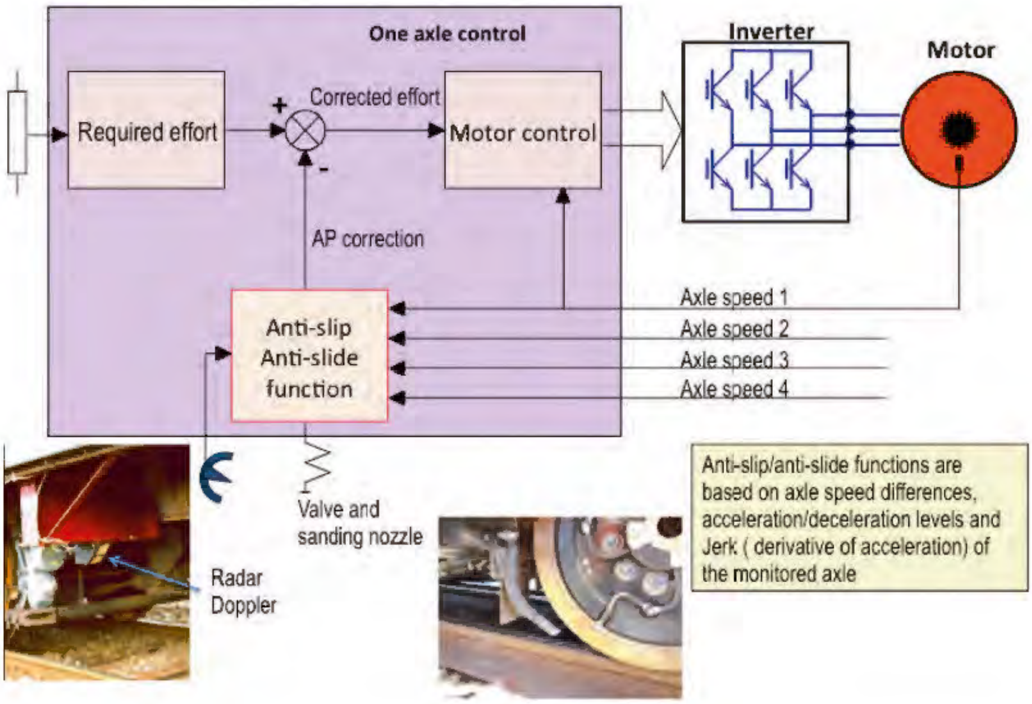

Fig. 10: Anti-slip function.

Figure 11 shows an example with successive slips. The max available adhesion is about 27 %, the anti-slip device parameters have to be adjusted so that the average tractive effort approaches at best the adhesion envelope curve.

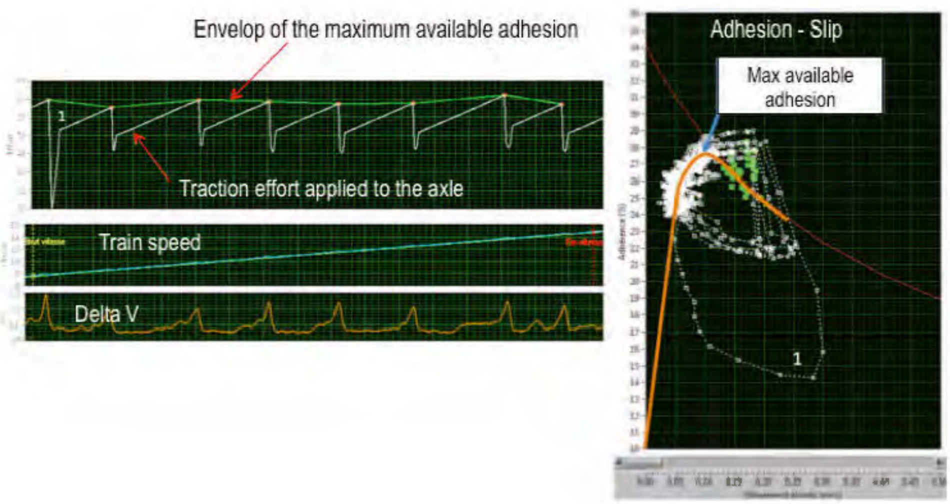

Fig. 11: Simulation of successive slips with degraded adhesion.

8.1.3.4.2 Anti-slide function or wheel slide protection device (WSP)

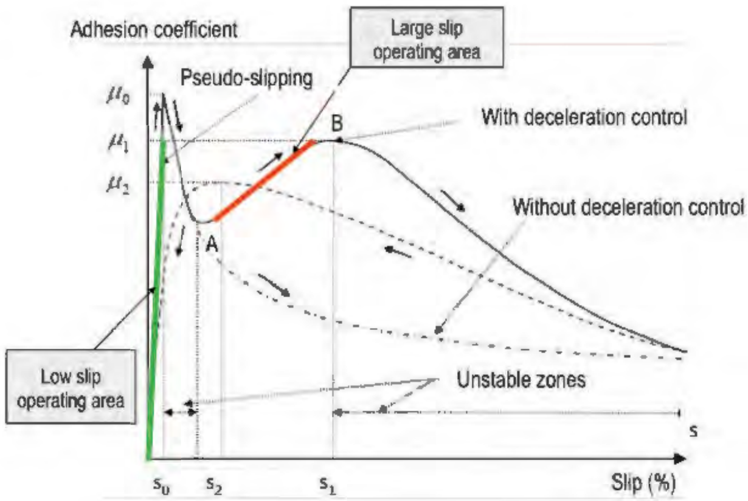

Fig. 12: Adhesion recovery in braking by deceleration control. (Michel Boiteux 1986)

In braking the anti-slide function can operate similarly to the anti-slip function in the micro-slip area, about some percent (it is an anti-slide with a weak slip), this is to prevent wheel slip as soon as the solicited adhesion exceeds the peak μ_0. Mainly used for holding and retarding braking, it avoids high energy losses due to prolonged significant creepage and thus reduce the wear of wheels and rails.

But in braking it has been observed that a slip control in a range of the order of 15 to 20 % allowed to transmit a significantly greater effort than when the slip is not controlled. The adhesion curve as a function of wheel slip then has a second positive slope with a maximum μ_1 (point B of figure12), this maximum changes over time and may even become greater than $\mu 0$ as the speed decreases. The phenomenon arises under the effect of the injection of energy into the wheel-rail contact provided that it lasts long enough (several tens of seconds). It is possible to regulate the slip stably in the region of positive slope between points A and B, the other parts with negative slopes being unstable by nature. Furthermore, it has been shown that this slip control has a beneficial effect on the adhesion between wheel and rail, resulting in a phenomenon of adhesion regeneration, phenomenon all the more effective that the train is long: it occurs an effect of "cleaning" of the rails by the sliding of the first axles, cleaning which benefit the following axles. The average effort on the entire train is therefore significantly improved.

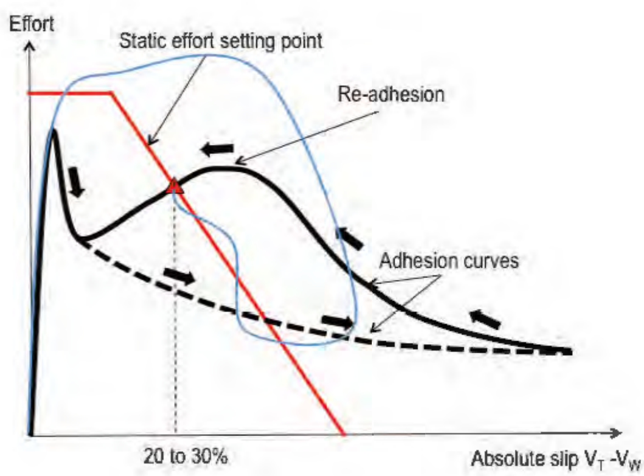

Fig. 13: High slip anti-slide: Path of the effort in the effort-slip plan with adhesion recovery.

Figure 13 shows how the anti-slide with high slip reacts: when the effort at the wheel rim exceeds the first adhesion peak μ_0 there is a loss of adhesion. The regulation controls the effort (dotted line) to converge at a crossing point between the static effort demand depending on the wheel slip (red line) and the adhesion curve, near the second peak μ_1. The phenomenon is dynamic and the adhesion curve changes with time

Experience shows that an AE-FG (high slip anti-slide device) is more efficient than an AE-fG (weak slip anti-slide device) with respect to braking distance in degraded conditions. It is used mainly during service or emergency braking modes. The lengthening of the stopping distance is then around 15 % to 30 % depending on the vehicles and, in particular, the length of the train. With an AE-FG the wheels having a peripheral speed V_W at rims much lower than the speed of the vehicle V_T, the difficulty for the slip control is to "estimate" the actual speed of the vehicle called reference speed. The estimation of this reference speed is easy with a speed measurement on a non-motorised axle (ideal case) or with an axle voluntarily under-braked by moment for adjusting the reference speed on the real speed of the train. But this is not always possible, so we resort to fairly complex and often patented algorithms.

Details on the anti-slide function and the standards in force for the certification are given in the chapter dedicated to braking.

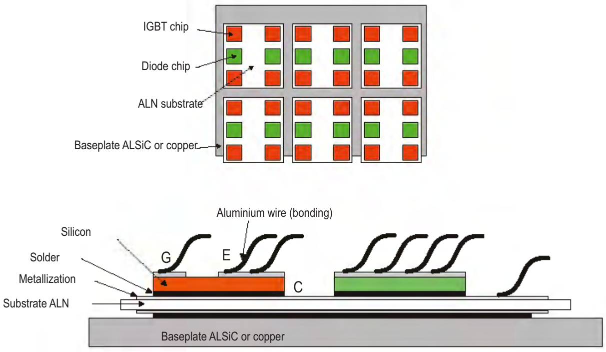

Fig. 286: IGBT structure, a stack of layers of different materials and many welds and solders.

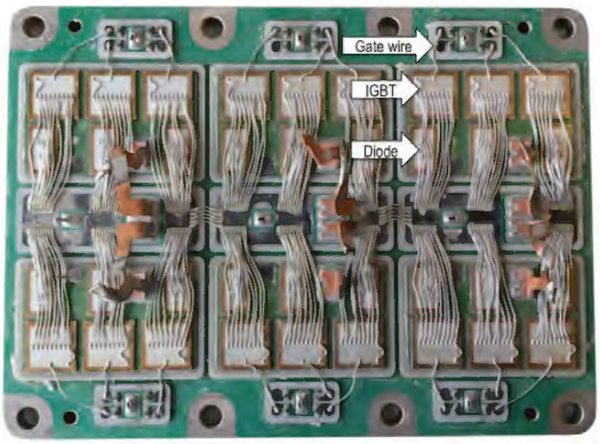

Fig. 287: Internal view of a Mitsubishi IGBT module.

Aluminium wires, named bonds, are welded onto the top of chips and connect the emitter current to the output power terminals, other bonds gather the gate control wires. It is obvious that this mechanical assembly is much more complex than that of a press-pack thyristor or GTO. The stacking of several different materials as well as the numerous solders and brazes can cause reliability problems if the technology is not perfectly mastered. We will come back to the thermo-mechanical fatigue created by the thermal cycling of the modules.

Figure 287 shows the internal lay-out of a Mitsubishi IGBT equipped with 18 IGBT chips and 18 diode chips, brazed on 6 substrates.

One can see the bonding wires collecting all the emitter currents, and the gate wire at the periphery of each chip. As AlN substrates are fragile, their size is intentionally limited in order to avoid cracking or rupturing due to mechanical stress when the baseplate of the module is fixed on the cooler which may have imperfections in flatness.

A layer of thermal grease of about 100µm is always laid under the baseplate to mitigate surface irregularities. For the dielectric strength, the assembly of chips and bonding connections is covered with a silicone gel, which can be covered or not by a hard resin. The case allows the power connections to pass through its top so that it is not really waterproof. This raises the problem of resistance to humidity in general, especially in tropical regions.

8.1.10.1.3 Range of IGBTs in electric traction

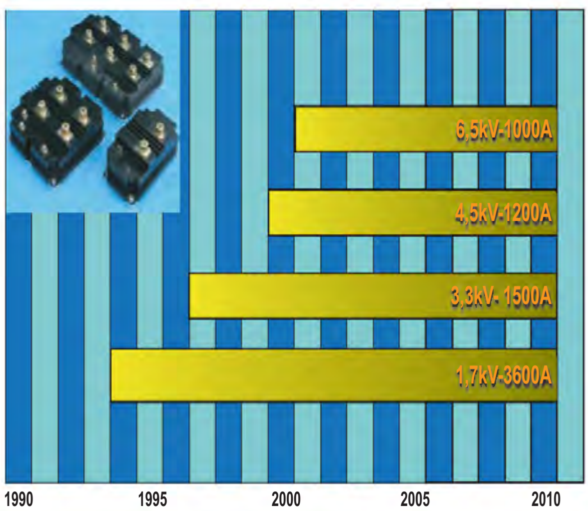

Fig. 288: Evolution of IGBT range used in electric traction

IGBTs which appeared in electric traction around 1990, had a relatively low voltage withstand of 1600 V, which rapidly was increased to 1700 V for metros and tram applications under 600 V and 750 V lines. Then the range was extended to 3300 V IGBT for applications under 1500 V networks or even 1800 V DC bus. Later 4500 V IGBT were produced with the aim of replacing the obsolete 4500 V GTOs. In the end 6500 V IGBT were designed for applications on 3000 V networks (figure 288).

Nowadays, the IGBT range is able to cover all the standardised DC voltages defined by EN 50163, without the necessity to connect components in series as it was in the past, which very much very much the power circuit diagrams.

Nominal currents have also progressively increased for the same chip surface installed. The tendency is to loss reduction, junction temperature increase and a better mechanical resistance to thermal cycling.

The IGBT arrangement in the modules has also diversified to better meet the demands of the designers (figure 289).

Currently, the “dual” module with two independent IGBTs per case seems to take precedence over the “single switch”, because it allows the building of a very compact full arm for an inverter or rectifier with a minimum of stray inductance, the consequence of which will be studied later.

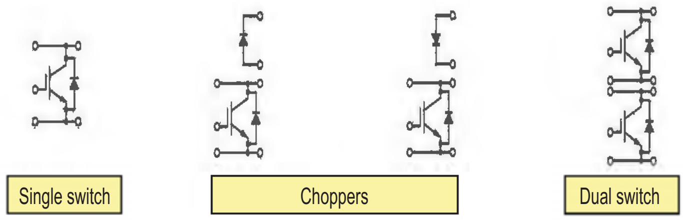

Fig.289: Some different arrangements of INFINEON IGBT modules.

8.1.10.1.4 IGBT implementation – electric and thermal constraints

Without entering into all the design details of an IGBT-based converter, it should be noted that these switches must respect at least 4 fundamental constraints to ensure their function with excellent reliability (some hundreds FIT) and a significant life time (twenty to thirty years).

FIT (Failure In Time) is $1{\cdot}10^{-9}$/h: it corresponds to one fault per billion service hours. IGBTs have significantly improved the reliability of converters and the high voltage IGBTs, although the most stressed, present a FIT below 100. The power modules of converters are thus able to reach a service reliability of 500 000 to 1 million hours. A commercial service year in the railway domain is approximately 3000 h to 6000 h according to the type of rolling stock and the operating mode, the probability of a fault becomes very low: 1 failure per power module every 100 years!

The four basis constraints to respect are:

- Not to exceed the specified max voltage in blocking state or at any moment.
- To maintain the IGBT inside its current-voltage safety area during commutation.
- To limit the temperature of silicon junctions.
- To limit the number of thermo-mechanical cycles.

Permanent voltage withstand

The rule is that the permanent DC voltage in service (DC bus voltage) does not exceed about 60 % of the IGBT maximum voltage (V_{CES}: collector-emitter sustaining voltage) specified by the manufacturer. This is a key point to keep a good reliability over the long term (figure 290).

DC bus voltage	Choice of IGBT max voltage (V_{CES})			
4000V max				6500V
2800V max			4500V	
2000V max		3300V		
900V max	1700V			

Fig.290: Choice of IGBT max voltage (V_{CES}) as a function of the nominal DC bus voltage.

Operation inside the safety area

During switching, the IGBT and its associated diode must be maintained permanently inside a safety area in the current-voltage diagram. For an IGBT this is the RBSOA (Reverse Bias Safe Operating Area) and for a diode this is the SOA (Safe Operating Area). Figure 291 shows the two safety areas of a 6500 V- 600 A IGBT module of Infineon manufacturer.

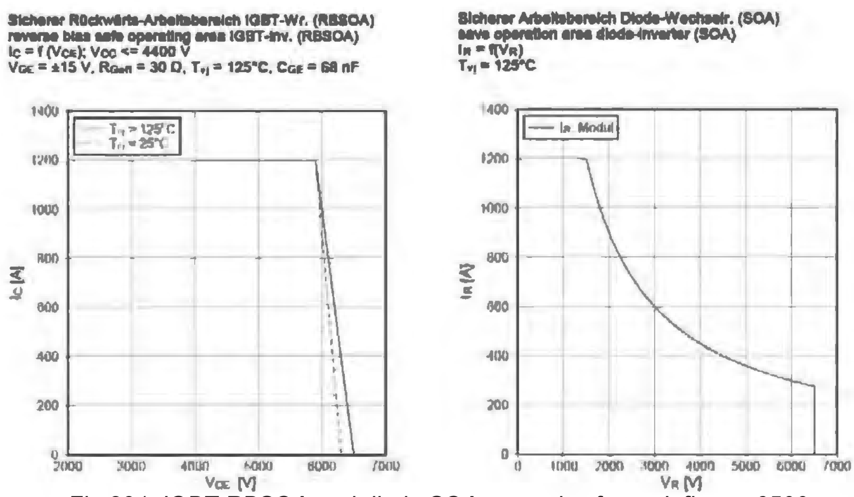

Fig.291: IGBT RBSOA and diode SOA examples for an Infineon 6500 V-600 A module

3 The “consist” lines and the train lines

The “consist” lines are the electrical cables that carry digital signals (True/False, True = presence of voltage, False = no voltage) from one end to the other of a trainset i.e. a consist of vehicles.

Train lines are electrical cables that carry digital signals along the whole train. They cross from one consist to another via the electrical coupler.

4 The driver’s cab and the man-machine interfaces

Most of the rolling stock man-machine interfaces are located in the driver's cab. These interfaces consist of switches, pushbuttons, selectors, signalling lamps, displays, screens (tactile and non-tactile) and keyboards.

5 The power supply of the train control and monitoring system.

The circuits of the train control and monitoring system are powered from the battery voltage of the rolling stock. When the rolling stock is powered, power converters charge the battery and at the same time supply the train equipment with energy and feed the circuits of the train control and monitoring system.

6 The UIC 568 audio bus

This analogous signal bus specified by the UIC 568 leaflet is used for audio intercommunication. Modern trains normally use an Ethernet computer network to handle audio communication as it allows other features. In this case the UIC analogous bus backs the Ethernet network for safety redundancy.

7 The safety loops

In railway engineering language, a safety loop is a circuit that conveys a continuous electrical signal that gives information, or causes the execution of an action, related to the safe operation of the train should the signal be interrupted. An example is the door loop.

The function of the door loop is designed to give the information that at least one of the train’s door is open. The following figure illustrates its operating principle.

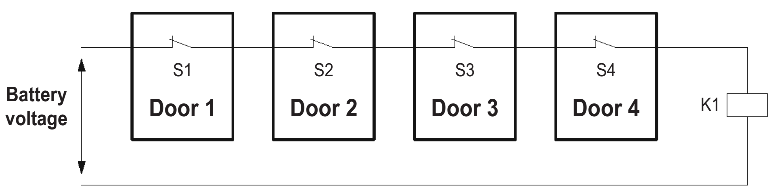

Fig. 2: Example of a safety loop.

Each door has a limit switch (S1, S2, ... Sn). The limit switch contact informs about the closing of the corresponding door. If there is at least one open door, there is no electrical continuity and the relay K1 will not be energised as the loop remains open.

9.4 The specification of the train control and monitoring system

The methodology used for the design and specification of the train control and monitoring system is based on a functional analysis. This chapter provides a general overview of this methodology.

9.4.1 The functions

The on-board control and monitoring system of a rolling stock performs actions (braking, opening the doors, etc.) which are the result of an analysis of input variables. It means that, in order to be able to specify the control and monitoring system, functions have to be well identified, including the degraded operating modes,. The input variables can be requests sent by man-machine interfaces (pushbuttons, touch screen, etc.), or parameters identifying the status of the train (for example: stationary train, moving train), or requests and measurements issued by rolling stock systems or subsystems (speed, voltages, temperatures, etc.).

To standardise the designation and structure of the functions associated with the rolling stock, the standard EN 15380-4 is generally used. It is the standard used in this book, and all chapters which refer to a given on-board subsystem relates to this standard[6].

[6] Of course, such a standard cannot claim to be comprehensive but using it has the advantage of providing a common railway framework for the management of interfaces, particular requirements, or even the architecture of the TCMS monitoring system. But there is always a possibility of unlisted functions or of a standard function designation that does not exactly match the requested functionality.

9.4.2 The origin and identification of functional requirements

The main sources of requirements for the design of the rolling stock control and monitoring system are:

- The regulations (mandatory requirements from national laws or international guidelines such as the TSI),
- The standards (normally required by the regulations or customer specifications),
- The dialogue with the customer,
- The lessons learned from other trains or systems,
- Existing equipment, requiring the consideration of specific functionality,
- The know-how of the developer.

From the above elements it is necessary to clearly identify and separate the requirements between functional characteristics (or functional requirements) and those required without functional characteristics (i.e. non-functional requirements).

- *Example of a functional requirement:* "The direction of travel can be selected only when the train is stationary and in the absence of traction effort demand".
- *Example of a non-functional requirement:* "The arrangement of the cables must avoid friction between them or against any other neighbourhood organ"

9.4.3 The train status

The execution of the actions by control and monitoring system is conditioned by the status of the train. The following table gives a list of the most typical situations:

Status	Description
Prepared train	Preparing a train corresponds to the battery powering of most control and monitoring equipment and circuits. This state corresponds to " train activation". The obtained train status is called "prepared train".
De-prepared train	De-preparing a train, corresponds to the interruption of the battery power supply to most of the equipment and circuits of the control and monitoring system. The obtained state is called "de-prepared train". This is the reverse operation of the preparation. In the de-prepared state, some electrical circuits remain powered by the train batteries (for example, the control and the supply of train signalling lights).
Standstill train	Due to the limitations of the speed measurement, it is considered that the train is in standstill when its speed is below a specified speed threshold (typically < 3 km/h). It can also be considered that the train is stationary only when the speed is below the threshold and the brakes applied.
Train in service standby	The train is at a standstill, prepared, fed with high voltage (or thermal engine running), without any cab in service and with driving controls neutralised. This state is typically used when the driver is changing cab.
Moving train	When the train is not in standstill (see status standstill above).
Cab in service	Cab where driving controls are active. For safety reasons it should not be possible to have more than one cab in service on the train. The cab in service is also called occupied cab or active cab.
Coupled cab	Cab connected to another cab via the train coupler.
Neutralised cab	Cab that cannot be put in service because another cab is already in service on the train.
Train in pre-conditioning	Status used to activate the train air conditioning and fill the compressed air system (if applicable) before the train is put into service. Normally this state can be activated automatically from a de-prepared train. In this state, the train is at a standstill, fed with high voltage, with no cab in service and with at least the relevant systems (air conditioning and air compressors) operational.

Table 1: Typical train status.

11.1 Introduction and scope

At the beginning of the 19th century, in the early years of railways, the centre of attraction was the locomotive - the steam locomotive. Never before had had man built a land vehicle that was so strong and powerful, and that could go so fast. To the general public the early steam locomotive was preposterous, often seen as a life threatening monster; it conveyed fears but also bewilderment. To engineers and technicians it was a major technical breakthrough, a masterpiece of innovation. To them it was an object of great pride. The locomotive also caught the eyes of famous painters, such as Lyonel Feininger, who captured the character of steam locomotives in numerous drawings; sometimes as black odd looking contraptions passing through the countryside spewing clouds of grey smoke and scorching ash into the sky; sometimes as friendly, obedient workhorses beautifully coloured in red, black, and green, surrounded by elegant passengers and proud engineers, see figure 1.

Fig. 1: The Old Locomotive; one of approximately 40 drawings of locomotives by Lyonel Feininger, a major contributor to cubist and expressionist schools of art in the early 20th century.

The early locomotive inspired also song writers. Well-known is the title Chattanooga Choo Choo, beautifully interpreted by Glenn Miller and his orchestra. And further, the locomotive found its way into classical music with the movement symphonique, Pacific 231, of Arthur Honegger. It is said that he loved locomotives passionately. There is no doubt of this when listening to the sounds of the heavy machine as it starts with powerful strokes begins to accelerate picking up speed slowly, charges through beautiful landscapes, and comes suddenly to a thundering stop. Latest with this orchestral work the locomotive has become an integral part of our culture.

Early on, the locomotive proudly portrayed the identity of a railway. Now, much of the past glory of the locomotive is gone. The locomotive has received competition from many other types of rail vehicles: EMUs, DMUs and self-propelled trains of all types. And often these attract more attention to the general public than do locomotives. In many railways today, the locomotive has become a standard product, a statistical unit, one of many parts of train operations.

With the beginning of rail liberalisation in the mid-1990s, locomotive development followed the industrial trends, also of the airplane industry, e.g. Airbus and Boeing, combining innovation with standardisation in a global environment. In fact, in some ways, to design locomotives is more challenging than to design airplanes. There is worldwide a single homogeneous airspace in contrast to many very different rail infrastructures, typically unique in every country. And although there is a continuous intention of unification towards the “Single European Railway Area” (SERA)[1], system complexity remains high. The task to achieve interoperability in this environment is often left to the ingenuity of the locomotive engineer. Thus, in a different way, the further development of the railways (and locomotives) can be seen as on-going technical art-work.

This locomotive chapter summarises the current status of locomotive design. It portrays what has been achieved over the last decades, and lays open the hurdles yet to be overcome. Main focus is on mainline locomotives in Europe. Here, advanced propulsion and data communication technologies stimulated a multitude of innovations. These have fostered standardisation and product variability, which are in line with the political objectives of seamless cross-border services in a liberalised railway market. An outcome has been the development of locomotive platforms, which today dominate all major railway fleets in Europe.

Scope: Focus is given primarily to European designed locomotives and power heads with AC propulsion, initiated in the late 1980s by the availability of GTO power semiconductor devices. With this technology, a traction power beyond 1.6 MW per wheelset has been reached, allowing locomotives to attain 230 and high speed trains 350 km/h. Although the main focus is on electric locomotives, diesel-electric locomotives are also covered – with the primary difference being within the propulsion systems. At the end, a list is provided of all major European and export mainline locomotives with GTO, and IGBT[2] based propulsion technology using asynchronous traction motors.

[1] See vol. 1, chapter 3.
[2] GTO: Gate turn-off thyristor. IGBT: Integrated Gate Bipolar Transistor. For more details, see chapter 8.1, Electric Traction.

11.2 The generic locomotive

11.2.1 The principles of a locomotive

A locomotive is defined[3] as: “a traction vehicle (or a fixed combination of such vehicles) that is not intended to carry payload, and that has in normal operation the ability to be uncoupled from the train and to operate independently”. Apart from providing traction, in most cases it also supplies the train with energy and information. From a technical standpoint, this chapter covers also similar vehicles, e.g. power heads (see paragraph 11.2.2.4), which are generally an integral part of a train.

In general terms, it can be said that railways do not earn revenues with locomotives, but with what they haul. Thus from an operations perspective, the locomotive should be as small and light as possible, so to permit a maximum possible train load at a fixed overall train length and weight. But on the other hand, the locomotive must have the physical capability to pull a train; it must have a certain size and weight to generate tractive effort and power onto the rails. These tractive ratings are defined at the wheel rim, i.e. at the contact points of the locomotive wheels to the rail; here the locomotive “grips” the track to pull or brake the train.

The tractive effort is the most important characteristic of a locomotive. It is generated by the torque of the traction motor acting via the gearbox and the wheelset onto the track. The locomotive design process often starts with the manufacturer deciding on the maximum adhesion coefficient (μ)[4] between wheel and rail (averaged over all wheels) that he wishes to exploit with the locomotive in a specific railway environment. With dry clean tracks an adhesion coefficient in the range of $0.35 < \mu < 0.45$ is attainable. On the other hand, on wet and contaminated tracks (due to oil, rust, coal dust, etc.), the values can be much lower, $0.15 < \mu < 0.35$, and in some cases even lower than 0,15. For most European railway undertakings a design value of approximately $\mu = 0.36$ is selected. For high-speed power heads it is lower; for heavy haul locomotives operating in an arid environment it can be higher, $\mu > 0.40$.

The relation between locomotive weight and the maximum starting tractive effort is given by:

- Min locomotive weight [kN] = max starting tractive effort [kN] / max chosen adhesion coefficient

If the manufacturer requires 300 kN starting tractive effort, then the weight of the locomotive must be at the minimum 300 kN / 0.36 = 833 kN, which is 85 t. This is the weight of many European 4-axle locomotives. If it is 90 t, then the starting tractive effort can be increased to 320 kN, as is the case of the French Prima I locomotives.

The traction power is the second most important characteristic. The installed traction power is calculated by the needed tractive effort at the wheels to reach the required train speed:

- Traction power [kW] = tractive effort [kN] · speed [km/h] / 3.6

Thus, if a 150 kN tractive effort is needed to pull a freight train at 120 km/h, then the power at the wheels must be 150000 · 120 / 3.6 = 5 MW.

The available technology determines if a locomotive with the ratings of 300 kN and 5 MW, in fact, can be built at the target weight of 85 t. The locomotive weight may indeed be higher, although mostly undesirable, but in any case it must be below the allowed design limit (in Europe typically 90 t for a 4-axle locomotive). On the other hand, if the available technology allows reaching the target locomotive traction power at a lower overall weight, then the desired weight for the target tractive effort can be reached either by adding ballast, or by increasing the traction power, or by utilising the weight and space reserves for new locomotive functions, e.g. multi-system capability, additional signalling systems for cross-border services, or last mile diesel engines. This example shows why locomotive design is technology driven - why lighter and more compact systems allow adding new functionalities to meet the changing market needs. These step-by-step improvements led to a multitude of locomotives types over the last decades.

The locomotive application can be in many ways[5]. Locomotives can pull or push the train, be positioned in the front or at the back of a train, or be in an intermediate position. European freight trains are typically pulled with a single or multiple locomotives. Different types - diesel and electric, shunting and mainline locomotives - can operate together. Regional and intercity trains typically use locomotives at one end for push/pull and a driving coach at the other. Such trainsets can run in double or triple formation for train coupling and sharing. Locomotives can operate in train compositions with EMUs, DMUs and with locomotives of different technology.

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3 See vol. 1, chapter 2, definitions relating to rolling stock.

4 The adhesion coefficient (μ) is the ratio of the maximum attainable (traction or braking) force to the vertical force of a wheel onto the track. See 8.1.3 for more details.

5 See vol. 2, chapters 6.2, 6.3 and 6.4

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Eric Fontanel has graduated as an engineer from the Ecole Centrale de Paris and has spent his entire career in the rail industry, holding several high level positions in engineering and project management at Alstom Transport.

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Besides the edition of the book together with Eric Fontanel, he wrote in this third volume the enclosure in chapter 8 dedicated to innovative traction technologies in public transport.

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François Lacôte graduated from the Ecole Polytechnique and of the Ecole Nationale des Ponts et Chaussées in Paris. He has devoted his entire professional life to railways, first in SNCF where he started his carreer in the maintenance department and then with Alstom from 2000 to 2014.

In 1982 he was appointed head of the SNCF high speed rolling stock programs and as such he was responsible for three TGV generations. He has also been Rolling Stock Director and International Development Director , and finally Director for Research and Technology (1997 to 2000) and President of the AEIF. In 2000 he joined Alstom as Senior Vice President in charge of technical development and innovation. He directed the operations leading to the world speed record of 574.8 km/h and the development of the AGV. In 2012 he received the "European Railways Award" of UNIFE and CER and in 2014 the UIC Award for Research and Innovation".

With his profound knowledge François Lacôte supported the editors and authors of this book by his friendly advice.

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Florent Brisou

Florent Brisou is an engineer from ENSEM Nancy. At Alstom since 1989, he is a senior expert in braking systems. He has been in charge of the development of braking systems for several platforms of rolling stock, trams as high-speed trains, and today of the new range of AVELIA VHST. He has also worked in support of other product lines, locomotives or regional trains. Florent Brisou is a member of several European standardisation groups, an internal trainer at Alstom, and a teacher in the « mastère spécialisé systèmes de transport ferroviaires et urbains » and at the Ecole Centrale de Nantes. He is the principal author of the major chapter devoted to braking systems.

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François Cabillon, CESTI and ISMCM engineer from SUPMECA Paris, has spent his entire career in the railway industry. He has been in particular Engineering Director at SAB WABCO (now Faiveley Transport), and then joined Alstom Transport as a "master expert", to take responsibility of the braking systems skills network. At CEN, he has been a long-time member of the braking systems Working Group, as well as Chairman of the Subcommittee for Rolling Stock Subsystems. François Cabillon contributed to the braking systems chapter for regulatory and normative aspects, braking performance and links with signaling, he also wrote the chapter on the production of pneumatic energy.

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Marc Debruyne is an engineer in electrical engineering from HEI Lille, who spent more than 40 years working for the railway industry, particularly in the field of electric traction, at Jeumont-Schneider then Alstom. He was director of traction systems engineering at the Tarbes Alstom site. As Master expert in traction systems, he was also in charge of technical coordination between the three traction system design sites in Tarbes, Sesto (Italy) and Charleroi (Belgium). He has been involved in several European research projects, including Modtrain-Modpower and also in CENELEC standardisation groups as a member or convenor. He wrote numerous articles on railway traction and teaches in this domain in several engineering schools and particularly in the framework of the French Master in Rail and Urban Transport Systems. Marc Debruyne is the author of the major chapter on electric traction.

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Markus Hecht holds a degree in mechanical engineering from the University of Stuttgart and a doctorate from Aachen Technical University. After starting his career at SLM in Switzerland where he was deputy director of engineering, he has since 1997 been a professor at the Technical University of Berlin and a lecturer at TUM Asia Singapore. He is dedicated to teaching and research in several areas of railway rolling stock. Expert for the railways with the SAS and DAkkS accreditation services in Switzerland and Germany, at the European level he is a member of the scientific committee of ERRAC and a member of the expert committee on noise at the European Commission. Markus Hecht wrote the chapter on the future of rail freight transport in Europe.

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Dominique Hegy graduated from the CESI engineering school in Nancy. After an early career as an electronics technician in the automotive industry and a move into auto racing that gave him the thermal engine virus, he quickly became a specialist in diesel and gas energy production and marine propulsion groups at Wärtsilä in Mulhouse in 1999, then at Heinzmann GmbH & Co. KG in Schönau in Germany until 2007. He then joined the railway industry as a locomotive project engineer and expert in diesel traction and power generation at Alstom firstly, then Bombardier and today ABB in Switzerland. Dominique Hegy teaches diesel traction as part of the French Master in Rail and Urban Transport Systems, he is the author of the chapter devoted to thermal traction.

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François Maumy, a specialist in electromagnetic compatibility (EMC) for more than thirty years, obtained a PhD in this field in 1985. He is responsible for EMC management at Alstom since 1989, with the title of Master expert, leader of the specialists internal network in this field and responsible for overseeing in this aspect all design of rolling stock and traction equipment. François Maumy has been and still is a very active member of all CENELEC standardisation groups on EMC in the railway field, as well as of the ERA working group on compatibility with train detection systems. He wrote the specific enclosure on EMC in this third volume.

Ralph Müller

Graduated from the Hannover University in railway engineering, Ralph Müller has made his career in the DB group. After holding several positions in the field of railway operations and technology, he was successively head of the department of technology of electric locomotives, further on responsible for the MODTRAIN project and standardization of rolling stock, then head of technology management of the DB group, responsible for technology strategy, innovation management and technical regulation and standardisation. Since 2016, he has been responsible for R & D in control, command and signaling at DB Netz, the infrastructure manager of DB. Ralph Müller is, with Janis Vitins, one of the authors of the locomotive chapters and driving cabs and contributed to several other articles in the three volumes of this book.

Joao Palma

Joao Palma is an engineer from the Technical University of Lisbon (Instituto Superior Técnico de Lisboa). After an early career in the Portuguese industry, he joined Bombardier Portugal in 1997 as head of electrical engineering department. He continued in the same field since 2002 at Bombardier France, in Crespin, where he took responsibilities as manager of the electrical production engineering, and after in project engineering for the propulsion, auxiliaries and TCMS system. He was a representative in France of Sweden Bombardier's propulsion and control division, responsible for inter-divisional interfaces and technical support for propulsion and control systems. He was also in charge of technical audits of ongoing projects and he had the function of innovation manager in the context of global product management. Today, he is working as head of the global center of expertise (CoE) for the electrical architecture. Joao Palma teaches in the French Master on Rail and Urban Transport Systems and wrote the chapter on Train Control and Monitoring Systems.

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Xabier Pérez is a doctor from the University of Navarre in San Sebastian. He started his career at the CEIT research center as a specialist in rail vehicle dynamics and, after several years as a research fellow at the Metropolitan University in Manchester, he joined CAF in 2008, where he is now head of the R & D strategy team. He also participated for CAF in numerous European R & D and standardization projects and was deeply involved in the preparation phase of the Shift2Rail initiative, as coordinator of the rolling stock innovation program. Xabier Perez, with the help of his Shift2Rail colleagues, wrote the chapter on future developments for European passenger rolling stock and, together with his CAF colleagues, contributed to the chapter on variable gauge systems in Volume 2 of this book.

Lisa Stabler

Lisa A. Stabler holds a bachelor's degree in mechanical engineering from the University of Dayton and a master's degree in mathematics from Wright State University. After holding several management positions in engineering and quality in the US automotive industry, and in rail transportation at BNSF, Lisa Stabler has been since 2011 president of the Transportation Technology Center, Inc. (TTCI) in Pueblo (Colorado), a subsidiary of the Association of American Railroads (AAR). Ms. Stabler was also Chair of the AAR Advanced Technology Security Committee. Lisa Stabler wrote the chapter on the future of freight rolling stock in the United States.

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Graduated in Electronic Engineering in 1982 at the Turin Politecnico University, Roberto Tione has worked in the Avionic industry until 1993, when he joined Sab-Wabco, today Faiveley Transport, where today he holds the position of Research & Development Director in the Brakes & Safety Division. Author of several patents and technical publications, he is the author of the enclosure dedicated to electronic braking in freight trains.

Janis Vitins

Janis Vitins holds a Ph.D. in Physics from the Swiss Federal Institute of Technology in Zurich and was a researcher at MIT Cambridge, USA, from 1976 to 1978. After starting a career in power semiconductors at ABB in Switzerland, he joined in 1989 ABB Transport in Zurich (now Bombardier), where he was responsible for mainline locomotives sales and projects for Switzerland, Austria, Scandinavia and Russia. From 2000 to 2013, he was Bombardier's product marketing director for electric and diesel locomotives, and supervised, among other things, the development of the TRAXX platform. Since 2013, he has been an independent senior railway consultant. Janis Vitins wrote the chapter on locomotives with the collaboration of Ralph Müller and collaborated with him in writing the cabs chapter.

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