

# Railway Technology Review

- Assisted, automatic or autonomous operation
- Track monitoring
- Dynamic track deflection measurements
- New Commuter and Regional Train Platform











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## Dear Readers,

Considered globally, transport by rail finds itself in a challenging situation. The one side to that is that railways of all sorts are absolutely essential for coping efficiently with the traffic volume and thus for meeting the climate targets. The other side is that transport by road in individual vehicles would appear to be on the verge of making inroads into some of the systemic advantages of rail transport, with the electrification of transmissions and the possibilities of driverless operation. The effect is an increase in competitive pressure between the modes of transport.

With that as its background, this latest issue of the ETR International Edition focuses on the innovations with which the industry supplying the railways is setting about facing up to the challenges. Our contributions cover the whole breadth of rail as a system – from the potential of automated or even autonomous railway operation through new technologies and methods concerning the permanent way to improvements in the management of vehicles and fleets. What is striking is that virtually every one of these examples is making the frequently invoked digitalisation more and more of a



tangible reality and is giving us a clearer idea of the possibilities for rail resulting from the improved capture and utilisation of various different forms of data.

Making the most out of these opportunities for the entire industry calls for academics, manufacturers and operators to all toe the same line. In the process, the industry supplying the railways must face up to global competition more strongly than ever before. For the railway suppliers in the German-speaking part of the world that means contending with new challenges, but at the same time it also means the release of additional innovative forces. The boom in railway traffic considered on a worldwide scale and the pending leaps forward in innovation doubtlessly represent opportunities for the suppliers from the German-speaking countries.

In such a situation, we are delighted that this issue has once again come about in close cooperation with the VDB (the German Railway Industry Association) and that for the first time the Austrian Association of the Railway Industry has also been involved. The ties between the German and Austrian industrial businesses have been traditionally close, especially since the development of the railway systems in the two countries have always run in parallel in many respects. In that way, the railway supply industries in Germany and Austria enjoy the best possible preconditions for being successful together in a global railway transport market.

The initiatives presented in this issue are evidence of that. We live in challenging times, yet in many places transport by rail is viewed quite clearly as contributing to solving transport and environmental problems. The next step is for tangible solutions and achievements to be put into practice!

Bosel

Manuel Bosch, Publishing Director DVV Media Group | Eurailpress







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## **SCHAEFFLER**

# Digitisation of the industry supplying the railways is advancing at full speed

Digitisation is creating the best rail mobility that there ever was: causing less harm to the climate than ever before, even safer, even more economic, even quieter and even more comfortable. That is the aim that the companies in Germany supplying the railways are setting out fulfil with their technologies. It is at all times human beings who are at the heart of this digital revolution in mobility; it is they who are benefitting from the technical progress of "Rail 4.0" through participation in society and sustainable mobility.

## A NEED FOR TOTALLY NEW MOBILITY CONCEPTS

More and more people throughout the world are yearning for sustainable mobility in their everyday lives. The threat of total gridlock in numerous metropolises, the frustration of searching in vain for a parking spot and the unbearable smog – all of that is making new mobility concepts indispensable wherever in the world we happen to be. What is more, digital rail "made in Germany" is able to deliver such concepts. With ever greater comfort and convenience. The capacities of "S-Bahn" trains running automatically, for instance, can be adapted in real time to match the effective demand. A simpler way of putting that is: railway running when customers need them. That might play a role, for example, with large-scale organised events. Let's imagine an open-air concert ending earlier than planned on account of a rain storm; the more flexibly trains can then be deployed, the better it will be. Of course, travel is pleasanter if passengers are given individualised information in real time and can make more flexible use of their time once onboard - thanks, for instance to WLAN and mobile-telephone repeaters. The benefit of digitisation is very tangible.

And with it too is the contribution of those working on digitisation day in, day out in throughout the railway sector – developing, integrating, manufacturing and selling. Digital control, command, signalling and safety technology for the infrastructure, digitally assisted maintenance, which is able to work in a forward-looking way thanks to intelligent data analysis, intermodal networking in the transport of freight, the responsible handing of data – all of these things are making transport by rail better in future. Digitisation is indeed advancing at full speed.

## DIGITAL TECHNOLOGY FOR MORE CLIMATE PROTECTION

The European Union is pursuing the ambitious goal - and quite rightly so - of reducing greenhouse gas emissions in the transport sector by 60% by 2050. By 2020, 10% of the energy needed in the transport sector is to come from renewable sources. Moreover, the energy reguirement is to be brought down by 10% (compared with 2005). However, transport has so far been the only large sector in the EU that has not succeeded in achieving an overall reduction in CO<sub>2</sub> emissions. "Rail 4.0" is the key to more climate protection, because digital technology has the capacity both to increase the proportion of rail-based electro-mobility in the modal split and to further reduce the consumption of resources in rail traffic.

Transport by rail is predestined for low-emission mobility not based on fossil fuels. Those of us involved in inputs to transport by rail are already in a position to implement much of what is needed for climate protection. Climatefriendly electro-mobility? With rail, it's already a reality. In 2011, 92% of operational movements in Germany were carried out by locomotives and multiple units with electric traction. Recuperation of braking energy? With rail, that too has already been commonplace for a long time. The German Federal Government's mobility and fuel strategy rightly classifies rail as the principal protagonist in the energy revolution. It is making the best possible use of the growing proportion of renewable energies in the generation of power to channel it into railguided electro-mobility.

## DRIVING AUTOMATICALLY ON RAILS SAVES ENERGY

The picture painted of sustainable mobility



**Dr. Ben Möbius** Managing Director German Railway Industry Association (VDB), Berlin Further information at: www.bahnindustrie.info

has all too often been one in sombre colours. Doing without is what has been stressed – and those who do have been made to feel guilty to boot. Rather than that, "Rail 4.0" is a promise – one of sustainable mobility that is there for the people, that looks after the climate and that makes travel fun.

Digitisation is enabling enormous progress, and that can already be felt today. One example is that metro trains running automatically consume around 30% less energy. That is not a result dreamt up in a theoretical exercise; it can be observed in practice in places like London with its Docklands Light Railway. It is a success that comes above all else from an optimised driving style, avoiding unnecessary acceleration and braking. Automated vehicles protect the environment precisely because of the combination of almost entirely recyclable materials and reduced masses. With regenerative energies and digital technologies, rail is opening up gigantic opportunities to become independent of fossil energy sources more rapidly. Comprehensive climate protection considers the entire life cycle, which, in the case of all modes of transport, means not just the day-by-day operation but the manufacture of a product (consumption of energy and resources) and its recyclability.

#### **RAIL FREIGHT 4.0**

Globalisation means division of labour. Every exporting nation is dependent on an excellent system of logistics. Manufacturing and trading are otherwise likely to face a blackout. Logistics must also demonstrate greater concern for the climate. The transport of freight by road is based almost 100% on oil. That has prompted the EU to formulate a target: by 2030, 30% of all the goods that have up until now been transported by lorry over distances greater than 300 km are to be transported by rail. The German Federal Government's Round Table has also expressed its commitment to transporting freight by rail. It is a fact that investments are needed there. Intelligent infrastructure is capable of increasing the capacity of the railways in future, especially in the hinterlands of the ports. Intelligent infrastructure, precise tracking, careful monitoring of cargos, multimodal exchange of data, automatic train formation and predictive servicing – it is only by going digital that the transport of freight by rail is going to be able to perform so strongly that its market share increases and the emissions decline. The industry manufacturing for the railways in Germany has turned many digital projects into realities - mainly in exports. The fact remains that it is only digitisation that can strengthen the transport of freight by rail so that it becomes an integral component of an intermodally networked future logistic system.

#### DIGITAL, EFFICIENT AND HIGH-PERFORMING

Mobility by rail means quality of life, particularly in metropolitan regions. Transport by rail supports local environmental protection, cultural participation and social cohesion. It is a matter of making sure that conurbations are capable of functioning – and that they retain their competitiveness for the future. Megacities, particularly in fast developing regions of the world, are today already often wobbling on the brink of what is tolerable in terms of transport and health. Such cities only have a sustainable, functioning future ahead of them by espousing the digital transport of passengers by rail – and intermodally too.

On the routes between the big metropolises, trains based on digital technology are going to be able to offer a globally more important alternative to flying. One good example is the railway route between Madrid and Barcelona, which has been upgraded with ETCS Level 2 and which today is already the choice of one traveller in two. High-speed trains are contributing to a particular extent to economic development worldwide.

#### "MADE IN GERMANY" AND "MAKE IN GERMANY"

"Rail 4.0" needs both: a sense of proportion and a pioneering spirit. There are many technologies raring to go and to play their part in this fundamental innovation. Very often they have been developed and are produced in Germany. "Rail 4.0" is intended to be "made in Germany", but at the same time it ought also to mean "make in Germany". The one naturally gives rise to the other: being the leading supplier and the leading market. That is the only way that Germany can reap full benefit from the potential of "Rail 4.0": more quality of life, more climate protection and more wealth creation. Three maxims for those in government to take to heart can be built on that:

- → Encourage innovations through a national railway research programme;
- → Insist on innovations through sustainable tendering practices that are a better reflection of the life cycle and also through seed programmes; and
- → Apply innovations boldly f. ex. pilot projects that could include automated driving.

"Rail 4.0" has the makings of a German success story but that depends on industry, government and operators writing it together.



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# The rail supply industry in Austria

By international comparison, the industry actively manufacturing for the railway in Austria starts from a position of way-above-average strength and inventiveness. Its innovative drive is evident in particular in the areas of rails, switches and crossings, track-engineering machines, electric transmissions, running gear and bogies, passenger stock, metro and light rail trains and trams and also in systems for protection, control, command and signalling and communications. What is needed for playing a decisive part as a world leader here in future too – in other words for occupying a top position – is, of course, continuous further developments and innovations with a market impact.

The Austrian Association of the Railway Industry presented a study by the Economica Institute into the economic importance of the rail supply industry in the "Haus der Industrie" in Vienna a few weeks ago. What up-to-date findings did that study produce?

*Th. Karl:* The study confirms that the Austrian rail supply industry is a true champion by international comparison. That is documented, for instance, by the fact that, on a world-

wide scale, Austria is the country with the highest density of inventors holding railway-relevant patents measured as a percentage of its total population. That means that our branch of industry is in a top position as regards innovative performance in such a strategically important segment.

#### Are those innovations also being transformed successfully into substantive economic advantages?



#### Thomas Karl President, Austrian Association of the Railway Industry

Thomas Karl qualified as a telecommunications engineer at the Vienna University of Technology. He has already held various management positions with FREQUENTIS AG and, as Director Public Transport, he is currently head of the business unit responsible for information and communication solutions for railway and local public-transport systems. Thomas Karl has been a committed member of the Association's board of directors for many years and was elected its President in 2015.

#### Ronald Chodász Managing Director

### Managing Director, Austrian Association of the Railway Industry

Ronald Chodász had completed his training (in telecommunications and electronics) at the TGM School of Engineering in Vienna and had embarked on a course of business studies when he was recruited by a large company producing for the telecommunications sector and spent more than twelve years with it in the functions of development, commercial coordination and marketing. Considering Austria's EU ambitions, he made the move into representing industrial interests and has been the Managing Director of the Verband der Bahnindustrie since 2005.

Th. Karl: Yes. It goes without saying that it does not stop at obtaining a successful ranking for innovation indicators. Tangible economic successes are measurable in export orders. The Austrian rail supply industry is also considered to be a world champion when it comes to exporting. Despite being a relatively small country, we are in fifth place worldwide as regards exports in the field of "railway vehicles and associated equipment". Measured in per capita terms, Austria even has the highest level of exports from the rail supply industry. In order to continue to give these successes the international visibility they deserve, we are particularly pleased to appear in the "ETR -International Edition" as a successful medium of the railway sector.

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Dipl.-Ing. Thomas Karl (President of the Austrian Association of the Railway Industry) – Ing. Ronald Chodász (Managing Director of the Austrian Association of the Railway Industry) (© Claudia Pohl)

## What are the challenges going to be in the coming years?

*Th. Karl:* Innovations that can be put to use in practice and that are rapidly visible are vital for the survival of rail as a system in the competition between the modes of transport. That is where we have simply got to succeed in achieving an immediate total shift in emphasis by pursuing ambitious projects jointly with innovative companies operating in both the field of heavy rail and urban local transport. That must also be an element in the general trend towards the digitisation and networking of all modes of transport.

If, however, the innovative drive of the active companies supplying the railways in Austria, Germany and generally in Europe is to continue to be converted into economic success, there is one truly essential precondition: namely a fair, non-discriminatory environment for international trade relations.

Back in 2016, the European Parliament adopted a resolution by an overwhelming majority in favour of safeguarding the competitiveness of the European rail supply industry.

#### What do the framework conditions for the further development of transport by rail look like in the field of transport policy?

Th. Karl: The European Union's latest transport white paper establishes an ambitious

framework for transport policy. For example: it defines the need for a modal shift in transport to achieve an effective reduction in greenhouse gases. By 2030, 30% of the freight transported by road over distances greater than 300 km is to be moved onto rail or the waterways. By 2050, that proportion is to be increased to 50%.

When it comes to passenger traffic, the white paper formulates the objective of completing the European high-speed railway network by 2050 and of trebling the length of the existing high-speed network by 2030.

*R. Chodász:* In conjunction with the modal-shift aims formulated in the white paper, the Austrian Association of the Railway Industry has adopted a stance against the introduction of "extra-long trucks" (or "monster HGVs"), which various groupings are advocating. To allow them would be in blatant contradiction to the aims of the white paper, since in larger areas they would lead to the transport of freight being shifted back onto the roads.

In many fields of transport, rail is quite simply the problem solver. That is the case both as regards transport between the big economic and population centres and especially as regards local passenger transport in the towns and cities and the regions around them.

Environmentally friendly electro-mobility has been evolving on an impressive scale for a long time in all railway segments. At present, innovations that have come from the rail supply industry are helping to improve still further the efficiency of electric drives.

Another highly topical issue is autonomous driving. By its very nature, rail-guided transport is predestined for that and is already demonstrating it safely and reliably in a number of fields in everyday operations. Here too, further innovations are soon going to lead to the opening up of new application fields.

#### What expectations does the rail supply industry have as regards the provisions in the European railway packages?

*R. Chodász:* In the current, fourth European railway package, the rail supply industry is primarily affected by the so-called technical pillar. Its aim is to create a single European railway area and to simplify and unify the railway systems that have developed very differently in the past as regards their technical and operational rules. As a rail supply industry, we support this process, since it is a field in which massive cost savings can be achieved. That ought to increase rail's competitiveness impressively compared with the other modes of transport.

At all events, it is our view that the signals have been correctly set for a positive development – for both the companies operating within railway systems and for those supplying them and closely related with them.

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# Assisted, automatic or autonomous operation – potential for rail traffic

Rail-guided traffic has systemic advantages for automatic or autonomous operation compared with road traffic. Different opportunities and recommended actions are found to exist for each of the market segments of local passenger traffic, long-distance passenger traffic and freight traffic. They can be compound to create an attractive service to offer in future.

#### **1. INTRODUCTION**

To the best of scientific knowledge, traffic as it is observed and exists is an outcome of locational factors, their accessibility, the transport on offer and the personal behaviour of each individual using it. Therefore, transport is the consequence of the fundamental need for mobility, serving the purpose of activities and exchange relationships involving people and goods for the purposes of living, employment/education, supplies (including the transport of goods) and leisure pursuits. These basic needs are achieved in reality on the basis of the distribution of locations, the

transport on offer and the personal preferences or considerations of convenience in the form of nontransport (on foot or taken. by bicycle) and in the

case of both passenger and freight transport making use of collective modes (trains, buses, trams and metros) or individual motor vehicles (cars or lorries). The transport infrastructure is an essential component in this, since it has a crucial impact on the accessibility of places. If we follow the trias of environmental policy, "avoid - reduce - make compatible", then what matters most of all today is to avoid physical transport using vehicles and/or aircraft powered by internal combustion, to avoid the environmental impacts of the remaining transport as far as possible and to create the necessary preconditions for that - in other words to arrange the transport installations and services to be as compatible as possible with the urban and natural environment. On top of that, information and communication technologies are creating potential for networking between the individual modes of transport and are expanding the technical and organisational requirements made of transport

planning and infrastructure design by adding the aspect of organisation and design of services encompassing various modes of transport. One example of that is that the societal trend towards "sharing rather than owning" can be supported by interlinking schemes for hiring bikes or sharing cars with local public transport. In the "final development stage" of such systems, the complete integration of such offers may lead to an expansion of classical integrated transport associations to comprehensive mobility associations [1] and to new customer potential, thereby improving the economic efficiency of local public transport, which, in turn, could

As far as rail is concerned, the basic preconditions for driverless operation are very good, and crucial motorised modes of preparatory steps have already been

that, attention must be paid to arranging the transport offered to be customer-friendly

also reduce the

burdens on the

environment

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and reliable. The increasing spread of low-cost and partly mobile sensors is opening up the possibility right at the outset of obtaining more up-to-date and comprehensive information about the particular traffic and pollution situation and of building on that to use traffic control and management strategies in a more up-to-date, individualised and efficient way. Today, mobile terminals and navigation systems in vehicles are able to calculate routes dynamically in both public and private transport on the basis of up-todate situational information, so that congestion can be avoided and thus reduced; such systems are also able to pick alternatives in the event of delays and cancellations. In that way, it would also appear feasible, looking to the medium term, to create dynamic environmental zones, varying in the area covered and over time, and also to issue recommendations for avoiding them.



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For the time being, the discussion is focusing primarily on the technological potential. Research still has to be carried out into the users' perspective and their acceptance and also the timeframe for market penetration. It can, however, already be taken as a recommendation today that, for all structural, technical and organisational measures, interfaces ought to be envisaged for future sensor systems, data transmission and actuator systems, leaving open the possibility of future adaptions and enhancements. It is possible that such smart technologies might have specific effects when it comes to interlinking transport and energy supplies and also managing traffic.

Turning specifically to transport, it is to be assumed that the control of traffic as a whole and also individual vehicles will become increasingly automated, starting with the assistance systems already in use today and progressing to autonomous vehicles. It is expected that these technologies will increase in efficiency through better-balanced loads and driving styles, a control of capacity uti-



1 GOA = Grade of automation as defined in IEC international standard 62290-1

2 SAE Levels 0 – 5: Grades of automation as defined by the Society of Automotive Engineers (SAE)

FIG. 1: Steps in the automation of rail (top) and motor traffic (bottom)

(© Siemens AG)

lisation, optimisation of the use of capacity and a marked improvement in traffic safety.

A crucial issue affecting those developments, whose ultimate target is driverless operation, however, is deciding on where to draw the line for final responsibility remaining in the hands of the human being or operator. The central problem as the burden on the driver or operator is more and more reduced, with assistance becoming increasingly sophisticated, is maintaining their attention at a sufficiently high level to ensure that, if the need arises, they can react quickly and correctly and that the decisions they take will be the correct ones [2]. To that extent, strongly automated or partially autonomous processes also go hand-in-hand with error susceptibility, which be borne in mind. Fundamentally, any form of support from an assistance system may contribute to reducing the propensity to make mistakes, thereby improving traffic safety.

#### 2. POTENTIAL FOR THE VARIOUS MODES OF TRANSPORT

In the media, the subject of "driverless driving" is currently concerned primarily with road traffic, but it ought not to be forgotten that aircraft have had autopilots for decades, and that they are capable of controlling aeroplanes in most situations. In the field of rail transport, we are talking about metro and people-mover systems, of which there are more than 80 lines operating without drivers and completely automatically in about 60 so networks around the world [3]. One effect of the intensive media reporting has been to cause confusion as regards the terms used for this subject. A look, for instance, at the current discussion of definitions going on within the German Academy of Science and Engineering (Acatech) shows that no clear distinction is being made between autonomous and automated driving [4]. That makes it worthwhile to get the terms sorted out:

Autonomous driving: the vehicle moves through the traffic space entirely by itself thanks to the sensor systems installed onboard and its artificial intelligence. It reaches its destination even without external information and utilities – possibly at a reduced performance. It is able to react to unforeseen changes in the environmental conditions.

The automotive industry is propagating this technology as the ultimate stage in driverless driving [5, 6]. It is interesting to note that the intermediate stages on the way there are described as partly, highly and fully automated, whereas the proper terms ought really to be partly, highly and fully autonomous. The final aim ought surely to be for the autonomous system of "vehicle + driver" to evolve into an autonomous system of "vehicle + sensors + artificial intelligence".

Automatic or automated driving: The vehicle moves like an automaton. It is generally steered from the outside, and, if it loses its link with the control centre, it must react in a failsafe way, in other words by coming to a standstill or by continuing on sight. Given the external monitoring of the vehicle in combination with the protection of its track, it is possible for it to operate at high speeds. It is a technology that is favoured by the rail transport sector [7]. On account of the long braking distances needed by railways, driving on sight is not a meaningful option, so today's railway vehicles too cannot be operated without a central control, command and signalling system.

Assisted driving: Assistance systems can be used to support autonomous driverless driving, automated driverless driving and driving with a driver and thus to improve performance and safety. They are not, however, an indispensable necessity for autonomous or automatic operation.

In the field of rail traffic, the basic preconditions for driverless operation are very good, and crucial preparatory steps in that direction have already been taken. The first point to make is that, on account of the very fact of vehicles being steered by rail, there is only one degree of freedom, namely longitudinal. Thanks to the signalling infrastructure, the monitoring of railway lines and existing technologies, such as LZB or ETCS, the systems for operational control are already there, suitable for remote control and basically capable of controlling vehicles on the spot or of replacing the driver and are already partly doing that in some instances.

In road traffic, the vehicle has two translational degrees of freedom in a single plane (longitudinal and lateral). In roads outside of built-up areas, on long-distance roads and in fenced-off areas (ports, airports, etc.) driverless, automated and even autonomous operation is thinkable today, making use of modern driver assistance systems and developing them further. Such scenarios, however, describe a form of operation in which a driver can still intervene and, in the final analysis, must intervene should the need arise. As an alternative, it is possible to contemplate very low speeds with the option of stopping at any time (for example in warehouses), which in the case of road traffic is »



FIG. 2: Hong Kong Metro, featuring platform screen doors

(© IFS, Aachen University)

propagated under the term of so-called "valet parking".

In air traffic, where all three translational degrees of freedom are available in space, a system exists in the form of the "autopilot" that fundamentally permits a fully automated flight, but where the pilot must be present and ready to assume control at any time. Apart from that and depending on particular limiting conditions, it is already possible nowadays for an aircraft landing to be carried out completely automatically.

## 3. POTENTIAL FOR THE VARIOUS SEGMENTS OF RAIL TRAFFIC

The potential for driverless operation, the

necessary technologies and the degree of maturity are different depending on which segment of rail traffic is considered.

In the case of metro and people-mover systems (of which the latter function primarily for transport to and from airports), the issue of driverless automated driving is already state of the art. The reason for that is that these rail-guided vehicles operate on a track that is isolated from other transport systems. Apart from in their stations, there are no interfaces with other modes of transport. Here the supervision of platforms (such as on Nuremberg's metro network) or the installation of platform screen doors (such as on the Hong Kong Metro, Fig. 2) ensure that passengers cannot be hit by railway vehicles or fall onto the track. On elevated systems like the "H-Bahn" in Düsseldorf Airport, platform screen doors are compulsory.

Modern metro systems in particular are essential for megacities to function. Automation is a way of saving personnel costs and ensuring improved adherence to the timetable. There would appear to be hardly any scope for a further shortening of the very brief headways, which are already down to a minimum of approximately 90 seconds. For that reason and on account of the very high passenger numbers, metro traffic needs to operate with high-capacity trains.

The situation looks different if we consider the possibilities for regional rail services. What is meant by that are railway services within regions with a fairly low population density and/or connecting services over



FIG. 3: Small, comfortable, autonomous railwayvehicle unit (© Siemens AG)



FIG. 4: Autonomous or automated shunting (© IFS, , Aachen University)

short-to-intermediate distances from the conurbations to and from such regions or linking subcentres with one another. Regional rail does have further interfaces with other modes of transport apart from at its stations and also possibilities for unauthorised persons to get onto railway property, for instance at level crossings or along unfenced lines away from stations. Today, depending on the population structure and the individual line, these trains run with fixed headways ranging from roughly every 20 minutes up to two hours. Switching over to driverless trains would offer the possibility of running a more frequent service with smaller units and thereby enhancing the attractiveness of the service offered by the railway (Fig. 3). These units do not even need to have particularly powerful motors, since it would suffice to offer travel times roughly equivalent to those by motorcar, i.e. not exceeding a mean of 60 km/h along country roads. A problem does, however, occur with the limited numbers of trains that such lines can carry today on account of the existing signal blocks. Moving over to a higher frequency with small, driverless units would require the introduction of continuous train protection in combination with shorter block sections or even a moving block system (for instance ETCS Level 2 or 3). It would also be necessary to check the need to introduce some form of protection against trespassers for critical interfaces like level crossings and possibly even open tracks.

As an alternative to automated operation with a central control, command and signalling system, it would be possible to run regional services autonomously with small units. That would admittedly mean placing a severe limit on the vehicles' maximum speed, since they would have to be able to stop within the "field of vision" of their onboard sensors, if they were to detect an obstacle. It would be possible to support them with external assistance systems supplying them continuously with information concerning, for instance, the position of the vehicle immediately in front of them or immediately behind them or the "state of occupation" of level crossings. Where the regional traffic on several lightly trafficked branch lines converges onto a single trunk line it might be possible to configure the single autonomous vehicles or short trains travelling at slow speeds to form fast, automated trains as far as a destination junction, where they would be divided up again.

The speeds of long-distance trains are so high that braking distances of a kilometre or more occur. At such high speeds, the movement of trains and the infrastructure are generally kept under observation from a control centre. Completely autonomous driving at speeds like that is totally unthinkable in the absence of a central control, command and signalling system. Long-distance rail traffic is taken to mean services over longer distances between conurbations and is today often called intercity and/or high-speed traffic. The stops, level crossings and open track are all critical interfaces, as are non-stopping stations with platforms, which require a safe form of supervision if long-distance trains are run automatically. The advantages of driverless operation for this segment lie in reliable compliance with the timetable, thanks to optimisation possibilities in running the operation, rather than in cost savings. High-speed, long-distance traffic in particular must remain competitive relative to air and motor traffic or must further extend its advantages as regards comfort and convenience and short travel times. As long as it is impossible to fit in a round business trip between most ICE stations in Germany within a day, air traffic will also continue to play an important role in domestic transport in that country.

A further development of long-distance rail as a system is to be expected to come rather from the optimisation of automated operations supervised by human beings in the direction of autonomous operation through automation of the control, command and signalling systems.

One particular challenge facing rail traffic is the transport of freight. Despite the fact that volumes have been increasing steeply, the proportion of freight carried by rail in Germany and Europe stands at around 16-17% [8]. The principal reasons are the long lead times for ordering such consignments and, at least in wagon-load business, the long transport times. The latter come about because the individual wagons first of all have to be marshalled together to form trains in junction terminals. These trains are often taken to destination hubs overnight, from where they continue their journeys once again as small units. It often happens that the final delivery of small units is done by lorry. Transport by lorry throughout is thus clearly faster, provided there is no congestion en route. In container traffic, at least the cargo loaded onto the wagons is always of the same type, which makes it possible for trains to be preconfigured. Despite that, transhipment from lorry to wagon and back onto lorry at the destination is time-consuming and labour-intensive. It is only the third category of freight transport that can be completed in a short period of time, namely the mass transport of bulk cargoes all of the same type or of breakbulk cargoes such as steel coils or cars.

Big savings can be made in both time and human resources by automated or autonomous shunting (Fig. 4).

For freight trains moving along open tracks, similar considerations apply to those for long-distance passenger traffic. There would also be further scope for automation of loading and unloading operations in the container terminals. Big seaports represent good examples of that [9]. One relevant bottleneck affecting the train leg between the terminal of origin and the destination terminal - the main leg of the journey, in other words – is that freight and passenger trains use the same tracks, and it often happens that freight trains enjoy a lower priority in traffic management, so that if conflicts arise, they are forced to wait on a siding until the following passenger train has overtaken. That is a circumstance that automating the traffic would not solve either, given that passenger and freight trains travel at different speeds. The idea of operating freight trains at high speeds too would appear to be uneconomical, given that high-tech wagons would be required. Rather than that, it would make sense to take the segregation of passenger



FIG. 5: Autonomous tram in a networked transport environment

(© IFS, Aachen University)

and freight lines still further by constructing additional tracks and lines.

The last category of rail-based transport to be considered is tramways - or, in more modern parlance, urban light railways. The difference between the two when operating inside cities is that a classical tram runs exclusively in normal street traffic, whereas at least parts of an urban light railway network make use of their own, separate tracks, which may be on the surface or underground. Today, most of these systems have moved on from being pure tramways and when they run on underground, elevated or fenced-off lines the same considerations apply to them as to metros. On a segregated open track, they can be driven on sight (i.e. autonomously) at a slow speed. If the aim is to drive them faster and without drivers, then protective measures would need to be erected along the line here too and especially at level crossings, which often have no barriers. On the road, trams will have to run autonomously if that is also the technology to be used by motor vehicles in future too. In order to avoid accidents and keep the traffic flowing, road users in towns and cities will even be in continuous contact with one another, which is known as "car-to-X communication" [10] (Fig. 5). Trams must use the same communication technology and the same action algorithms as the motor vehicles, failing which they will be categorised as a safety hazard and rejected on that basis in the age of autonomous motor vehicles.

The complete automation of motor traffic

would, however, also lead to autonomous buses. Given that scenario, there is one question in particular that has to be asked: whether, and if so where, might there be system advantages for trams. If extra-long buses are also going to be permitted, then the rail-guided vehicle will lose its capacity advantage. One question still awaiting a general answer is whether small, autonomous tram units with short fixed headways are more attractive than trams with a length of 30-40 metres running less frequently. During the night, such units could run on call. That result could, however, also be achieved with a bus. The tram would, nonetheless, retain the advantage of offering a very clearly better ride comfort.

#### 4. CONCLUSION

The current debate about assisted, automated or autonomous driving is very strongly focused on road traffic. That does not do justice to the fact that automatic operation has already become a reality in many areas on the railways. Outside of closed systems, such as metros or people movers, which are already operated completely automatically today, technologies like LZB and ETCS are available for heavy rail and would make it possible for it to operate automatically – at least in part. Given that mechanical rail guidance offers rail vehicles fewer degrees of freedom than road vehicles, the former are particularly predestined for further develop-

ment right through to autonomous vehicles. Particular advantages for rail vehicles acting autonomously arise in regional networks and for shunting operations, where flexible and demand-driven services can be made a reality. Autonomous driving may lead to completely new vehicle concepts and adaptations to the current operations, which might have a knock-on effect on the transport market. Whereas the railway is especially competitive today in conurbations (as a means of mass transport) and in longdistance transport (with high end-to-end speeds), autonomous rail vehicles might also be able to create an attractive offer with comprehensive territorial coverage and an alternative to (autonomous) transport by road. This development will also have its implications for the rail vehicles of the future, to which smaller, individual units will be added to meet regional demand and to be coupled together to form trains on main lines. The potential that exists for rail traffic must be put to use to make sure that this environmentally friendly transport system is able to hold its own in competition.

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# Greener travel with reduced emissions and lower resource consumption

As climate targets become more and more ambitious, rail is rapidly emerging as the best way to attain them: No other mode of transport offers such energy-efficient mobility. But although trains already have considerable green credentials, there is further scope for improving their environmental footprint by reducing energy consumption, cutting noise emissions and making added-value chains more resourceefficient.

#### LOWER MASS, LOWER ENERGY CONSUMPTION

There is one obvious way to cut the energy consumption of a railway vehicle: by reducing the weight of its systems, products and components. Any mass that does not have to be accelerated does not require energy to be expended. Especially for metro trains, which operate with frequent phases of acceleration and braking, the reduced translational and rotational mass of light-weight aluminum brake discs can bring significant energy savings. On the new trains recently delivered to Hong Kong Metro (Fig. 1), for example, Knorr-Bremse has achieved weight savings of more than 400 kilograms per car. It is a win-win situation in both economic and environmental terms: Although the initial cost of purchasing aluminum brake discs may be higher, the bottom line is lower, because of the long-term energy savings.

At subsystem level there are other components that lend themselves to weight reduction – for example the entrance doors. In the case of the fourth generation of IFE entrance systems, a combination of new materials and a more compact door design has resulted in a 20% weight reduction compared with the preceding model. Emissions can also be reduced: a new design of door leaf has cut heat losses by 50 %, while soundproofing has been improved by a factor of three to four.

#### LOW-NOISE FRICTION MATERIAL

The operator benefits from any savings achieved through greater efficiency, but it is the residents alongside railway lines who stand to gain most from improvements in brake pad design. Retrofitting of low-noise brake pads has been kick-started by statutory requirements and the threat of operational restrictions, but progress has so far been relatively sluggish, despite proven technologies having long since become available on the market.

Organic brake pads act on the running surface of the wheel during braking. Whether a train rattles along noisily or glides





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smoothly over the track depends largely on the condition of that surface: If it is rough, this causes wheel and rail to vibrate and generates noise. Freight wagons, which operate mainly at night, are especially noisy, as the current fleet is still largely braked with grey cast-iron brake blocks that roughen the contact surfaces and therefore also the tracks. By installing composite pads (which are also lighter) it is possible to reduce the noise generated by wheel/rail contact by around 10 dB(A) – which the human ear perceives as a halving of the noise level. Cast-iron shoes can be replaced with organic LL pads without any need for modification of the braking system. The so-called K pad has a similar effect. While low-noise organic LL pads are designed for retrofitting, K pads are the organic versions for new vehicles. In the European Union their installation in such vehicles has been compulsory for several years.

Knorr-Bremse is involved in this move towards low-noise friction materials. Following its acquisition of the rail vehicle division of brake lining specialist TMD Friction, the company is now also offering friction material under the brand name of "Cosid 704" – one of the first applications for the second generation of composite pads. Other new products are organic pads for hydraulic brakes and the ultra-low-wear material "Cosid 828" for mainline trains.

Apart from the noise generated at the point of contact between wheel and rail, another unpleasant sound is the characteristic screeching of sintered brake blocks as trains apply their brakes on entering a station. This can now be eliminated to a large extent by fitting so-called 'whisper' brake pads (Flexpad Silent), which involve a combination of skillful pad design and clever use of materials. Unfortunately this technical improvement has not currently been put to use.

#### **REDUCING COMPRESSOR NOISE**

Optimizing noise emissions from air supply equipment is one of the biggest challenges faced by Knorr-Bremse's Air Supply division. Despite the use of soundproofing materials, there still has to be an adequate flow of cooling air through the system. The development engineers at Knorr-Bremse use state-of-the-art simulation techniques such as numerical fluid mechanics to ensure this. The company has also invested in its own soundproof chamber equipped with acoustic cameras (Fig. 2), to develop and assess the effectiveness of acoustic optimization measures for air supply equipment, compressors and air dryers.

The result has been a considerable reduction in noise emissions. One example is the VV120-T oil-free compressor, which the company developed and acoustically optimized for the S-Bahn systems in Stuttgart and Frankfurt. At a distance of seven meters, the sound pressure level is no more than 57 dB(A), and special silencers developed for air dryers reduce the venting sound pressure by up to 20 dB(A).

Knorr-Bremse has gone a step further with its intelligent air control (IAC) system: A skillful combination of various Knorr-Bremse systems (air-supply equipment and power converters) has made it possible to reduce noise emissions still further.

When regional trains that have been parked overnight are powered up again in the morning, this can be a source of irritating noise for local residents. The problem can be mitigated by running the compressors at a lower rpm. If, for example, their speed is reduced by 50%, the sound level can be brought down by as much as 9 dB(A). As already mentioned, human beings perceive a 10 dB(A) reduction as a halving of the volume. In technical terms, the acoustic energy given off is even cut by more than 75 %.<sup>1)2)</sup>

With intelligent implementation, the system can also remove the need for an auxiliary air compressor to raise the pantograph at the start of operations, saving the cost both of its initial acquisition and subsequent maintenance.

On top of this, the total energy consumption for air treatment is lower, so the initially higher investment is quickly amortized.

Once the logic has been implemented in the power converter, selective control can also easily be used in normal operations, for example to start a compressor up as gently as possible. This prevents high start-up currents and extends the service life of electrical, electronic and mechanical components.

## USE OF HEAT PUMPS IN AIR CONDITIONING

The use of heat-pump technology improves the efficiency of air-conditioning systems (Fig. 3), reversing the cooling cycle, drawing on ambient heat and massively reducing energy consumption by some 20,000 kWh per rail car per year – the equivalent of the energy requirements of almost five households each with 4 persons. <sup>3)</sup> Heat pump technology is especially efficient in cold climate zones.

Other eco-friendly technologies in the same field of application include energy recycling through heat recovery, brake energy recuperation, adjustment of air conditioning when passenger numbers are low, and variable output technology that enables the coefficient of performance to be maintained or even improved during part-load operation, whereas with traditional technology it normally declines.

#### DRIVER ASSISTANCE SYSTEMS

Knorr-Bremse is using the iCOM system and its 'iCOM Assist' app to pursue an approach that is not directly tied to any particular sub-

2) On this specific point: https://de.wikipedia.org/wiki/ Schalldruckpegel, last visited: 12:05 10.04.2017

 Electric energy consumption index table 2016, mean value excluding electrical water heating in single-family houses with four people per household: 4200 kWh, e.g.: http://www.diestromsparinitiative.de/stromkosten/ stromverbrauchprohaushalt/



FIG. 2: Acoustic survey results (Photos: Knorr-Bremse)

system but rather helps reduce a vehicle's overall energy consumption by ensuring that it is driven as efficiently as possible in any given situation. Using an online database containing information on the train's configuration, route and timetable, and also drawing on information about its current speed and location, iCOM Assist calculates specific, individualized recommendations for the driver. (Fig. 4) These might involve, for example, reducing traction and allowing the train to coast to the next scheduled stop, finally bringing it to a halt using the brakes. By acting on the specific recommendations that appear on his display, the driver can save energy, improve punctuality and reduce vehicle wear and tear. All the system needs is a connection to the locomotive's power supply. Since there is no intervention in the train control, it does not require approval and is easy to retrofit.

To even begin to assess energy-saving »

FIG. 3: Air conditioning heat-exchanger



FIG. 4: iCOM Assist, a system for energysaving driving recommendations



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No.	Sustainability criterion	Economic	Ecological	Social
1	Protection of local business environment (safeguarding jobs, reducing the amount of internal and external transportation)	Х	Х	
2	Increasing traffic safety and optimizing traffic flow	Х		Х
3	Low emissions throughout entire life cycle (excluding energy)		Х	
4	Low energy consumption throughout entire life cycle		Х	
5	Responsible use of materials		Х	
6	Demographic change (e.g. ergonomic design, increase in mobility of elderly people)			Х
7	Consideration of impact of urbanization	Х		Х

FIG. 5: Criteria for assessing sustainability of Knorr-Bremse innovation portfolio

measures, a reliable energy metering system is required. Within the iCOM system, that function is assumed by the 'iCOM Meter' app. Working on the basis of the current standard for energy measurement (EN 50463), it supplies data, amongst other things, on voltages, currents and reactive energy, along with the location and time of consumption. After appropriate processing, this consumption data is used by operators as a reliable basis for further efficiency optimization and calculation of energy costs. In line with the concept of 'Industry 4.0', it is an extremely flexible system with easily programmable architecture similar to a standard smartphone operating system, an absence of interaction, and clearly-defined external interfaces.

As demand grows for greater comfort, convenience and safety in rail vehicles, the number of devices requiring electrical power is also on the increase. The more vehicle subsystems are installed, the more necessary it becomes to have an intelligent energy management system to ensure their efficient operation. The aim here must be to establish a central 'smart energy' link that incorporates power supplies, consumers and electricity grid feed-in. Intelligent controls for auxiliary systems fulfil this function and are centrally coordinated.

#### RESOURCE-SAVING MANUFACTUR-ING PROCESSES AND OPERATIONAL INFRASTRUCTURE

It is clear that rail's contribution to an ecofriendly transport mix must be both demonstrable and measurable. This means that when a decision is made for or against the development of a new product, it is important to methodically and transparently assess its environmental impact and its contribution to low-emission operation. At Knorr-Bremse, this approach is an integral

FIG. 6: Sustainability assessment of Knorr-Bremse innovation portfolio in December 2013



part of the company's innovation portfolio management, with no fewer than seven defined environmental criteria covering the entire product life cycle (Fig. 5).

The crucial step is not necessarily to feed this result directly into the product assessment process. What is more important is for engineers to give serious consideration to such connections in the first place – and to subject their work and results to critical analysis. (Fig. 6).

Even though sustainability assessments of new products are becoming more widespread throughout the sector, it would be wrong for their contribution to be limited to product-related energy savings and emission reductions. Development and manufacturing processes deserve similarly close scrutiny in terms of their sustainability. And consistent sustainability analyses are also required along the entire added-value chain. What matters in the final analysis is to establish a stable and preeminent position in the market by taking into account not only economic but also environmental and social criteria.

Here, once again, it is essential to have an appropriate infrastructure within the company. It is impossible to try to achieve everything at a single stroke – companies have to be constantly on the lookout for further potential, to identify it and then to leverage it. It is also a question of seizing opportunities. A number of years ago, for example, when Knorr-Bremse began to plan its new development center in Munich, the emphasis was on maximizing efficiency, and this included installation of a low-emission heating system. As a result the building is now partly supplied with waste heat from the test rigs (Fig. 7). ◀

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**FIG. 7:** Waste heat from the universal train test rig is used to heat the buildings





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# Real-time track monitoring for sustainable maintenance strategies

The monitoring of train and infrastructure components is a fundamental task for railway operators. Highly specialised devices make it possible to monitor rails as well as vehicle and track components, but they are generally in one fixed location. With the introduction of Distributed Acoustic Sensing (DAS) to the railway industry, Frauscher is creating new possibilities for this particular application. Some of these possibilities have already been tested, while others are still to be developed; they are the subject of this contribution.

## 1. MAINTENANCE AND SERVICING JOBS ON THE RAILWAY

Compliance with the prescribed maintenance cycles and the scheduled performance of maintenance jobs form the basis for safe, trouble-free railway operations. To achieve that, it is also necessary to detect and correct any damage that occurs unexpectedly. There could be many different causes. Flat wheels, for instance, cause an increase in the mechanical loads acting on the track. Futhermore, inadequately maintained tracks may lead to massive impacts at neuralgic points, such as rail joints. [1]

These interrelationships already give us a good idea of how closely the drawing up of servicing plans or maintenance strategies are connected with availability and safety in railway traffic. However, the monitoring systems mentioned at the beginning of this article often give only sporadic insights into the condition of the infrastructure and so they generally do not allow for more than the application of corresponding measures as reactions. With its evaluation of the possibilities of applying Distributed Acoustic Sensing (DAS) in railway operations, Frauscher, in cooperation with various operators, is developing a solution for the continuous, real-time monitoring over long distances of infrastructure components in the track network and on the railway vehicles.

The data acquired using DAS provides support for both the detection of defects that are acute in their occurrence as well as the development of predictive and preventive maintenance strategies. In that way, they are making an essential contribution to reducing costs and optimising utilisation. They do that, firstly, through the possibility of being able to react immediately to damage as it occurs and, secondly, through the precision planning and coordination of the deployment of maintenance vehicles and maintenance activities.

#### 2. USE OF "DAS" IN RAILWAY OPERATIONS

In the course of the past six years, DAS has been subjected to extensive tests in various railway networks around the world. In cooperation with interested infrastructure managers, who have now been thinking seriously about strategies for using this approach throughout their whole networks, Frauscher has taken the findings and developed them further and has integrated this technology in its sensor portfolio. [2]





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#### 2.1. DAS TECHNOLOGY

DAS is based on the principle of recognising changes in the reflection of laser pulses injected into an optical fibre cable. The changes are triggered by sound waves that impact those fibres. DAS does that by making use of a phenomenon known as Rayleigh scattering, which was discovered by the 3. Baron Rayleigh, John William Strutt, when he realised that light waves are scattered by miniscule particles.

This phenomenon occurs in optical fibres when injected laser pulses are scattered by innumerable natural inclusions of atomic size, so-called scatter sites. The opposite end of the optical fibre to the emitter is adapted to absorb the injected laser pulses. It is possible to pinpoint scatter sites precisely on the basis of the reflexion and the elapsed time since the pulse was injected. If structureborne sound waves or vibrations come into contact with the optical fibre, they have an effect on its physical structure, which, in turn, modifies the backscatter (cf. Fig. 1). It is possible to analyse such changes and to classify them by applying specific algorithms. In that way, an optical fibre cable can be transformed into a sensor that functions like a virtual microphone.

## 2.2. POSSIBILITIES AND LIMITATIONS IN THE RAILWAY INDUSTRY

Experiments using DAS on the railway have shown that a single DAS unit can cover a distance of up to 40 km of optical fibre. Within that range it is possible to classify various signatures of people on the railway track or moving trains. Whereas people and comparable noise sources can be detected within a radius of 5 m around the optical fibre cable, trains, which produce very much higher acoustic energy, can be detected at a distance of up to approximately 50 m.

The pulse repetition frequency is determined by the length of the optical fibre cable to be monitored, since the backscatter of each emitted pulse must return to the source before the next pulse can be injected. From that, it can be calculated that a section of track 40 km long can have 2500 pulses of laser light injected into it every second.

In the test installations that have been tried out to date, various applications have been set up for applying DAS for the functions of train tracking, infrastructure monitoring and safety/security requirements. The successes included recording trains in real time, recognising flat wheels, broken rails and rock fall and detecting people on the track.

Along with numerous advantages, certain limitations have also been identified and they must be taken into consideration when DAS is used on the railways. One example is that a solution based on this technology is not yet able to determine precisely which track a train is on in a group of parallel tracks. In order to provide that information, it is necessary to have the input from an additional sensor.

#### 2.3. FRAUSCHER TRACKING SOLUTIONS FTS

To achieve that, Frauscher has integrated the fundamental potential of DAS in its existing sensor portfolio and combined it with other solutions that already exist. That has resulted in the Frauscher Tracking Solutions FTS, in which they offer various possibilities of combining the railway-specific DAS system, Frauscher Acoustic Sensing FAS, with triedand-tested wheel sensors, wheel-detection systems and axle counters. In that way, it is possible to further improve on the quality of the data captured with FTS-FAS. The integration of SIL 4-certifed axle counters makes it possible, moreover, to supply additional information in safety-relevant applications. With a single FAS unit, it is possible to monitor a total of 80 kilometres of track, i.e. 40 km



FIG. 2:Waterfall diagram of five trains within a section of 40 kilometres of track

in each direction. With the fundamental possibility of recording all the trains moving on a track, FTS is creating several new approaches to train and operational management against that background.

Figure 2 contains an excerpt from a waterfall chart that is output when several trains move along an FTS-monitored section of track. Indications of time can be read off the Y axis, while distances are shown on the X axis. It is easy to recognise the trains detected on the basis of their acoustic energy and also their trajectories. It is possible to read off the length, speed and current position of each individual train.

The algorithm for detecting and classifying people on railway tracks was one of the first to be used when DAS was introduced for the railways. This application, which is already available, can be used as the basis for the accurate positioning of both people trespassing on railway tracks and work crews. It is also possible to detect particular activities, such as digging. Further development is currently going on with infrastructure managers around the world into generating information about single animals or herds of animals on railway tracks.

## 3. FTS-BASED APPLICATIONS FOR INFRASTRUCTURE MONITORING

The test installations for the applications described above gave rise to further insights into the possibilities that are opening up for the use of FTS for monitoring train and infrastructure components. It is particularly in combination with proven wheel- detection systems, which also make it possible to use it on complex track networks, that various advantages soon became evident.

#### 3.1. RECOGNITION OF BROKEN RAILS

Given the current state of the art, it is track circuits that are the technology most frequently used for detecting broken rails. It is, however a method that is not capable of detecting all damage locations. Furthermore, it can only point to the section in which the rail break has occurred. FTS is an economic means of recognising and locating broken rails under a moving train along a monitored section of track. The positioning accuracy is around 10 m.

The basis for developing the algorithm for classifying broken rails was established over a two-year period in an experimental setup in the TTCI Test Center in Colorado, USA. Figure 3 shows what a broken rail detected by FTS under a 2.4-km-long freight train looks like. Detection and classification of the break is done in real time. Any train moving over the corresponding location afterwards also triggers the classification and the information to go with it. That gives the infrastructure manager the possibility of taking action immediately.

#### 3.2. LOCATING ROCK FALL

In certain regions, rock fall may represent a very considerable threat to railway traffic. Falling lumps of rock produce a considerable amount of energy on impacting the track or landing near it, and that can also be detected using FTS. That gives the infrastructure managers the possibility of warning drivers in good time and of improving the management of train movements considerably to cope with the situation.

One installation for carrying out field tests has already built up an extensive library of acoustic signatures generated by falling »



**FIG. 3:** In addition to broken rails, numerous other acoustic signatures were detected on the test track

rocks (cf. Fig. 4). The analysis of the data collected and its systematic arrangement and input back into the detection system are now making it possible to develop a precise classification and positioning of rock falls. Against this background, fine adjustments are now being made and possibilities examined for recognising the trajectory of rocks rolling down a slope.

#### 3.3. LOCATION OF FLAT WHEELS

Currently, devices for detecting flat spots in wheels are installed in selected locations within the railway network and recognise such flat spots as trains pass over them. If FTS is used, then they are recognised in real time over the entire length of the monitored section, as is illustrated in Fig. 5.

The next step is to examine and further develop possibilities for the precise classification of the detected flat spots. One particular challenge is to recognise the continuous growth in the zone affected on the wheel, given that, as this zone "grows", so too do the negative consequences for the tracks and the components installed on them. Trend analyses can be used to identify sections in which flat wheels occur particularly frequently.

#### 3.4. CATENARY FLASHOVER

Depending on circumstances, short circuits in the catenaries may lead to damage to the contact wire. The ability to locate such occurrences with the greatest possible accuracy may lead to targeted checks on the corresponding infrastructure components and thus possibly repairs to them and, finally, to keeping the railway operational.

A series of tests was performed with one infrastructure manager in order to investigate the use of FTS for detecting short circuits in overhead wires. The results show that most of the short circuits produced artificially in these tests can be successfully identified and that it is also possible to localise them. The next step is going to involve a further check on the results to date in new measurement processes along with a more detailed examination of particular parameters, with a view to defining the possibility for localising the short circuits detected as taking on various forms with greater accuracy. [3]

#### 4. POTENTIAL AND PROSPECTS: INFRASTRUCTURE MONITORING

It has become clear, particularly in the pro-



FIG. 4: Acoustic signature of a rock fall cess of researching the possibility for recognising broken rails (as is evident in Fig. 3), that when FTS is used for monitoring, numerous acoustic signals are detected. In focusing on broken rails, the developers initially assumed that when the corresponding signatures occurred these other signals would be caused by events wrongly interpreted as broken rails. However, when teams went and examined such locations more meticulously they found that various forms of damage had indeed occurred in the rails, the rail fastenings or the ballast.

It is true that no specific algorithms exist as of yet for classifying damage of this type. It has, however, been shown that the detection and location of these acoustic phenomena from around the track offers a series of advantageous development possibilities. The challenge now is to identify the cause of each individual signal and to set up a database of acoustic signatures to facilitate the precise identification and location of various forms of damage to the infrastructure.

The first thing to be done here is to distinguish between signals caused by progressive changes in the condition of the sound source (due to attrition, wear and similar causes) and those that can be ascribed to a component defect occurring suddenly.

## 4.1. MONITORING CHANGES IN ASSET CONDITION

Background noise may be caused, for instance, by switches and crossings, bridges or viaducts as well as air-conditioning plants, pumps and generators activated and deactivated close to the track. Given its high sensitivity, FTS-FAS also picks up acoustic interferences caused by such sources in the vicinity of the optical fibre cable. The precise categorisation of these environmental noises might therefore form a valuable and important basis for highly efficient real-time monitoring systems.

The challenge resides in identifying those acoustic signatures that point to a noise source that is relevant for the infrastructure manager against the general background of noise arising in this way. On that basis, it ought to be possible to rapidly derive a visual representation of the acoustic surroundings of the track over a length of 80 km and to determine at what interval each of the influences occurs:

- → permanent or regular
- $\rightarrow$  daily, weekly, monthly, annually
- $\rightarrow$  once, a single, isolated event

All those changes, which are recorded as comparisons with reference values indicat-

#### Track monitoring



ing the optimum condition of the corresponding components, can be presented in an uncluttered form. Focal points and trends that stand out make it possible for the infrastructure manager to coordinate maintenance work better and to maximise the efficiency of the teams deployed. That shows clearly how the recording of environmental noise and the comparison of data sets produced in such a way can further enhance the quality of the information obtained with FTS.

## 4.2. POTENTIAL FOR PREDICTION AND PREVENTION

In order to maximise the potential in these approaches for monitoring infrastructure components and for bringing them up to a level that facilitates the development of preventive maintenance strategies on the basis of forecasts and trend analyses, railway infrastructure managers and their maintenance teams must work together closely with DAS technology and the data acquired through it. In that way, it is possible to analyse acoustic signatures and their triggers in fine detail. That process is described in the following section taking the example of monitoring the wear on rail joints in a case like the one illustrated in Fig. 6.

The first step involves recording the acoustic signature of a train's wheelset running over a rail joint. The corresponding spot in the track is subsequently classified and photographed by maintenance workers. This signature forms the basis for the following process. As the condition of the rail joint changes, the deviation in the acoustic signature to that previously recorded is analysed. In addition, the maintenance team inspects and documents the affected location in order to secure corresponding information material.

In the course of time, a clear picture is built up of how quickly rail joints show signs of wear, in what form and, importantly, of how this change is reflected in the acoustic signature. The algorithms developed on that basis might be able to contribute to issuing automatically generated alert messages, which would make it easier to achieve better coordination of the corresponding maintenance measures. The aim of this process is to categorise such alert messages depending on the level of wear detected. In that way, it might be possible to set visible marks to show that a rail joint is functioning correctly or to draw attention to the fact that maintenance will be required within a period of time defined beforehand.

This process is also applicable for other sources of noise in and around the track mentioned above. Apart from that, the occurrence of short circuits in overhead wires described in section 3.4, for instance, could be shown in time to allow for a precise analysis of particularly affected sections. It is also worth mentioning:

- → damage to track, such as corrosion or the formation of cracks, fissures and pits
- → damage to track fastenings, such as clips, fastening or connecting plates and also to sleepers
- → weak points in the ballast and track foundation, such as cavities, erosion or compacting, or problems affecting bridges, viaducts and tunnels.

The decisive point, whatever the case, is to record data accurately and to draw up those strategies that can be derived from it for the maintenance activity for which an infrastructure manager is responsible.

#### 4.3. CLASSIFICATION OF ACUTE COMPONENT DEFECTS

This permanent monitoring of all infrastructure components also forms the basis for being able to identify and locate any acute damage that occurs suddenly. That includes, for example, the rock falls described in section 3, which usually occur without any prior

FIG. 5: It is possible to identify flat wheels



**FIG. 6:** The analysis of changes in rail joints supports the development of sustainable maintenance strategies

warning and represent an acutely aggravated risk for railway traffic. Depending on circumstances, broken rails are not necessarily presaged by weaknesses developing beforehand and may appear suddenly.

In order to be able to issue appropriate alert messages, the system must clearly recognise the corresponding signatures from other acoustic sources. That permits the infrastructure manager to launch measures immediately.

#### 5. PROSPECTS: FURTHER DEVELOP-MENT OF THE TECHNOLOGY AND ITS POSSIBILITES

Currently, the Frauscher Tracking Solutions FTS support the implementation of a whole range of applications. In itself, the potential for further development, as regards the accuracy and classification of detected events, gives a good idea of further possibilities to come. In the course of the coming years, Frauscher will be working on the further development of the FTS in close cooperation with various railway operators. Just the different requirements coming from global railway markets are enough for generating a broad range of ideas and inputs for new applications.

In addition, developments in fields such as data management and data communication as well as optical fibre production or laser technology are further expanding the possibilities for using FTS. In the not too distant future, it is thus going to be possible to identify acoustic influences clearly and to locate them with more or less pinpoint accuracy.

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# Predictive analytics for railway – monitoring and maintaining point health with smart sensors and AI

Points (switches and crossings) are amongst the essential components for efficient and flexible railway operations. Point failures are closely associated with delays in train schedules, which is why infrastructure managers are relying more and more on continuous monitoring using sensors. Innovative IIoT sensors in combination with smart analytical systems facilitate holistic insights into point condition. KONUX GmbH uses this system solution to monitor, analyse and predict the health status of railway points. It combines IIoT hardware with artificial intelligence and enables infrastructure providers such as Deutsche Bahn to make predictive maintenance a reality.

▶ Point failures are known to disrupt railway operations and are among the principal causes of train delays and high maintenance costs. For that reason, infrastructure managers are trusting more and more in sensors to perform continuous monitoring in the field. By combining these measuring devices with analytical systems based on artificial intelligence, it is possible to arrive at a holistic view of the condition of points and to make predictive maintenance a reality.

The primary function of points is to enable trains to move flexibly from one track to another without needing to stop, and they thus rank amongst the essential components of an efficient railway operation. At the same time, point failures often affect several train paths simultaneously and are thus closely associated with delay minutes. It therefore comes as no sur prise that, in recent years, points have been one of the infrastructure elements account-able for the largest number of minutes of delay [1] [2]. DB Netz's report [3] as well as opinions voiced by European railway infrastructure managers, show that delays due to point failures remain an urgent problem.

Many infrastructure managers have reacted to that situation by doing more to carry out continuous monitoring of points. The overarching goal of such initiatives is to reduce the number of malfunctions and bring down mainte- nance costs by deploying sensors in the field:

- As a first step, continuous condition monitoring is intended to detect anomalies and draw attention to malfunctions,
- 2. Subsequently, data analysis helps diagnose causes in order to be able to solve problems quickly and reduce the duration of disruptions,



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3. In a final step, more advanced algorithms are used to predict potential disruptions so that infrastructure providers can plan maintenance actions ahead of time and avoid further downtimes.

Theoretically, these steps could be followed simultaneously. This will only become possible, however, once there is sufficient experience with the data gathered in the field, and once an appropriate database has been created. Such a database is particularly indispensable for the correct analysis of railway points. Their condition is influenced by a large number of parameters (age, load, environmental effects, etc.) that it is impossible to monitor with a single measurement principle or even a single sensor.

Furthermore, for historical reasons, two separate professional groups have been involved in monitoring, analysing and maintaining points. For this reason, rails, including switch blades, frogs, rail fastenings, sleepers and ballast are considered to

#### FIG. 1: Components of a simple point



be part of the conventional track, whereas slide chairs and switch blade rolling devices, point machines and locks fall within the purview of signalling (Fig. 1). This demarcation line can be found in textbooks [4] [5] as well as in Deutsche Bahn's internal rules [6] [7]. Only when continuous monitoring gets introduced will it become practicable to bring these two perceptions together. Given that faults in one perception are interdependent of the other one, the target is to arrive at a holistic assessment of rail infrastructure.

Reliable measuring systems for monitoring points have been in existence for a long time. One such example is the monitoring of point machines and the switching process through continuous measurement of the switch current. The correct functioning of point heating device, as well as corresponding meteorological data, are also monitored continuously. Geometric parameters can be captured with measuring trains or hand-held measuring devices. In addition to that, more and more data records of various inspections and continuous monitoring, which are marked with universal characteristics such as time and location, have become available in digital form. These preconditions make it easier to automatically link different data sources for further analyses.

Dedicated developments, such as laser measurement of the wheel or running-edge profile [8] and the Industrial Internet of Things (IIoT) are giving rise to new sensors (for examples, see Fig. 2) that, in turn, enable the economic viability of further use cases. IIoT devices in particular, offer clear advantages. Smart sensors need little energy, are natively interconnected and self-monitoring [9]. Given that much of the heterogeneous data is beyond the scope of what human beings can manage, powerful analytical systems are becoming essential. Furthermore, this technical progress opens up new possibilities for a holistic view of the condition of points.

## WHAT DOES A HOLISTIC VIEW OF CONDITION LOOK LIKE IN PRACTICE?

When we speak of a holistic view we mean the automatic observation of parameters that directly or indirectly permit forecasts to be made regarding remaining useful life (RUL). DIN EN 13306, in turn, describes RUL as the "inventory of the possible fulfillment of asset function under pre-defined conditions that are inherent to the asset on account of its manufacturing, maintenance of improvement." [10 p. 5]. The observed parameters are integrated to produce a targeted diagnosis and, finally, a prognosis.



FIG. 2: Examples of sensor principles used frequently in the field of IIoT

It is possible for this data fusion to take place at the level of the raw data of individual sensors, at the object level or the information level. The data fusion has the effect of eliminating "blind spots" in the diagnosis. The underlying idea is that of making multiple use of data sources. It is similar to the way, in which environmental detection for automated driving integrates video images with laser or radar data to enhance accuracy. In our case, data fusion improves diagnosis and prognosis and is used for reciprocal interpretation going beyond its original purpose.

When applying this general approach to switch points, is has to be defined which parameters will be observed and which error patterns are the most suitable indicators of potential point failures. For a detailed overview of the different parts of switch points and their corresponding error patterns, see [11].

If the aim is to predict maintenance needs, then the sensor system used in the field have to measure continuously and automatically transmit the field data for further analysis. One way of doing this, for example, is to feed the sensor data into a platform, where smart algorithms form the final layer of detection, diagnosis and prognosis.

A number of the (sensor) modules in this concept are already being used in practice. To give an example: The Austrian Federal Railways (ÖBB) have installed switch current monitoring on 4,510 of the 13,760 switch points in their rail network [12].

At the end of 2016, DB Netz had approximately 5000 similar systems in service and, by 2020, plans to have around 30,000 of its 67,000 points [13] equipped with switchingcurrent monitoring solutions. Many pointheating units also measure climate parameters; of these, temperature and precipitation are likely to be the most relevant for the purpose of interconnected analysis.

Far less common are permanent systems measuring track or point geometry. Precisely such geometric parameters, however, have a significant influence on the condition of points. Geometric faults cause unwanted vibrations and dynamic forces, and are thus responsible for the mechanical wear of switch elements. That explains why the combination of geometric parameters and switchingcurrent data is seen as particularly useful for assessing the condition of switch points in a holistic way.

One such example is a malfunction known as "untimely notification of incorrect positioning". The term is a problem-code text, which forms part of the incident documentation, which DB Netz generates in SAP. Out of more than 40 possible problem-code texts, this particular malfunction was among the five most frequent errors over a period of several years. The occurrence of an "untimely notification of incorrect positioning" means that the end-position surveillance is dislodged, so that the CCS system can no longer assume that a safe end position has been reached. The point concerned is reported as having failed.

CCS specialists are sent to solve the problem on the spot, they often reportback that there is no longer any evident sign of the phenomenon. It is an error that is frequently »



caused by vibrations affecting the point machine or switching rods, which, in turn, can be ascribed to inadequate point suspension or faulty geometry. In some cases, this malfunction is caused by no more than a train passing on a neighbouring track.

Since conventional measurement of point geometry is associated with considerable effort and, given that the parameters involved usually only change slowly, measurements take place in larger time intervals. In the case of Deutsche Bahn, that means every three to six months [6]. For the purpose of analysing knock-on effects on other point elements, such as the switching rods, it would, however, be advantageous to have more frequent measurements. It is at this juncture that the IIoT solutions mentioned earlier can render a valuable service. Relatively low-cost sensor systems can be used permanently in the field without the infrastructure manager having to concern himself with questions of energy supply, communication and functional checking.

#### ANALYTICAL SYSTEMS FOR POINTS BASED ON THE KONUX SOLUTION

The KONUX solution makes use of the advantages of IIoT on the hardware side and combines them with smart ana-lytical systems as well as the many different possibilities of artificial intelligence (AI). The portfolio contains a system solution for the continuous and autonomous monitoring of ballast condition, as illustrated in figure 3. This solution was tested in a pilot project with Deutsche Bahn last year and is currently being prepared for a larger roll-out [14].

which can be retrofitted on the sleeper and forms the basis of the solution, have been adapted with regards to the environment in which it is deployed as well as the customer's requirements. It is powered using a high-durability battery, and transmits the recorded data wirelessly to a back-end system. Its high performance, however, is mainly due to the symbiosis of firmware and analytical systems.

The firmware controls the system in such a way that the energy supply is guaranteed to last two years – even on the main highspeed lines. In addition to that, the firmware enables the pre-processing of the raw data and handles the sensors' self-monitoring. This ensures that the system is constantly available.

The back-end analytical platform provides data on the cavity and the condition of the ballast underneath the point sleeper, along with additional information that is relevant for a holistic assessment of the health status. This additional data includes information regarding train types and dynamic forces. The principle is illustrated in Fig. 5. Integration and fusion with additional data sources at object or information level make it possible to draw further conclusions regarding, for example, the loads on points or the extent of wear and contamination of the ballast. The system solution has been designed to use lloT technology and artificial intelligence to gain insights into the health status of switch points that would be impossible with traditional means.

This approach can be visualized using the example of ballast condition underneath switch sleepers. Up until now, it was only measured intermittently and had to be done manually, requiring at least two maintenance workers in the field. During these measurements, no trains can operate on the track and both personnel as well as trainpath capacity are unavailable for normal railway operations. Measure-ments at frequent intervals, such as weekly, would thus be neither economic nor compatible with other maintenance tasks. In addition to that, only one specific parameter is recorded (the gap between the bottom surface of the sleeper and the ballast), so that it becomes virtually impossible to establish the relationship between dynamic forces and wear.

A holistic view on point condition benefits to a large degree from the KKONUX measurements and analytics if these are combined with switching-current data, timetable data and additional sources. One example is that the effect of wear on the switching rods can be modelled by com bining acceleration values, recognised train types and static train parameters. That, in turn, forms the basis for

FIG. 4: Konux sensor on a concrete sleeper for measuring the cavity under it







a forecast of the re-maining useful life and can also be used for optimum exploitation of the maintenance window. The "untimely notification of incorrect positioning" malfunction referred to above also becomes easier to diagnose when it is based on data fusion and a holistic view on asset condition. The continuous monitoring of ballast condition, for instance, allows for useful inferences: The larger the gap between point sleeper and ballast, the greater the probability that vibrations will occur and the higher the risk that this specific malfunction occurs.

Apart from that, examining the signal representation of the integrated ac-celeration and switching-current values from different perspectives can make it possible to precisely determine the cause of various malfunctions. By applying several AI-based methods, the analytics platform offers the correct tools (Fig.6). The aim is to transform highfrequency field data into characteristics that can be used for the detection, diagnosis and prognosis of the condition of switch points. Although the static and geometric characteristics used for the analysis of the switching current are a good representation of the information content of a time series [15], the application of artificial intelligence, and, in particular, arti-ficial neural networks, goes further still. With an appropriate network architecture, it is possible to interpret the relationship of individual points or several sample points to one another. Apart from that, it is possible to perform multi-stage processing with the ability to consider data fusion at various levels.

This approach is being tested with DB Netz AG in the context of the so-called "Smart Point" project. "Smart Point" offers an integrated view of various data sources: sensor measurements, monitoring ballast condition or switch current, along with train schedules. The project is intended not only to identify how important parameters pointing to asset health can be continuously captured but, first and foremost, how they might form a basis for a more precise diagnosis. One distinctive feature of this approach is the abandonment of the differentiation between conventional track and CCS, which makes it possible to consider the interactions between the two spheres.

This project offers a broad range of benefits for Deutsche Bahn:

- → More precise diagnoses ensure quicker repairs
- → There is a reduction in the number of repeated failures
- → Employees are able to concentrate on maintenance instead of being held up with manual measurements and analy-



sis. The overall goal is to reduce the number of point failures as well as maintenance costs.

#### FUTURE PROSPECTS

"Smart Point" and the holistic assessment of asset condition constitute only one step in the current era of digitisation. This technical progress is going to stretch beyond switch points to other infrastructure elements. True to the fundamental idea of the Internet of Things, all devices in the railway network will become interconnected, while existing safety measures have to be kept or expanded. The extension to other assets and the integration of additional data sources is going to bring tougher demands on the technical side. Data sources are going to be more widely distributed and more heterogenous, and there will be frequent changes in their overall composition. To cope with that, communication and processing must be flexible and scalable. This is another reason why KONUX trusts in IIoT technologies.

In parallel with the increasing numbers of monitored assets, prediction quality is also developing. The aim is to forecast potential failures with such precision that it becomes possible to prevent them. The successes that have been achieved with deep learning in the field of object recognition and classification are going to be transposed to time series analysis for an unsupervised definition of characteristics. Time alone will tell whether, in the foreseeable future, major progress similar to that in the field of classification can be made. The important point is to make optimum use of all the possibilities offered by smart sensors and analytics - to keep switch points and railway networks in the best possible condition.

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# Dynamic track deflection measurements in Gotthard Basis Tunnel

During the trial and test operation the elastic track deflection behaviour of the slab track systems in the Gotthard Base Tunnel were evaluated under operation conditions.

#### THE START OF OPERATION IN GOTTHARD BASIS TUNNEL GBT

Already in spring 2014 tests have been commenced on behalf of the final client AlpTransit Gotthard AG in a completely finished test section in the Western tunnel of "Faido-Bodio", before the main track and fitting work started. The interaction of the various technical components should be examined, which are necessary for the operation of the tunnel. In the 17 km long test section the trains ran with a speed of up to 220 km/h and among others, the interaction of the catenary and pantograph in the tunnel was focused. During these tests the first dynamic track deflection measurements have been performed by the Chair and Institute of Road, Railway and Airfield Construction of the Technical University Munich

In November 2015, after finalizing the fitting work, track deflection measurements have been performed in additional tunnel sections during the start of operation (also on behalf of the final client AlpTransit Gotthard AG). During the high-speed trials and driving-dynamic approval maximum speeds of up to 275 km/h have been reached. A main focus of the measurements lies at the verification of elastic support of the slab track system to comply with the planning approval ruling (PGVf) of the Swiss Federal Transport Office (BAV).

Defined track stiffness is required to achieve a distribution of the wheel load on several rail supports and to limit the increase of dynamic forces during operation from imperfections of the wheel-track interaction.

## SLAB TRACKS IN GBT AND TRIAL SECTIONS

In general in Gotthard Basis Tunnel the slab track system (STS) LVT (low-vibration track) was installed. The system consists of individual concrete blocks LVT 2 – ATG with rail fastening W14 and rail pad Zw 700/100 kN/ mm (system supplier Vigier Rail). In the slab track system the concrete block with the fastening system is resting on a resilient block pad in a rubber boot embedded in unreinforced concrete.

In a section at Erstfeld, with increased vibration protection requirements, the STS LVT-HA (LVT High Attenuation) is installed. The system is characterised by its larger dimensions of the concrete blocks (block width 340 mm instead of 264 mm) and a softer block pad compared to the standard system LVT.

The transition construction from ballasted track with sleepers B91 with undersleeper pads to the LVT slab track consists of concrete sleepers type T1 and T2 with undersleeper pads and additional short rails, which shall balance rigidity deflections.

In the area of Erstfeld a so-called perspective switch is located, which shall allow the extension of Gotthard Basis Tunnel into the north (mountain variant long). At the perspective switch the sleepers have been aligned in the supporting concrete slab, but only standard rails UIC 60 have been installed. Thus no switch tracks, swing nose or other movable track components have been set out. Only in the near of switch sleeper lengths of  $\geq$  3.0 m additional rails have been mounted, which comply with the side track rail.

#### **TEST OBJECTIVE**

Theoretically an elastically mounted track support reacts stiffer with increasing load frequency, connected with actual lower rail deflections. This can be put down to the non-linear and frequency-depending forcedeflection behaviour of elastic elements (here rail pads and resilient block pads). On the other hand there is the dynamic wheel force variability, which is covered for example in defining the superstructure with dynamic factors to the "quasi" static wheel load. This force increase is connected with greater vertical rail deflections. Therefore the measured deflection values are related to driving speed to receive predicates about the elastic



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behaviour of rails in increased speeds and to define the effects of dynamic influences and the systems' reaction.

#### **TEST PROCEDURE**

In each of the total four test sections, three, in principle identically built up measurement sections (MS) have been installed according to the specific circumstances of the track system. Fig. 1 shows the installation of measurement sections in the LVT track. In detail the vertical rail deflection was measured at both rail foot edges. From this the vertical rail deflection in the rail foot centre and the horizontal rail head deflection can be calculated. The vertical block deflection is also captured with two displacement transducers (LVDT) and allows in this way the definition of the vertical block deflection related to the rail foot centre and the block tilting. Additionally a horizontal displacement transducer has been fixed to the block, which captures the lateral deflection. Thus per supporting point 5 sensors have been placed. Per test section 2 measurement sections have been set up, which comply with a support point pair at the inner and outer rail (Fig. 1 and Fig. 2). In this way 30 measurement channels could be captured at the same time in each test section. All measurement value pick-ups have been connected to QuantumX universal measuring amplifiers (supplier: Hottinger Baldwin Messtechnik). At each measurement section a measuring box has been placed at the outer edge way (related to the tunnel axis), in which the measuring amplifier, power supply and network technology and thus the hardware for the MS were located (Fig. 3).





section LV1

The measuring amplifiers in a test section were linked with each other via LAN-connection to make sure that the measurement in the test section was simultaneously started and recorded when a train was passing by. The data collection took place via PC and SSD storage mediums, which were located in cross passages and connected with each other via LAN. The measurements and recordings were autonomously arranged during the test periods. By means of so-called trigger signals the passing of trains at individual test sections was detected and the measurement data was automatically captured and stored with a sample rate of 4.8 kHz per channel. Via the network of GBT the recording PCs of the individual test sections were accessed. The evaluation of data took place after the measurement. The dynamic measurements have been performed during the movements of the trains with different speeds and measurement compositions. In table 1 the speeds and related test vehicles are summarised.

#### **TEST RESULTS**

Below the results of the trial operation (LVT system) and test operation (transition construction, LVT-HA and perspective switches) are described. The focus in this article is laid on the vertical rail deflection.

From the individual time dependant measurement signals the maximum values below the axes of the traction units have been determined and associated with the respective driving speeds. In this way the speed dependency for each measurement channel can be analysed. Fig. 4 shows the exemplary time dependant vertical rail deflection for a passing by of an ICE-S at the transition construction, which lies in a curve with a radius R = 5000 m with an inclination of u = 40 mm.

FIG. 1: Alignment of the measurement sections LVT 1 – LVT3 in the test FIG. 2: Typical installation of displacement transducers sensors at a rail seat support (here LVT-HA)

Measurement date	Driving speeds [km/h]	Measurement compositions (load vehicles)	Test type	
February 2014	10			
	80	RE 420	Trial operation	
	120			
March 2014	160			
	180	2 RE 460		
	200	+ 1 steering vehicle		
	220			
N 1 2015	40 – 275	ICE-S	Test operation	
November 2015	Drives with various work and test trains		approval drives	

TABLE 1: Overview driving speeds and test vehicles

#### "VERTICAL DEFLECTION MEASURE-**MENTS" AT THE LVT SYSTEM**

The test section was located at a straight track. Fig. 5 shows the vertical rail deflection

of the three measurement sections. The runs with up to 120 km/h have been performed with the measurement composition 1 RE 420. The runs from 120 km/h to 220 km/h have been performed with the measure-»

FIG. 3: Instrumented measurement section of the system LVT-HA







(source: DB AG/author)



#### FIG. 5:

Mean value of the maximum vertical rail deflections Sv of the system LVT (RE 420 and RE 460)

ment composition 2 (RE 460 in double traction). During the tests the air temperature at the measurement section was between 24°C and 28°C.

At the in total 12 runs during the first test period with the train RE 420 (older series) the vertical rail deflection is more diversified than in the total 44 drives of the 2nd test

period with the more modern series RE 460. This can be associated with a better running of trains or the condition of the newer trains' wheels.





FIG. 7: Mean value of the maximum vertical rail deflections Sv of the three measurement sections of the system LVT-HA (ICE-S)



Fig. 5 shows the mean values of the maximum vertical rail deflection for all measurement sections of the individual driving speeds. Additionally a logarithmic regression was included into the graphic for the two test periods or measurement compositions respectively. The dynamic effects of the wheel load fluctuations are much more pronounced at RE 420 than the stiffing of the elastic components in the track. Whereas this was not occurring that clearly for the second test period with the trains RE 460 (modern series). The mean value of the measured maximum vertical rail deflections is almost the same with 1.32 mm for increasing driving speeds.

In laboratory tests of the Chair and Institute of Road, Railway and Airfield Construction of the Technical University Munich a stiffing of the LVT system with a factor of approx. 1.3 was detected under dynamic load, which complies with the operational load. For the comparison of the calculated vertical rail deflection with the values measured in GBT the calculated bending line is shown in Fig. 6. In this process the dynamic key values of elastic components in the LVT system as well as the key values of RE 460 have been defined. A good correlation of the measured vertical rail deflection with the calculated or forecasted values was shown. From the difference between the rail and block deflections the share of rail pad deflection can be derived. The maximum values of the rail pad deflection amounts about 0.5 mm in the LVT system.



The results were captured within the framework of the high-speed and approval runs for starting the operation in the GBT with the ICE-S in the western tunnel in the area of Erstfeld in November 2015. The test section is located in a curve with radius R = 5000 m and an inclination of u = 40 mm at the outer rail.

If the mean value of the inner and outer rails and the three measurement sections HA1 to HA3 is formed, the course of the vertical rail deflection at the traction unit axes with increasing driving speeds results as depictured in Fig. 7. The mean value of the maximum vertical rail deflection during passing by of the ICE-S lies between 1.52 mm at 75 km/h and 1.77 mm at almost 270 km/h and thus in the expected and forecasted range.

The mean value of the maximum deflection of the rail pads from the calculated time signal at the system LVT HA spreads by



**FIG. 8:** Calculated "dynamic" bending line of the rail at the system LVT-HA under a bogie in the traction unit of the ICE-S (axle load 19.8 t, axial space 3.0 m)



**FIG. 9:** Max. vertical rail deflection at the outer and inner rail of the curve in inclined tracks (measurement section 3 of the transitional construction with system LVT)

0.5 mm and thus fits well to the values of the LVT standard system, in which also a rail pad type Zw 700 was used. For the mean values of block deflection for all measurement sections it is seen that they are slightly declining with increasing driving speeds or lie constantly with values slightly above 1.2 mm.

For the LVT-HA system the "dynamic" bending line analogue to Fig. 6 for the passing by of an ICE-S bogie was calculated and depictured in Fig 8. The results comply with the measured values.

#### "VERTICAL DEFLECTION MEASUREMENTS" AT THE TRANSITION CONSTRUCTION

The results have been captured during the high-speed and approval drives in November 2015. The test section is located in a curve with a radius of R = 5000 m and an inclination of u = 40 mm at the outer rail.

Fig. 9 shows as an example the evaluation of the vertical rail deflection under the traction unit of the ICE-S at the measurement section 3 of the transition construction separately for the outer and inner rail of the curve. The points represent the maximum vertical rail deflection, which was measured during the passing by with the respective driving speed in the inclined track. In terms of figures a vehicle would not face a centrifugal acceleration at a driving speed of 130 km/h in the centre of gravity. If the vehicle drives slower there is an excess of inclination connected with a relocation of the wheel load to the inner rail of the curve. In driving speeds higher than 130 km/h an inclination deficit occurs, which results in a relocation of the wheel load to the outer rail of the curve. Basing of the recorded linear regression (dotted line) the wheel load relocation to the outer rail of the curve is visible with increasing driving speeds.

This shows that the superstructure acts »

System	Twin axle bogie RE 420 21 t	Twin axle bogie RE 460 21 t	Twin axle bogie ICE-S 19,8 t	Twin axle bogie 22,5 t
	Measured value [mm]	Measured value [mm]	Measured value [mm]	Forecast value [mm]
LVT	1,3 – 1,5	1,3	-	~1,5
Тсо	-	-	1,2 – 1,4	~1,5
LVT-HA	-	-	1,5 – 1,8	~1,9
Pers. switch	-	-	1,75	~2,0
Speed ranges [km/h]	10 – 120	160 – 220	40 - 280	

TABLE 2: Cross reference of rail deflections of the systems

according to the driving-physical correlations and results with increasing vertical deflection in higher loads. The mean value of the maximum vertical rail deflection during passing by of the ICE-S lies between 1.20 mm at 40 km/h and 1.40 mm at almost 250 km/h and thus in the expected and forecasted range and complies with the values measured in the section Faido-Bodio (Fig. 10).

#### "VERTICAL DEFLECTION MEASUREMENTS" AT THE PERSPECTIVE SWITCH

The results have been captured during the high-speed and approval drives in November 2015. The test section was located at a straight track.

In the test section of the perspective switch the drives of the ICE-S have been recorded

**FIG. 10:** Mean value of the maximum vertical rail deflections Sv of the three measurement sections at the transitional construction (ICE-S)



FIG. 11: Mean value of the maximum vertical rail deflections Sv of the three measurement sections at the perspective switch (ICE-S)



with speeds of 144 km/h to 290 km/h. Fig. 11 shows the mean value of the maximum vertical rail deflections over all three measurement sections. It shows a vertical deflection of 1.75mm, which is almost independent of speed but occurring with a larger dispersion compared to the transitional construction and the system LVT-HA. The particularity of this test section is that each measurement section is located at a sleeper with a different length (I = 2.6 m pW1, I = 2.8 m pW2 and I = 3.0 m pW3). Whereas the sleeper at pW1 is loaded centrally concerning the sleeper centre, the load is shifted from the centre to the inner rail at pW3.

As the sleepers are elastically mounted in the perspective switch, the rail deflection is mainly influenced by the elastic mounting of the sleepers. It shows that with increasing sleeper length ( $pW1 \rightarrow pW3$ ) the vertical deflections at the inner sides were increasing compared to the outer sides. This is caused by eccentric applied loads. The largest difference of vertical deflection between inner and outer side shows the measurement section pw3 with the 3.0 m long sleeper. Insofar the placing of a side or auxiliary rail is recommended to stabilise the eccentric loaded system.

#### OVERVIEW

On behalf of ARGE Fahrbahn Transtec Gotthard (AFTTG), Stans (Switzerland), dynamic vertical rail deflection measurements under train runs have been performed. The main focus of attention lies at the verification of the elastic mounting of the slab track system. The dynamic measurements have been performed by the Chair and Institute of Road, Railway and Airfield Construction of the Technical University Munich at stationary, temporarily set up measurement points.

Table 2 shows a summary of the measured and forecasted values. Depictured are the mean values of the maximum vertical rail deflection during the passing by at the measurement compositions and the forecast for 22.5 t axes.

Overall it needs to be stated that stable measuring results were captured for all test drives. They show that there is elastic deflection behaviour of the examined slab track systems in Gotthard Base Tunnel, in which no undesired dynamic processes such as resonances occur. The slab track systems are proportionally answering to the loads. The behaviour at the different train speeds shows a declining tendency of dynamic deformation increase. The vertical deflection behaviour complies overall with the forecasted and underlying values of the dimensioning.

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# Innovation boost in track maintenance

The developments in track maintenance on show in Münster at iaf 2017 were fully dedicated to INNOVATION FOR YOU.

► The International Exhibition for Track Technology "iaf" is the world's largest of its kind. It provides the ideal forum for presenting innovations in track maintenance. Four years have passed since the iaf was last held. Since then, so many developments have been made that it is fair to speak of a boost in innovation. However, the innovations are not an end in itself. They are based on the analysis of the needs of railways, infrastructure operators and the operators of track maintenance machines.

In addition to new developments in machine technology, such as the electric operation, this article focuses on the rapid evolution of the entire machine industry. The topics range from digitisation and automation to ergonomic design and ecology, training and service, and the further development of maintenance technologies in this field.

#### ELECTRIFYING TRACK MAINTENANCE

At the Convention of ÖVG (Austrian Society for Traffic and Transport Science) held in Salzburg in September 2015, track maintenance machines with hybrid drive technology were introduced for the first time. Under the E<sup>3</sup> brand, a continuous action 4-sleeper tamping machine and a ballast management system were operated. The machines can be powered with the electricity from the overhead line, meeting the requirements of the DB2020+ corporate strategy of Deutsche Bahn (German Railway). The strategy aims at promoting a sustainable, strategic development in the interplay of economic, ecologic and social aspects [1]. The hybrid machines have been designed to reduce emissions, increase energy efficiency and lower noise.

Measurements undertaken as part of a master's thesis [2] focussed on the noise emitted by diesel operation and electric operation.

In idle mode the reduction in the tamping machine section was 6.1 to 7.9 dB (A), in the stabiliser section it was 2.0 to 2.9 dB (A). During work in electric operation, a reduction of 4.6 dB (A) was measured in the tamping machine section at a distance of 7.5 m.

Another machine from the E<sup>3</sup> series, the Unimat 09-32/4S Dynamic E<sup>3</sup> universal tamping machine, was supplied to the track contractor Krebs Gleisbau AG as early as in 2016. For this machine model, a 10-year con-



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tract has already been concluded with SBB. For winning this contract, ecological aspects were crucial. From 25th November 2016 to 10th March 2017, the electrical performance data of the machine were analysed. During this time, the machine was operated electrically for 110 hours and consumed 44,420 kWhr (energy recovery deducted already). Powered via the diesel engine, the machine would have consumed 12,548 litres. This results in cost savings of more than  $\in$  100 per hour in electric operation and enables CO<sub>2</sub> to be reduced by 31,5 tonnes in total.

## ELECTRIC DRIVE FURTHER EXPANDED

The machine design with hybrid drive is further expanded. One example is the Unimat 09-4x4/4S  $E^3$ , a universal tamping machine for fully electric operation and diesel-electric operation, i.e. in diesel operation, a diesel-electric drive is available. For operation in tunnels, the machine is fitted with a PURITECH filter system. The new vibration drive of the tamping unit provides the following benefits:

- $\rightarrow$  increased energy efficiency
- $\rightarrow$  precise control mode
- $\rightarrow$  faster response characteristic
- $\rightarrow$  more compact design
- $\rightarrow$  further increases in process reliability

**FIG 1:** The new Unimat 09-4x4/4S E<sup>3</sup> universal tamping machine has been designed for fully electric or diesel-electric operation



#### VEHICLE WITH BATTERY TECHNOLOGY

The HTW 100 E<sup>3</sup> catenary maintenance machine is operated completely differently (fig. 2). Using the diesel drive, the machine travels to and from the work site. On the work site, the machine is powered electrically. For this purpose, the machine is fitted with accumulator units, designed for two shifts. During the journey using the diesel drive, a generator charges the accumulators. In addition, the braking energy is used to charge the accumulators. External power supply via a shed socket is possible as well. Benefits of battery working mode:

- → the exact amount of energy required for a certain task is used
- ightarrow no emissions during work
- → the machine works quietly and is suited for night-time operation
- $\rightarrow$  unrestricted operation in tunnels

Further interesting details on the machine: To control the machine, a speed controller function can be used. During measuring runs, it ensures more precise results. When the battery power level has reached 30%, the automatic start of the diesel engine is recommended. The diesel engine is equipped with a particulate filter.

The HTW 100 E<sup>3</sup> is equipped with many work units to ensure a high level of productivity during inspection, maintenance and installation of the overhead line: column lifting platform, railway loading crane with work basket, contact wire and carrying cable holding device, earthed pantograph, workshop cabin, and measuring equipment for the contact wire position.

## TAMPING AND STABILISING IN NEW DESIGN

The aim of track maintenance is to produce a durable, high-quality track geometry. Tamping and stabilising in combination with precise measuring systems have made it possible to reach this aim to a large extent today. Plasser & Theurer tamping units have been continuously further developed since the introduction of the non-synchronous uniform-pressure tamping technology in 1953. Today, they are the standard in development [3]. New control technology for vibration and multiple-sleeper tamping complements the well-proven hydraulic squeeze technology, which ensures uniform squeeze pressure underneath the sleepers.



FIG 2: The new HTW 100 E<sup>3</sup> catenary maintenance machine is equipped with batteries for electric working operation

## ROTATION SPEED MODULATION FOR TAMPING UNITS

The rotation speed modulation makes it possible to change the vibration frequency during tamping in a controlled manner.

At a higher frequency (45 Hz), the tamping tines penetrate highly compacted ballast beds more easily. During squeezing, the optimum frequency of 35 Hz is used. When the tamping tines have been raised, they vibrate at an idling frequency of  $\leq$  28 Hz. The vibration drive of the eccentric shaft ensures a constant vibration amplitude of +/-4 to 5 mm. This is crucial to achieve a high tamping quality and process reliability.

Good experiences have been gained with the rotation speed modulation technology. The reaction forces from vibration and penetration resistance are reduced. Wear on the tamping units is further reduced. Due to the good experiences with the reliability of the units, the warranty period for new tamping units and following a general overhaul of tamping units has been extended to cover 24 months or a maximum number of 500,000 tamping insertions (with and without rotation speed modulation) [4].

#### **GRADUAL 2-SLEEPER TAMPING**

In highly compacted ballast beds, the tamping tines of multiple-sleeper tamping machines must meet a high level of penetration resistance. The new development for 2-sleeper tamping units is a major improvement. Split in longitudinal direction, the tamping units are lowered gradually. This gradual technology significantly reduces the number of tamping tines penetrating the ballast at the same time. As a result, the penetration resistance is reduced. Gradual lowering causes hardly any loss in performance. In hard ballast beds, gradual tamping enables the working speed to be increased significantly compared to standard 2-sleeper tamping.

## TRACK STABILISATION WITH IMBALANCE REGULATION

Dynamic track stabilisation has become indispensable in track maintenance.

Track stabilisation following tamping is crucial to ensure optimal and durable work results. This technology has been a success for four decades. More than 900 machines operated in 45 countries demonstrate this [5].

The effect of track stabilisation is shaped by the stabilisation frequency, vertical load, working speed and the dynamic impact force. The first three parameters are modified during machine operation. The impact force is determined by the eccentric flyweights. The required settlement of the track is controlled by the levelling system; modifications of the vertical load regulate the longitudinal level. However, the imbalance affects the track settlement the most. This is why the DGS can be equipped with an adjustable imbalance enabling the track settlement (and the levelling of the track) to be regulated by adjusting the imbalance. This is of particular interest for track sections. in which the vertical load does not suffice to »





FIG 3: The new 8x4 tamping unit

regulate the track position. Moreover, the improved adjustment benefits buildings requiring particular care. When the machine stops, the imbalance is immediately reduced to zero. Therefore, there is no need to reduce the frequency. Resonance vibrations are avoided.

#### UNIVERSAL TAMPING MACHINES

When tamping turnouts, it is crucial that the tamping tines reach as many areas as possible. To ensure this, the tamping units of the "4x4" series have been developed. They are fitted with individually tilting double tines and designed as Split Head units, with one unit halve to the left, and one to the right of the rail. Each tamping unit halve is fitted with four tines, hence "x4". The units are used on cyclic action 08 machines and continuous action 09 machines (fig. 3).

Theurer's Unimat Combi 08-275

#### UNIMAT COMBI 08-275

The Unimat Combi was developed for the operation in the regional sector and for spot fault repair. In Germany, the machine model is known as Unimat Sprinter. The Unimat Combi 08-275 for the Italian Railway Infrastructure Company RFI is a universal tamping machine with ballast profiling trailer (fig. 4). The Unimat Combi 08-275 exhibited in Münster was the 16,000th machine to be manufactured by Plasser & Theurer. This "multipurpose tool" combines the following technologies: tamping machine for plain track and turnouts, integrated ballast plough and sweeper brush, complete inertial track geometry measuring system. Its

modern design is exemplary for machines of this kind. Following extensive testing of a sample machine, RFI decided to acquire a large number of machines of this model. One machine from this series is in E<sup>3</sup> design. It will be the first machine to be operated using direct current from the overhead line system.

#### OVERHEAD LINE INSTALLATION WITH TOP QUALITY

#### THE PREMIUM PROGRAMME FOR OVER-HEAD LINE INSTALLATION IN DENMARK

Under an electrification programme of Banedanmark, 1,500 kilometres of new overhead contact lines will be installed in Denmark by 2026. For the overhead line concept Sicat SX of Siemens AG used on this project, a new concept for the installation and machine technology has been developed. Overhead line installation poses considerable challenges to be met by the machines used, such as the FUM 100.260 catenary installation and renewal machine in particular (figure 5). Both a RiM 80 contact wire with a nominal tension of 15 kN and a carrying cable of aluminium alloy with a nominal tension of 30 kN must be installed in one pass. For both operations, a tolerance of +/- 5% of the nominal tension must not be exceeded. In addition, the FUM 100.260 must allow the installation of a RiM 150 contact wire with a nominal tension of up to 33.75 kN.

The FUZ catenary renewal train consists of several machines. Together, they form a system. The FUM catenary renewal machine

FIG 5 a und b: The FUM100.260 installation machine is part of the FUZ 100.273 catenary installation train



simultaneously installs the carrying cable and contact wire with final tension – and the proven high level of quality [6]. All machines are fitted with a work drive enabling them to be operated separately. In Denmark, the overhead line is installed in tight curves on superelevated tracks. Here, the machines' stability is of utmost importance.

#### MANUFACTURING QUALITY IN SERIES

Deutsche Bahn is striving for the standardisation of multi-purpose vehicles. Since 2014, DB Netz AG has received a standardised vehicle generation. Five carrier vehicles for measuring equipment were the first machines to be supplied. They have been operated successfully. A time-consuming quality assurance process confirmed the high production standards at Plasser & Theurer's Linz factory.

Despite many new challenges to be met, the project implementation confirmed Plasser & Theurer's outstanding manufacturing quality. The contract was based on specifications with 4,000 required items and seven quality gates to be met. All quality gates were passed successfully.

Martin Allweil, Head of Rail Vehicle and Machinery Fleet, DB Netz AG, Berlin, explains: "It is the core responsibility of DB Netz AG to provide around 400 railway undertakings with high-quality infrastructure and to ensure a high level of availability to enable them to operate it.

To perform the relevant maintenance works, we looked for machines that enable implementing a forward-thinking and demand-responsive maintenance strategy.

Plasser & Theurer fully implemented the complex technical requirements and developed a uniform vehicle design. Thanks to the use of standardised components in the differing vehicle types, we see savings potential in maintenance costs, spare parts stocking and training of the operating staff." [7]

#### ADDITIONAL CARRIER VEHICLES FOR DB

The principle of "quality in time" will also be applied in future: four tunnel inspection vehicles will be supplied. Comprehensively equipped, the TIF-LAE (fig. 6) makes it possible to work at several positions at the same time. Its equipment includes:

- → roof platform with hydraulically folding railing
- → hydraulic crane with 3.7 mt and a work basket suited for 170 kg
- → hydraulic crane with 25 mt and a work basket suited for 330 kg



FIG 6: TIF-LAE tunnel inspection vehicle

- → sound-insulated cabins with vibration decoupling
- $\rightarrow$  mounted parts for snow clearance

#### **TECHNOLOGIES 4.0**

#### THE SMART MACHINE

New research findings constantly shape the further development of track maintenance machines, enabling machines to be further improved.

The new smart technology is setting the course for Industry 4.0.

This has an effect on the machines' operation:

- → The cabins' interior design has been adjusted to take advantage of the new digital opportunities (fig. 7).
- → Touch screens make it easier to operate the machine. Menus provide access to all machine elements.
- → Work sequences have been automated to a large extent.

## DATA MANAGEMENT AND DIGITAL SERVICES

PlasserDatamatic and PlasserLiveInfo open new dimensions for the efficient management of individual machines and entire machine fleets. Working parameters and status messages of the machines or even the direction of work or transport can be accessed easily using a tablet or smart phone. Networking enables digital services. The data acquired can be further processed to optimise the machines. Established in January 2017, P&T Connected Gesellschaft mbH, takes care of this.

#### SUMMARY

Considering the high number and wide range of innovations presented at the International Exhibition for Track Technology (iaf), it's fair to speak of a boost in innovation. This time, a particular focus was placed on the opportunities opened by digitisation.

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**FIG 7:** Digital control elements and touch screens enable ergonomic operation and shape the cabin design on the latest generation of track maintenance machines



# Mireo – Siemens New Commuter and Regional Train Platform

In a similar fashion as the generation change by the introduction of Desiro City<sup>®</sup> train on the UK market in 2013, Siemens has now launched a new vehicle generation called Mireo<sup>®</sup> for the commuter and regional train market in continental Europe.

## STATE OF THE ART AND POSSIBLE INNOVATIONS

The low floor vehicles currently on the market differ only marginally, both from the operator's and from the passenger's point of view. The configuration of interfaces relevant to passengers is largely determined by the Technical Specifications for Interoperability relating to Persons with Reduced Mobility (PRM TSI). For the manufacturers the choice of components is based on similar technologies and suppliers. For the overall concept, most manufacturers have stuck to the typical unit size with about 200 seats and a length of about 70 m for a four-car articulated train with five bogies.

This approach does not allow further quantum leaps in terms of maintenance cost and energy saving, even taking into account detail innovations expected for the next years, such as permanently excited synchronous motors (PEM), silicon carbide converters and medium frequency transformers. The reduction of these constituents of life cycle cost have such a high priority, because the maintenance cost and the energy cost for 30 years of operation are each as high as the purchase cost of such a regional vehicle and are fully taken into account for the first time in modern European operator models. Furthermore, consideration of wear-dependent track access fees is becoming more important and has already become reality e.g. in Switzerland.

## DEVELOPMENT TARGETS OF THE NEW PLATFORM

At the start of the Mireo development project, extensive analyses concerning requirements, competitive situation and possibilities to optimise cost were made. The results were used for the definition of the parameters of a new platform.

The majority of the maintenance cost can

be directly assigned to individual components. It is well known that particularly the bogies together with the drives and the brakes mounted on the bogies represent about two third of the cost.

The reduction of the vehicle weight is a more important factor for the reduction of the energy consumption, even before the improvement of traction efficiency and aerodynamics. Similar as for cars, the total weight of rolling stock has increased dramatically in the recent years mainly due to comfort and passive safety. Bogies, drives and brakes account for about one third of the total vehicle weight.

As a result the reduction in the number of bogies, drives and brakes in particular is considered as the key to success for the cost reduction over all life cycle stages.

Additionally, heterogeneous requirements in conjunction with the relatively small order lots to be expected require a high level of flexibility in terms of capacity, acceleration, platform heights, equipment / comfort as well as IT infrastructure. Due to new types of operator and financing models, it seems desirable to be able to change as many of these features as possible in the future.

#### CHOSEN VEHICLE CONCEPT

To reach the above mentioned LCC targets, the Mireo has been developed as a proven articulated train concept with Jacobs bogies. Compared to a single car train and bogie offset articulation, this concept allows for the greatest length possible within the scope of UIC 505-1 and EN 15273 for a given width and number of bogies. When transferring proven typical bogie pivot pitches for single cars, lengths of about 20 m for the middle cars and of about 25 m for the end cars are obtained for a vehicle width of more than 2.8 m. This approach represents a rather complex but solvable challenge in respect of the required lightweight construction, the limitation of lateral play, the yaw angle of bogies,



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articulations and couplers as well as the car body contour. As a result, a customary vehicle length and/or a capacity of about 200 seats and a length of 70 m can be achieved by three cars and four bogies, whereas conventional articulated trains have one more bogie and one more car including HVAC system, gangway etc. and conventional single car trains have two more bogies for the same number of car bodies.

The bogies represent a further development of the lightweight bogies with inboard bearings of the Desiro City platform. Worth mentioning is the challenge of integration of wheel disk brakes in addition to the reduction of the air spring height and the increase of the axle load. In spite of this we have achieved a free combination of powered bogies, Jacobs bogies and magnetic track brakes and a maximum speed of 200 km/h, in terms of braking and of running dynamics. Beside a significant weight reduction, the new bogies offer advantages regarding maintenance and aerodynamics. The maximum wheel load is restricted to 20.0 t to enable operation on all relevant tracks. The wheel-track wear for Mireo is lower than for conventional vehicles. Analyses based on UK-VTAC (variable track access charges) and on the Swiss track prices show significantly lower cost as for any other vehicle concept. The increased axle load is compensated by



FIG. 1: Comparison of the side view of different 70 m vehicles: 3-car single car train DML-MRB (top), 4-car articulated train SLT (middle) and 3-car articulated train Mireo (bottom)

the reduced total vehicle mass, the significantly reduced unsprung masses, the curvefriendly axle link and a short wheel base of 2,300 mm in the end bogie and 2,600 mm in the Jacobs bogie.

The selected traction concept is also based on the principle of a reduced number of components and represents a consequent further development of the Desiro City platform. Only one transformer, a 4QS, two current converters and only four drives provide peak power of 2.6 MW for a 70 m vehicle. The use of few, comparably powerful components reduces not only weight but also increases the efficiency of the equipment. The traction system is configured as a DC busbar and can supply not only two but also three or four powered bogies. This solution is "future-proof" in that all future options and technologies as the mentioned PEM drives, SiC converters and medium frequency transformers as well as traction batteries for bridging non-electrified track sections can be smoothly integrated. The auxiliary converters are connected to the DC busbar and can also be scaled.

This traction concept offers the possibility to scale the traction power and to adapt to all typical voltage systems in Europe. The required installation spaces and cable routes including mechanical and electrical interfaces for all versions are anticipated and reserved.

The body shell also significantly contributes to the weight reduction. In spite of the use of light-weight materials and principles, the chosen concept offers maximum ease of repair. The first meter of the vehicle is made of easily replaceable, bolted "sacrifice components" side buffers, obstacle deflectors, front fairing and centre coupler. The entire head structure is made of repair-friendly high-strength steel and is bolted to the tube of extruded aluminium profiles. The interface is chosen such that all relevant elements as e.g. the optional cab side doors, HVAC sys-



FIG. 2:

Bogie SF7500 with inboard bearings; different variants (top) and compared with the contour of a conventional bogie (bottom)

tem and all electric connections are incorporated in the head. The connection between the head structure and the car body is made in a later assembly step. This means, that in case of a heavy collision the head can be replaced without extensive dismantling works.

The omission of cab rear wall cabinets fits coherently into this concept. Both the cab and the passenger saloon are free of electric cabinets. This provides for unusually spacious working conditions and best ergonomics for the driver.

Due to the omission of cabinets, the highest possible vehicle length is made available for fare-paying passengers. The electric components are located in central ceiling containers which represent a consistent further development of the well known solutions of the De-»

FIG. 3: Modular traction and auxiliary system for 15 kV and 25 kV





siro City platformallowing the comfortable access to all maintenance-relevant components from inside the train. The installation of the brake panels also follows this philosophy. Additionally, the omission of the cabinets offers the "front view feature" with transparent car rear wall, offering passengers a free view onto the track, which is unique in this vehicle class.

#### FIG. 4:

Separation between the car body tube and the head for the assembly and/or replacement in the fully furnished state as well as "sacrifice modules"

#### CHOSEN MODULARITY CONCEPT

In order to cover the wide range of operator requirements and flexibility a multitude of variants are possible through the intelligent use of standardisation and interfaces. Thereby, 3 levels of modularity are defined.



FIG. 5: Basic configuration, i.e. selection of the number of cars (left top), traction system or motorisation (left bottom) as well as car length, number and width of vestibules and the position of universal and standard toilets (right)

FIG. 6: "Empty tube" with opened ceiling containers as well as furnishing for normal comfort demands (left) and Intercity standard with 2 + 1 seating combined with "front view" (right)



#### 1.) BASIC CONFIGURATIONS

The basic Mireo configuration is from two to seven cars, which corresponds to between 50-150 or 150-450 seats, with 2-4 powered bogies for a starting acceleration of 0.6 - 1.2 m/s<sup>2</sup>.

Furthermore, each car is equipped with a maximum of two doors per side and a toilet at pre-defined positions. Shortening end cars in one step and middle cars in three steps is possible. To achieve the seat / doorway ratio of conventional low floor rapid transit trains, doors with a clear width of 1950 mm can also be used, instead of 1300 mm, allowing 3 persons to pass abreast.

This allows covering all market requirements.

#### 2.) ADAPTABLE ENTRANCE ELEMENTS

Although the basic configuration requires different car body forms, depending on the above mentioned parameters, however, these structural parts remain unchanged for the different configurations of exterior doors and steps. The floor height in the low floor area is a consistent 700 mm above rail level. The low floor area is connected to the vestibules with heights of either 600 or 800 mm by small TSI compliant ramps. The same car body tube therefore always allows for both entrance heights as well as for the provision for three different retractable steps. Furthermore, an identical head structure is used for both head variants with or without side doors.

This concept permits the realisation of a barrier-free access for both current platform heights by implementing a 600 mm and an 800 mm entrance in the PRM car.

Furthermore, the configurability of the vestibules e.g. during overhauls increases the residual value of the vehicle.

#### 3.) FLEXIBLE FURNISHING

After the selection of the basic configuration and the vestibule elements, we have a completely panelled but empty tube, i.e. "empty vehicle concept", from which virtually each conceivable interior equipment configuration is possible without the need to change any of the panelling parts.

For this purpose, all interior equipment is fixed to the C-rails of side wall and ceiling without any attachment to the floor. In addition to the already proven cantilever seats, this has now been implemented consequently for tables, fold-up seats, standing aids, interior doors, windscreens, luggage racks, passenger information displays in socalled gondolas etc. As any longitudinal po-



FIG. 7: Schematic representation of the three networks: TCN, TON and passenger network

sition is possible for this equipment, an unlimited number of furnishing variants – e.g. seat arrangements, pitches, multipurpose areas, compartments etc. – is possible.

Therefore, each Mireo vehicle can be reconfigured with the minimum of effort to fit seasonal requirements or at the end of the lease term. Other advantages of this concept include a cleaner friendly environment and the avoidance of leaks and corrosion. Preparation for incorporating higher levels of comfort such as 2 + 1 seating, large tables and socket outlets are also considered giving maximum flexibility to realise almost all individual customer requests.

## CONTROL, INFORMATION, DIAGNOSTICS ETC.

The electronic systems are distributed over three networks: The train control network (TCN), the train operator network (TON) and the passenger network. The networks are securely separated by a security gateway.

The proven train control system Sibas PN<sup>®</sup> is the heart of the electronic control level and manages the train and vehicle control. ETCS is the envisaged train protection system, which can be combined with all country-specific devices commonly used in Europe.

The operator network and the passenger network are realised with TrainIT. This is based on standard hardware and software architecture. This fully integrated modular system offers a multitude of solutions for passenger information, -entertainment, -counting and also for diagnostics, maintenance and CCTV. It offers a standardised vehicle to landside interface and is highly flexible and extendable.

Through the strict separation of the homologation-relevant train control and TrainIT highest IT protection is ensured when considering the rapid innovation cycles of passenger information.

#### ADVANTAGES FROM THE CUSTOM-ER'S POINT OF VIEW

With Mireo, Siemens has opened a new chapter of regional and commuter vehicles offering customers the following advantages:

- Flexibility and individuality: The Mireo already offers a high number of variants in terms of capacity, length, acceleration, number and width of doors, entrance heights, number of toilets and driver's cab entrance doors. As a result of the "empty vehicle concept" an "infinite" number of interior equipment variants are possible. Different market requirements can be addressed flexibly and rapidly and be adjusted individually throughout the entire service life.
- Maintenance advantages: For comparable vehicle lengths and capacities, the Mireo vehicle has a minimal number of maintenance-relevant components such as bogies, brake components, motors, gears and HVAC systems. Further savings are achieved by increasing the electric brake power. This results in an unrivalled low level of maintenance expenditures
- 3. Energy savings: Through the weight reduction of about 25% the energy consumption is reduced by a similar percentage. Other large savings are achieved by a higher traction efficiency and better aerodynamics. Additionally, the driver advisory system and the increase of the electric brake power account for a substantial contribution to energy saving. This is a quantum leap, not only economically but also ecologically.

#### OUTLOOK

The largest market volume is expected to be a three-car variant of 70 m with about 200 seats, up to 6 doors per side, a universal toilet and a multi-purpose area. The starting acceleration with 2 powered bogies is about 1 m/s<sup>2</sup>, the total weight of such a configuration is about 112 t instead of the current 130 t to 140 t.

Beside the described multi-system variants, bi-mode-driven trains are under development.

#### FIG. 8: Mireo - outside view



# Karlsruhe pilot with eco-friendly turnout heating

Since winter 2016/2017, the public transport operator of the city of Karlsruhe (VBK) and the municipal utility company have been testing the energy-efficient heating of turnouts with district heat instead of electricity. For the trial operation with the new Turnout Sandwich Radiator (Fig. 1), four grooved rail turnouts at the Rheinhafen tram station were selected because at that location, the district heat infrastructure was already in place. This pilot project is the first to put the lifecycle cost focus on the energy consumption of turnouts. And with good reason: depending on the kind of heat pump, the energy saving potential exceeds than 90 percent.

Already two years ago, Vossloh started with the implementation of this concept as heightened environmental awareness and more stringent energy-efficiency laws and requirements had resulted in a general rethink. Urban transport systems stand for eco-friendly mobility so municipal operators aspire to be pioneers in sustainability also as regards their infrastructure – especially when the technical prerequisites for the use of renewable energies have already been established.



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FIG. 1: Schematic showing the four grooved rail turnouts at the reversing loop at the Karlsruhe Rheinhafen tram station (source: dibauco GmbH)



## STRUCTURE AND MODE OF ACTION OF THE TURNOUT HEATING

For the use of renewable energies, Vossloh developed a new high-performance turnout design based on the Monobloc sandwich type, using steel's thermal capacity, the required temperature increase and the heatup period as parameters for the calculation of the material volumes and the required heat transfer. This is important since the lubricants used in the turnouts must not be affected, let alone evaporate as a consequence of the heat input.

In comparison with other heating solutions in local public transport where the heating elements (such as heating panels and heating rods) are fitted on the outside, under the railhead of the turnouts, the innovative Turnout Sandwich Radiator has two interior hot water ducts for flow and return. Figure 2 shows various illustrations of the welded monobloc sandwich design. Like in an underfloor heating, an eco-friendly liquid with alcohol content is heated by the district heat in a secondary circuit and pumped through the ducts of the turnout heating. The district heat is supplied from the local district heating pipeline via a heat exchanger.

In Karlsruhe, the conditions were ideal because it was possible to use an already existing branch of the district heating network, which is supplied with industrial waste heat. From the substation, the pipes required for the turnout heating (Fig. 3) were laid and a heat exchanger with a capacity of 20 kW was installed together with a heat pump (Fig. 4). The average temperature in the district heating pipeline in the recirculation is 60 degrees Celsius.

#### ON-DEMAND ENERGY SUPPLY

In order to ensure a perfect operation of the turnout at freezing temperatures, the turnout must be heated or, to be more precise, the switch blades must be warmed. This will melt snow and ice accumulated between the switch blade and the stock rail. If the movable parts of the turnout, which determine the direction of the trains, do not have the right operating temperature, they will either become stiff or freeze up. This leads to interruption of regular train service would prove very costly.

Yet even during the winter period, a turnout is not heated continuously. To allow ondemand heating, additional instrumentation is installed for measuring precipitation along with the air and the rail temperatures, and the control system housed in a switch cabinet only enables the complex heating system in the track when the conditions so require.

During a first trial run at the end of November 2016, a swift increase of the rail temperature to more than 25 degrees Celsius was measured in the turnouts – with outside temperatures around freezing point and

a flow temperature of 50 degrees Celsius (Fig. 5).

## SIGNIFICANTLY LOWER LIFECYCLE COSTS

The economic benefit of using district heat mainly becomes evident in the analysis of »



FIG. 2: Illustration of the final development stage of the turnout heating based on the switch blade of the monobloc design (source: Vossloh AG)

FIG. 3: Laying the pipes for the secondary circuit (source: Vossloh AG)



FIG. 4: The four grooved rail turnouts are controlled by thermostatic valves, a selfregulating pump and a 20 kW heat exchanger (source: Vossloh AG)





FIG. 5: An employee of Verkehrsbetriebe Karlsruhe is testing the effects of the new turnout heating with an infrared thermometer (source: Verkehrsbetriebe Karlsruhe)

the lifecycle costs (LCC), i.e. the analysis of all actual costs over an assumed life. These range from the initial outlay for the turnout to the costs of its end-of-life disposal and also include the maintenance and cleaning costs as well as the costs of the raw materials used for the generation of primary and secondary energy. The overall costs are divided by the years of service life to yield the annual costs which are then comparable with each other.

In regions with moderate winter temperatures, heating the switch blades of grooved rail turnouts with electric heating rods to prevent freezing up of the movable components costs between  $\in$  550 and  $\in$  600 per year. In case of R190 Vignoles turnouts, these costs amount to more than  $\notin$  2,000 per year. Extrapolated to a service life of 20 years, this is equivalent to between 8 and 25 percent of the entire lifecycle costs.

The capital expenditure for a renewable energy based heat supply of a grooved rail turnout is roughly equivalent to twice the costs of its annual energy consumption. During the remaining 18 years, the electricity costs are a mere  $\in$  15 to  $\in$  20 per year – only 3 to 4 percent of the traditional energy costs.

## CONSIDERATION OF THE ENERGY SUPPLY COSTS

Such LCC analyses have until now, however, failed to include the costs of heating the turnouts, which are quite considera-

FIG. 6: Example calculation of the current energy consumption of a turnout system in the operation of a tram depot in Germany (source: Vossloh AG)

In local transport, a turnout requires about 150 W per metre (DB lines: 300 W/m). Depending on the speed and the curve radius, a turnout is between 10 and 18 m long.	150 W x 10 m = 1.5 kW 150 W x 18 m = 2.7 kW
This means that a heating output between 1.5 and 2.7 kW is required.	
Assuming that each turnout is heated for 18 hours during 73 days per year – which corresponds to the statistical freezing days $^{1}$ — the energy consumption is between 1,971 and 3,285 kWh per turnout and year.	1.5 kW x 18 h x 73 days = 1,971 kWh 2.7 kW x 18 h x 73 days = 3,548 kWh
For 50 turnouts and a rounded average of 2,700 kWh, this results in 135,000 kWh.	(1,971 kWh + 3,548 kWh) / 2 = 2,759 kWh 50 x 2,700 kWh = 135,000 kWh
At a price of 20 euro cent per kWh <sup>2</sup> , the operating expenses amount to 27,000 euros.	135,000 kWh x 0.20 € = 27,000 €
In addition, the seasonal performance factor (JAZ), i.e. the ratio of environmental energy to electricity, is Zero.	0 kWh/a 100 kWh/a
<sup>1</sup> Source: www.winterchronik.de <sup>2</sup> Source: www.stromauskunft.de for an assumed 50,000 kW/a commercial operation	

ble: over the service life of the turnout, the primary energy (nuclear power, coal, other fossil fuels) cost of electricity required for the trouble-free operation during the winter months more or less corresponds to the historical cost of the turnout. So these heating costs certainly deserve more attention, as is also illustrated by the example calculation of the energy consumption of a tram depot in Germany (Fig. 6). The operating expenses for the electric heating amount to € 27,000 per year whereas with district heating, there will be a onetime investment of a maximum of € 20,000 for the connection to the district heating pipework plus annual operating expenses of approx. € 900. Irrespective of increased energy consumption and rising energy costs, district heat is much less costly than electricity. Especially for infrastructure, district heat is a resource-friendly energy source that offers not only economic but also environmental benefits.

Against this backdrop, it was not difficult for Vossloh to win the support of the municipal utility company Stadtwerke Karlsruhe, the local transport operator of Karlsruhe (VBK), Technologie-Consult Karlsruhe GmbH (TTK) and Dienstleistungsgesellschaft für Bauen, Umwelt und Consulting mbH (DiBaUCo) for this pilot project. In fact, the Karlsruhe-based companies were so convinced of the overall concept that they financed a large portion of the project themselves.

#### OUTLOOK: MORE TO COME

After completion of the construction work and the commissioning of the turnout heating, the system will be comprehensively monitored this year, primarily to obtain robust data on the energy consumption. The novel sandwich design permits a more efficient use of the energy so that an 85 percent reduction in the share of the energy costs compared to current systems is targeted.

If the tests prove equally successful, the transport operator VBK intends to convert further turnouts to district heat. Already valuable expertise has been accumulated that will be incorporated in the next turnout heating systems. The aim is now to optimize the processes and further reduce the operating expenses. Apart from the environmental aspect, it is the economic benefit that makes switching to the cheaper district heat attractive for operators. And since Karlsruhe currently heats about 320 of the 486 turnouts in the city, the potential for substantial savings for the operator are very significant.

# First successful commissioning of GTB12 plugs (M12 plugs with bayonet lock) in Albula's new ALVA articulated trains of RHB

On occasion of the UNESCO World Heritage Days on June 11<sup>th</sup> and 12<sup>th</sup> 2016, the new train of Rhätische Bahn (RhB) was launched in Thusis. Before an audience of guests, the local RhB Administrative Board President, Stefan Engler, and RhB Director, Renato Fasciati, welcomed the youngest "child" to the RhB fleet and launched it under the name of "Alvra" (Rhaeto-Romanian for Albula).

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GIMOTA INC develops and produces connecting solutions for industrial and harsh environments. She is one of the leading providers of industrial traction connectors.

► The Alvra articulated trains will be gradually transitioned into operations starting in late 2016. It is expected that all six of the Alvra articulated trains will be in scheduled service by the end of 2017. The new GIMOTA M12 plug connectors with GTB12 bayonet lock also played a part in this.

Operating safety is a very high priority today for any railway operator. This is why it comes as no surprise that railway operators are not happy with the common industrial M12 plug connectors great volumes of which are already used today in railway technology.

M12 connector bayonet version





New Alvra articulated trains RHB

The train operator wanted to provide reliable Ethernet connectivity within its entire rolling stock fleet to ensure uninterrupted operation of the PIS application. Usually, railway equipment suppliers depend on M12 connectors to provide the critical connectivity between cables and equipment.

One frequently cited drawback of these industrial M12 plug connectors, however, is their contact connection with conductors/ strands. These are often offered as soldered versions, screwed versions or with insulation displacement connection (IDC) for field termination. According to experience, crimped contact connections make for the best results in terms of durability and vibrations.

The correct screw connection of the plugs where available space is tight is also considered to be problematic in many cases. Bayonet couplings compared to screwconnected plugs are much simpler, more safely lockable and they offer the greatest possible vibration resistance by virtue of a form-fit, defined clicking-in of the bayonet lock.

Because of this, bayonet M12 couplings developed by Gimota AG were used for this project, based on the M12 plug connection technology proven in industrial use and the standard EN 61076-2-101, and according to the draft standard IEC 61076-2-011. Compatibility is assured as this connector technology also allows connection with screw-type M12 connectors.

#### THIS MEANS:

→ The selected plastics meet the highest of standards of the railway industry for flame resistance



Switch solution with bayonet coupling

- → The components used are resilient and tested for the strong occurring vibrations in railway traffic
- → 360° shielding in an electromagnetically charged environment for reliable transmission of all signals
- → All products are tested for temperature shocks; these must not affect the electrical functions of products in any way

RHB is the first railway operator to recognise the manifold advantages of the GTB12 series and therefore relies on using the same in the complete, modern passenger information system of the new Alvra articulated trains.

# Deutsche Bahn awards certificate of maturity for IFE entrance system

The Knorr-Bremse division IFE has received the DB certificate of maturity for the E4 entrance system after two years of operation in a double-decker Deutsche Bahn train. IFE is the first to receive this certificate.

▶ In autumn of 2013, DB and IFE agreed to pursue new paths when introducing new products onto the market. Products should only be established on the market if they have actually reached maturity and all teething problems have been resolved.

"The vehicle operator, Deutsche Bahn, and the system supplier, IFE, met with a common goal according to this exact principle," Dr. Peter Radina, member of the management board of Knorr-Bremse Systeme für Schienenfahrzeuge GmbH, reminisced about the first meetings. "Both parties wanted to ensure that the new IFE entrance system was to be comprehensively tested and validated before being put into use in large quantities," said Dr. Radina.

The association of the railway industry in Germany (VDB) has worked together with DB and Knorr-Bremse to develop and implement the usage maturity model with which the fitness for purpose of new developments is classified into nine stages and then documented. Unpleasant surprises when using new components or systems in vehicles should be avoided, by them being subjected to a comprehensive field test even before procurement.

#### **TESTING IN PASSENGER OPERATION**

At that time, IFE was working on the development of the Generation 4 entrance system for regional train vehicles, which sets new standards in terms of simple installation, high reliability and reduced maintenance costs. All components of the drive system have been developed and validated with a focus on maximum service life.

At the location in Kematen/Ybbs, IFE has an extremely comprehensive in-house testing and validation centre, including a large-capacity climatic chamber, acoustic chamber and hydro pulse system. The trial in passenger operation cannot be carried out in this way, however, but it would be an important supplement to finalise the suitability for use and validation of a new development

**FIG. 1:** Dr. Matthias Müller, Head of Service Technology Rail Vehicles in Vehicle Procurement at DB AG, (right) awards the maturity certificate to Oliver Schmidt, Chairman of the Managing Directors' Board at Knorr-Bremse GmbH Austria Foto: © IFE



and therefore also have the series maturity confirmed by an external partner.

In November 2013, DB and IFE agreed on their common intention to test the E4 door system according to the new VDB maturity model in passenger service. Since mid-2014, the specialist departments of both organisations have been working on the practical implementation.

#### **INSTALLING THE E4 DOOR SYSTEM**

In July 2015, the conversion of a doubledecker vehicle of the DB Regio Elbe-Saale train was carried out and the IFE entrance system was intensively monitored in daily operation from this point on. In the two-year trial period, a total of 11 detailed inspections took place during which 56 parameters were collected and then evaluated.

Aside from small adaptations in the technical documentation, no technical problems were determined. "Testing was carried out without any problems – in two years of operation, not one single door fault was documented," confirmed Carsten Kretzschmar, specialist engineer for entrance systems and interior decoration at Deutsche Bahn AG.

#### POSITIVE CONCLUSION TO THE TRIAL

The two-year test phase came to a positive conclusion at the start of summer 2017. DB and IFE would both like to keep the entrance system in the vehicle and continue to monitor it. Intensive monitoring will be reduced, however, and DB will increasingly take over the supervision of the door system.

On 1<sup>st</sup> June 2017, the Deutsche Bahn has awarded IFE with the certificate of fitness for purpose – the maturity certificate – for the E4 door system. With this, DB confirms the achievement of stage 9, the highest degree of maturity. This certificate documents that the IFE entrance system has been tested, approved and is of high quality. ◄

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