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Railway Technology Review

- High-speed systems
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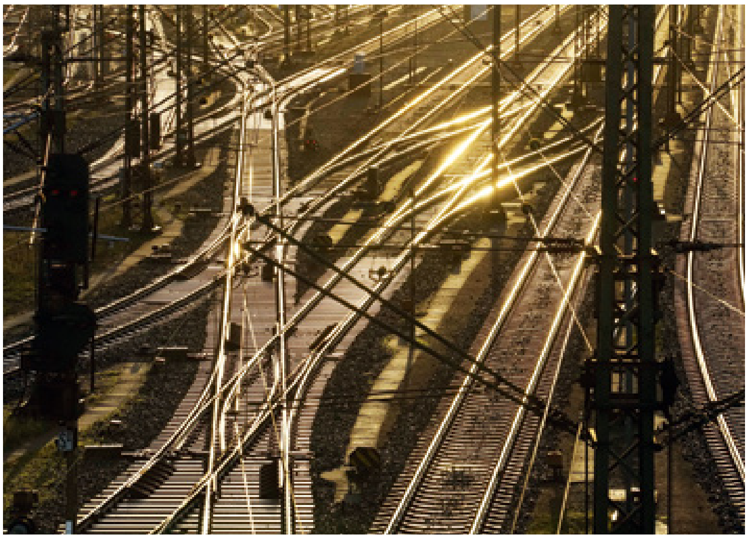
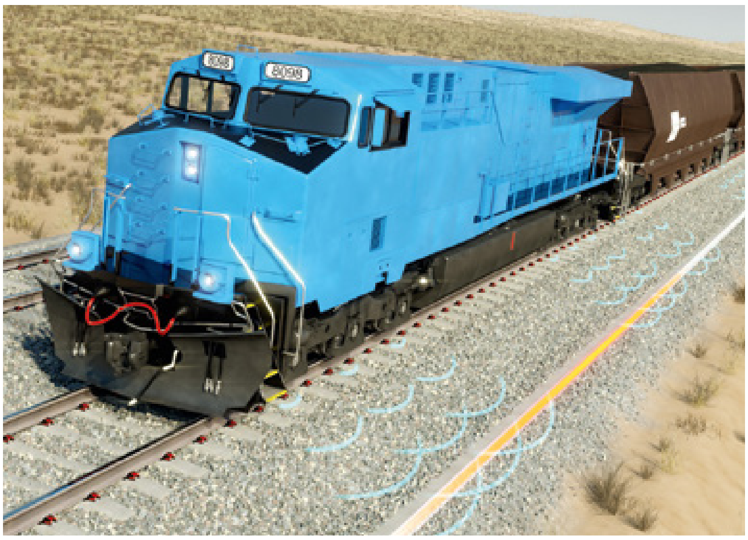
- Ground penetrating radar





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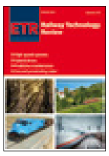

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An eventful autumn for the railway industry

An Austrian perspective with a focus on the fourth railway package, the current EU Council presidency, and Horizon Europe

Following a climatically hot summer, the Austrian railway industry is facing a politically eventful autumn. The current EU Council presidency gives Austria the opportunity to set priorities in the important issues of the EU budget negotiations; the design of the ninth research programme, Horizon Europe; and the fourth railway package.

The mobility of the future faces great challenges, and in view of growing infrastructures, this means a comprehensive digitalisation process. For the railway industry, digitalisation stands for the development of new applications, greater power, improved capacities, the renewal of infrastructures – and the hope for a faster introduction of new systems.

As innovative as our industry itself is, experience shows how sluggish Europe-wide approval processes for new systems can be. With respect to the changes we are facing, we place great hopes in the implementation of the fourth railway package, which is to come into force by June 2019.

The Austrian EU Council presidency plays a key role in joining with the European Union Agency for Railways to push forward rapid implementation of the package's technical pillars. The technical pillars of the fourth railway package are to create savings in time and expense during approval processes, including certification of technical and safety standards for operators and manufacturers of railway vehicles. For the railway industry, there is now finally to be an approval for all of Europe. The content of the technical pillars is currently being prepared in cooperation with the European Commission, the ERA, the national safety authorities, and other interest groups in the train industry. We expect to receive more information about progress in the implementation of the technical pillars from the EU Transport Council in Graz at the end of October 2018.

For the railway industry, there is now to be an approval for all of Europe.

The EU Council presidency holds many opportunities for the railway industry – from target research funding to implementation of the fourth railway package.

Austrian EU Council presidency: promoting sustainable, fair, competitive, safe transport systems


photo: Christian Husar

In the area of transport, the Austrian Council presidency's programme focuses on promoting sustainable, fair, competitive, safe transport systems. From the perspective of the Austrian railway industry, priority should be given to expanding the railways and especially to establishing a sufficient budget for European transport projects, securing the Connecting Europe Facility (CEF) 2.0, and more efficient planning phases.

Special focus is also on the design of the ninth research programme, Horizon Europe, much of which will fall within the Austrian EU Council presidency. From 2021 to 2027, around 100 billion euros are to be invested in research and development. From industry's point of view, Horizon Europe needs a substantial budget increase and a strong focus on key technologies to set a clear course. The railway industry also wants a focus on railway networks as part of the solution to societal problems and expanded options for financing projects via public-private partnerships (PPP) to be at the top of the agenda.

We are looking forward to this eventful autumn!

Dipl.-Ing. Dr. Angela Berger
Managing Director,
Austrian Association of the Railway Industry

The next mobility revolution

Every day, the German railway industry produces a little bit of a better future. Rail 4.0 – the digital mobility revolution – is shifting the limits of what is technically doable. Innovations from the railway industry's creative workshops are creating better climate protection and customer quality all over the world. Our mission: to join with partners around the globe to implement the best mobility there has ever been. The showcase for sustainable mobility will be in Berlin in the next few days: InnoTrans 2018. That is where the fascinating new inventions for railway traffic will be tangible. In the halls, the outdoor areas, and the conferences, InnoTrans is both a forum for and driver of digital rail.

Our mission: To join with partners around the globe to implement the best mobility there has ever been.

What if mobility were no longer a part of the climate problem due to high greenhouse gas emissions, but part of the solution? The Paris climate goals must be binding, and digital rail puts the vision of zero emissions within reach. For instance, state-of-the-art autonomous driving provides up to 30% greater energy efficiency. And emission-free electromobility will be available in future even without an overhead line – with innovative battery-driven, hydrogen, and hybrid solutions made in Germany. Electrification and ever-greater efficiency is also advancing.

And what if mobility in growing metropolises were no longer a load test with health-threatening emissions, but available around the world emissions-free for local inhabitants, safe, and always available? – Digital networking optimises urban traffic, and automated subways mean that, even at rush hour, there are no waits and no overflowing metros. This means better quality of life. Incidentally, a trendy, virtually developed design can contribute. Taking the train makes sense – and is fun.

What if high-speed cross-border connections that are always on time and reliable replace international flights? – ETCS, the digital control system, creates a more flexible, precise system. That is the condition sine qua non for digital rail. Between Berlin and Munich, Barcelona and Madrid, the train is becoming the vehicle of choice for more and more customers. Intermodally linked, data-based railway logistics – with load monitoring, precise geolocation, and innovative noise protection – can also win them over. Predictive maintenance is the hidden champion in digital rail, since it corrects faults before they even occur.

The mobility of the future has begun. Sustainable, emission-free, economical, extremely safe, and quiet. Of course, the foundation must be in order – cybersecurity. And the framework, too – free trade, open markets. But when the two mesh, the next mobility revolution can proceed. Our goal? – Progress. For people.

Dr. Ben Möbius
Managing Director
German Railway Industry Association (VDB)

High-speed systems: Four railways in Europe

High-speed railway systems are growing by leaps and bounds in Europe, as is the travel demand for these trains. In this article, we will focus primarily on four European countries whose railways operate high-speed rail.

Prof. Dr.-Ing. Eberhard Jänsch
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▶ The expansion of high-speed train systems is something that takes several decades in fragmented Europe – quite unlike developments in China. Framework conditions are different for each European country and solutions are customised as well. In the wake of the EU Directive on the Interoperability of the Railway System in the Community, structural subsystems of the railway system in Europe are subject to common regulations that are anchored in the "Technical Specifications for Interoperability" (TSI). This process is also taking decades. Below is an overview of the current performance figures, followed by a closer look at elements of Europe's four largest high-speed systems.

1. AN EUROPEAN OVERVIEW

Since the very beginning, the International Union of Railways (UIC) has followed the traces of high-speed lines in Europe (Fig. 1). The UIC's traffic statistics show the passenger kilometres (Pkm) travelled per year in high-speed trains (Fig. 2). France leads the way with its long lines and many high-speed trains. The way these statistics are defined means that they do not include Pkm data from conventional long-distance trains such as IC and EC trains, even if such trains travel partially along high-speed lines.

A cumulative representation of the growth of high-speed rail lines in Europe is shown in Fig. 3. Spain has overtaken France.

FIG. 1: High-speed lines in Europe (Source: UIC, updated)

2. FRANCE

High-speed rail in Europe began with the commissioning of the first section of the new Paris – Lyon line in September 1981. Since then, the network has been continuously expanded, with nearly all new lines originating in Paris (the exceptions being the eastern/southern Paris bypass route and the Rhine-Rhone line). There are 12 million people living in Paris and its greater area, the Ile-de-France (1000 inhabitants/km²), 18 % of the French population. The rest of the country is sparsely populated (103 inhabitants/km²), and the nearest metropolises are far from the capital (Tours, Le Mans and Lille about 200 km distant, Lyon and Strasbourg more than 400 km). Short non-stop travel times are therefore the right answer by the French state railway, SCNF, to transport needs. The average inhabitant of France travels 860 Pkm/year in high-speed trains (statistics from 2016). That is three times the mean common average for Germany, Spain, and Italy.

After the complete commissioning of the 472-km Paris – Strasbourg eastern line in July 2016, which the fastest train, at 320 km/h, can travel in 1 hour 46 minutes (mean travel speed 267 km/h), the two new lines to

Rennes and Bordeaux were opened in July 2017. The new lines bypass the cities of Le Mans and Tours, although branches connect them to the existing main train stations there (Fig. 4).

This network scheme has been the basis of new French lines from the very beginning. What is new is the Tours-Bordeaux financing via a private-public partnership (PPP model). The building consortia financed line construction and maintenance; they receive leasing fees during a 50-year contract period from the SNCF. The building programme for further TGV lines was deferred temporarily in the spring of 2018 for financial reasons. The French railway network is electrified with 25 kV/50 Hz to the north and east of Paris, but with 1500 V direct current to the south. The TGV high-speed trains were therefore designed from the very beginning as two-system trains, with a few three-system trains. The new lines to the southeast and southwest are thus isolated in their 1500 V surroundings. Mixed operations with conventional trains, common on new and upgraded German lines, were never intended in France. The first TGVs (Trains á Grande Vitesse) were the TGV-PSE (Paris Southeast) trains. They were powered by direct-current (DC) engines, and their successors were given three-phase AC motors. Their appearance has changed several times.

In 2013, the new brand "OuiGo" appeared on the scene, double-decker TGVs painted in blue with a greater number of seats, providing an economical alternative and marketed especially to a younger clientèle. Since July 2017, newly-built TGV trains are labelled as "InOui" trains – French for advanced learners (Fig. 5).

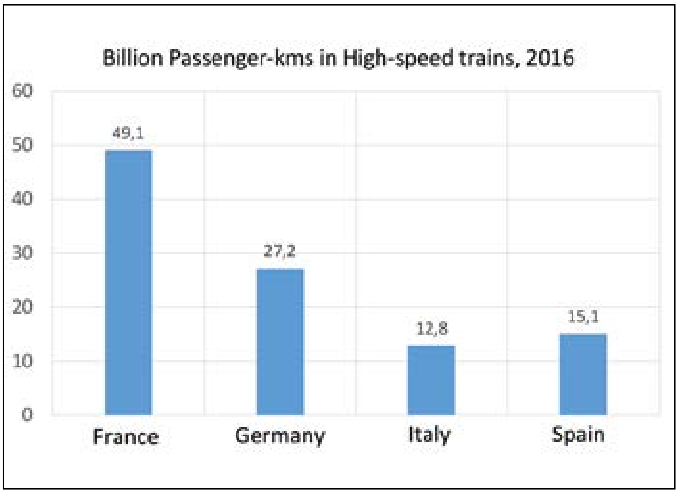

FIG. 2: High-speed rail transport performance, Europe, 2016

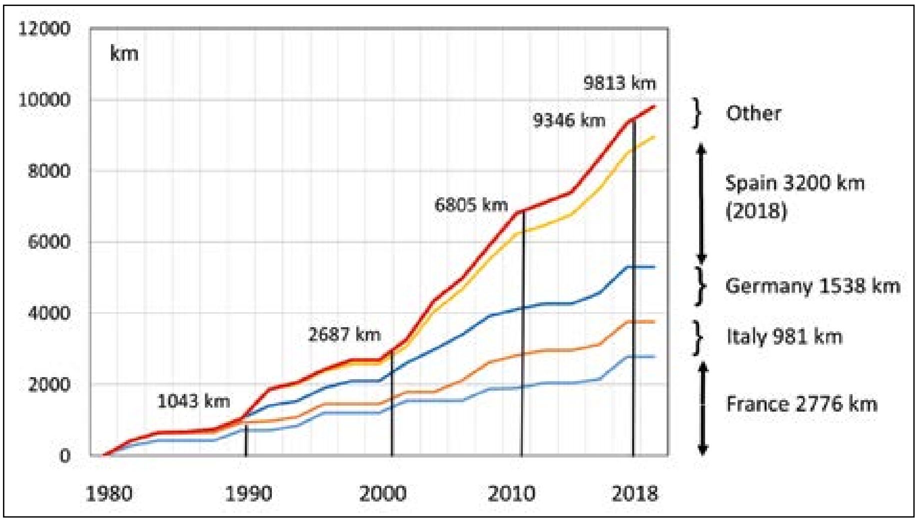

FIG. 3: Development of high-speed railway lines (V > 200 km/h) in Europe

3. SPAIN

As in France, Spain's high-speed network is fundamentally focused on the capital. Relative to its land area, Spain has very few people. Twenty years ago, Spain had 37 million inhabitants; current figures show 47 million, or 92 inhabitants/km². Major cities like Barcelona, Valencia and Málaga are far away on the coast, and the area in between is almost empty (about 30 inhabitants/km²). The railways' high-speed offerings are still focused on reduc- »

TGV traffic sees twice as many Pkm/year as Germany's ICE system.

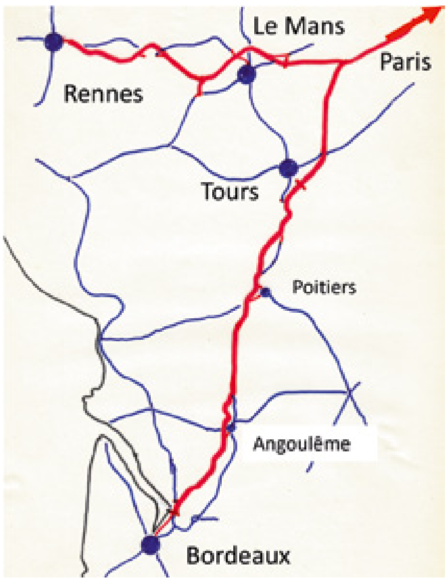

FIG. 4: TGV lines to Rennes and Bordeaux

FIG. 5: Surely a TGV, but not an "OuiGo". This is an "InOui"

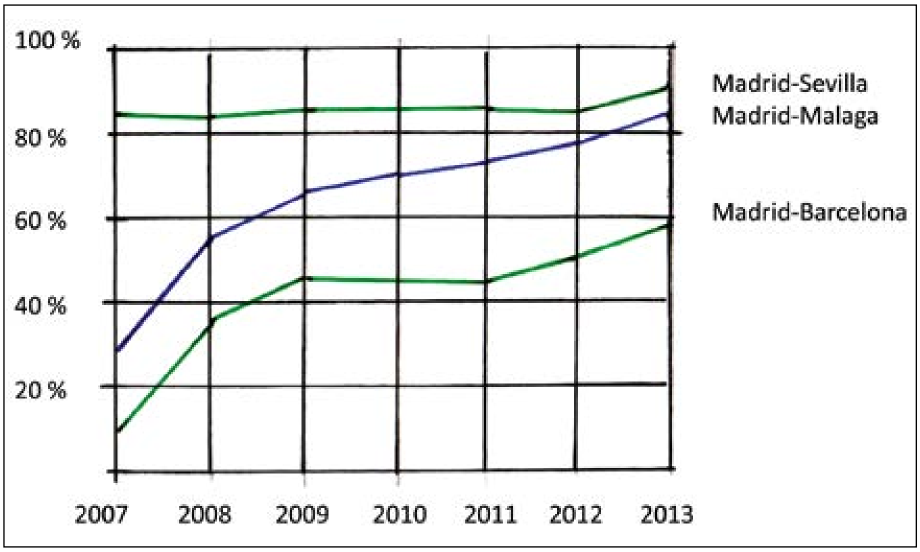

FIG. 6: Modal split in Spain. Bottom: railways (AVE), top: air traffic
Source: Molina, UIC HS symposium, Tokyo 2015

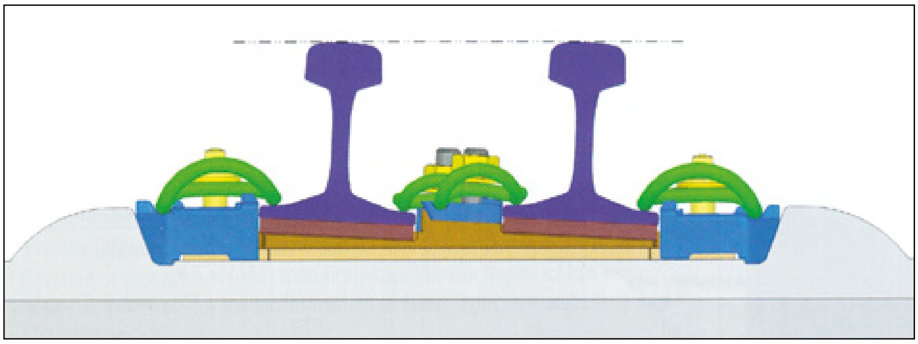

FIG. 7: Elastic support for a three-rail track (Source: Vossloh)

ing domestic air traffic. As expected, the dual modal split has changed in favour of the "Alta Velocidad Española" (AVE) system with each new high-speed line (Fig. 6).

The first line (Madrid-Seville) started high-speed train services in Spain in April 1992. A lot of German technology was used along the 471 km line, including DB's cab signalling with continuous automatic train control (called LZB) and high-speed switches from BWG/Germany. DE-Consult (now: DB Engineering & Consulting) provided advice during line design and supervised line construction. The line construction programme progressed continuously. Today, Spain's high-speed rail network is the longest of all railways in Europe, and by 2022, it is expected to grow to 3842 km. A relatively new member of the European Union (EU) in the border state area, Spain benefits particularly greatly from the various EC financing instruments.

European champion in high-speed rail network expansion – Brussels helps with the financing.

Its settlement structure makes construction planning outside of cities very smooth. The geology (soft rock, mostly light lime-bound conglomerates) allows quick, uncomplicated construction of cuttings, embankments and tunnels. For historical reasons, the railway network in Spain uses two track gauges: Iberian gauge (1668 mm) and metre gauge (1000 mm, primarily in the Basque region, where Euskotren uses it). The Directive on the Interoperability of the Railway System in the Community brought the normal gauge system with its third track gauge of 1435 mm to the Iberian Peninsula. The EU initially saw this as a condition for interoperability without which financial subsidies from common EU funds for high-speed rail could not be expected. Spain quickly backed off from its original intention of converting the gauge of its entire network. Today, normal gauge is generally used on high-speed lines, and in some peripheral areas of the network, there are three-rail tracks (Fig. 7).

Since December 2013, the high-speed network in Spain has been connected to the French network via the Barcelona – Figueres – Perpignan line. The parameters of a large part of the high-speed rail lines make them suitable for freight traffic as well. The first AVE trains were TGV trains from Alstom that were used on the new Madrid – Seville line. The state railway company, Renfe, ordered ICE 3 derivates (Velaro E) from Siemens for Madrid – Barcelona. Collaboration with Bombardier gave rise to Talgo trains in Spain. The fastest version is approved for 350 km/h (Fig. 8).

Trains of the Talgo 250 model with track gauge-changing ability and multiple-unit trains from Alstom/CAF were used. After undergoing a gauge-changing procedure from normal gauge, these trains operate on the broad-gauge network. This procedure is on its third generation, and gauge changes currently take no more than five minutes. They must also change from alternating current of 25 kV/50 Hz in the normal gauge system to direct current of 3000 V in the broad-gauge network. A large part of the old network has no overhead line. The hybrid Talgo 250H, which carries two additional generator cars, allows AVE operation all along the lines as e.g. to Santiago de Compostela.

FIG. 8: Talgo 350

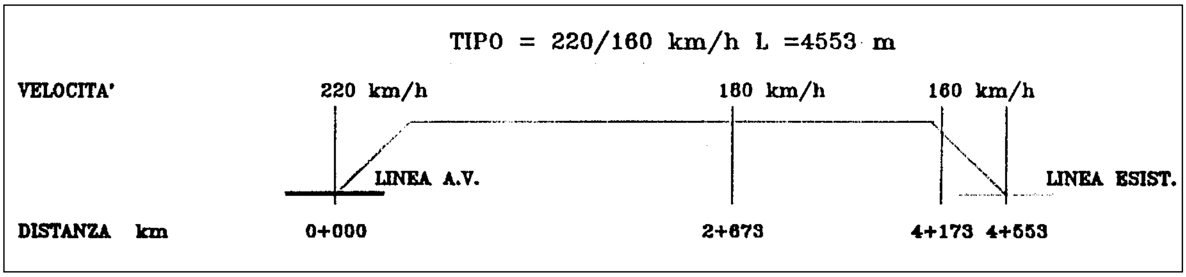

FIG. 9: Speed for the transition between a high-speed railway line (left hand) and a conventional line (right hand)

(Graphic: Italferr-Sis.t.a.f.)

4. ITALY

In Italy, high-speed rail began with incremental commissioning of the so-called Direttissima (Florence – Rome). Construction began in 1970 and was completed in 1992. At 248 km, it is considerably shorter than the old line (314 km), which had arisen between 1866 and 1874 from a combination of local railway lines and in no way met the standards of modern passenger and freight traffic. The Direttissima was therefore constructed and operated as a mixed-traffic-operations line, allowing 250 km/h and using the normal Italian electric system of 3000 V direct current. Because of the dense high-speed traffic that has come to use the lines, freight trains can use the Direttissima only at night.

All cities between the end stations are bypassed, although transition points to the old lines ensure that they continue to operate.

This principle was followed for all subsequent high-speed lines. On the newly built connecting tracks, the routing speed from the branch systems (220 km/h) to the old lines is reduced incrementally, which requires a great deal of length (Fig. 9).

In addition to the Italian high-speed rail network (currently 981 km), there are a total of 77 km of connecting lines (Interconnessioni) that are not included in the UIC statistics. We will focus on the tunnels, using the example of the 300 km/h Bologna-Florence line, of which 73 km is in tunnels. The newly constructed section begins 5 km beyond the Bologna main station, which has been replaced by a new underground station, and ends after 77 km in Sesto Fiorentino, 6 km from Firenze Santa Maria Novela. The tunnels have a free cross section of 82 m^2 and are equipped with niches, as are all Italian tunnels of new construction (Fig. 10).

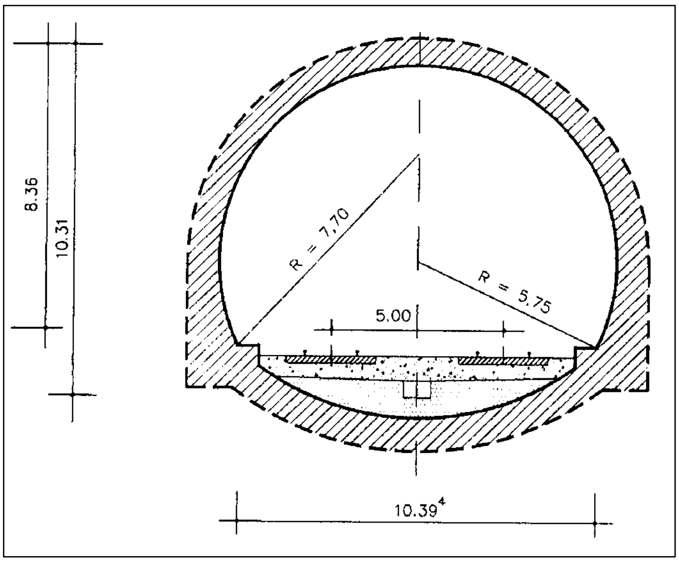

FIG.10: Cross section of the new line tunnels (Bologna-Florence, among others)

(Graphic: ItalferrSis.t.a.f.)

New line linked closely to the conventional network.

An in-house risk assessment was performed to ensure tunnel safety. The concept is based on special safety areas that are arranged at intervals of about 4 km. The intermediate access points created during tunnel construction are used as emergency exits (Fig. 11). The operations control system (ETCS Level 2), together with the train control system, is to ensure that, if there is an incident, trains stop only in the "safe areas". The new line is electrified with 2 x 25 kV/50 Hz. The system change is made near Florence at Sesto Fiorino, the beginning of the newly constructed section. The approach to the Florence SMN terminus station is made with a 3000 V overhead line. A new underground through station in Florence is still in the planning stages.

5. GERMANY

5.1. TRAFFIC AND NETWORK DEVELOPMENT

High-speed rail traffic in Germany is growing slowly, but generally steadily (Fig. 12). DB AG statistics show the registered Pkms in ICE trains. They agree with the UIC statistics, »

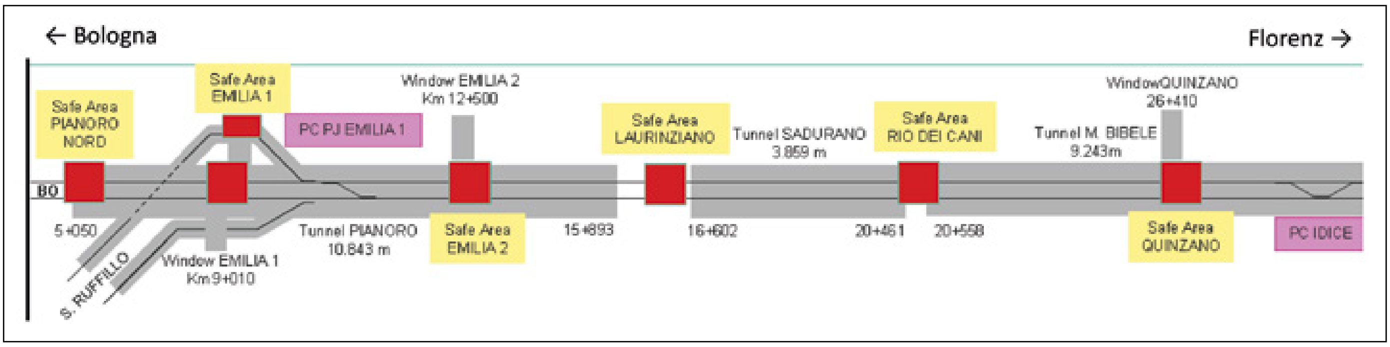

FIG. 11: Safety areas in the Bologna – Florence tunnel (detail)

Graphic: Senesi, UIC Highspeed symposium, Tokyo 1015

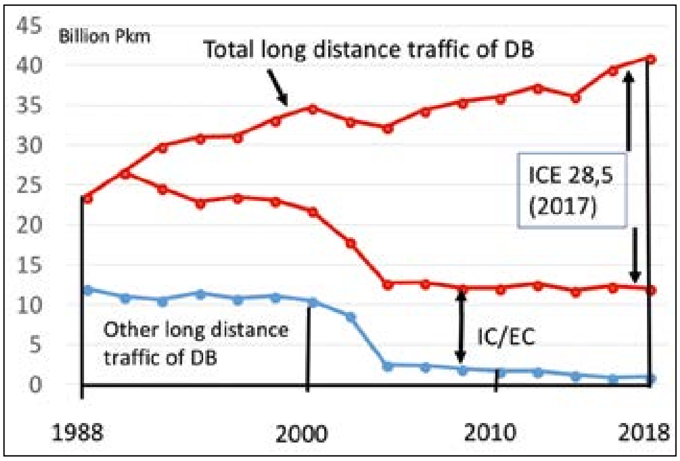

FIG. 12: Transport performance in DB long-distance passenger services

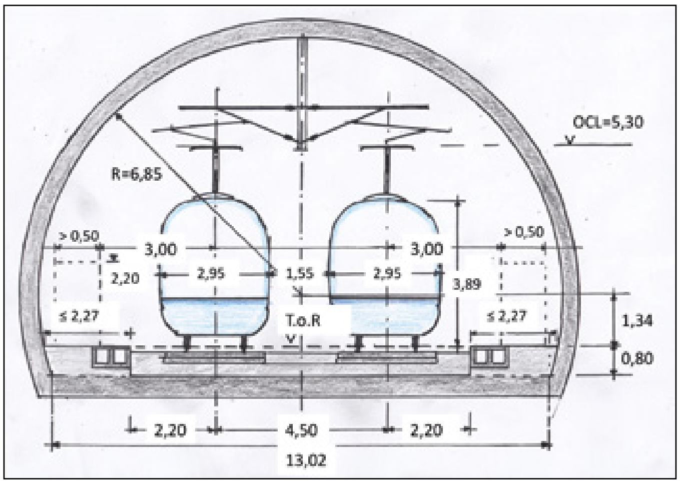

FIG. 13: Standard cross section of the two-track tunnel for the new DB lines, 92 m², 300 km/h

which list all Pkms in high-speed trains, no matter where these trains travel. In Germany, the ICE network consists of a mix of new lines (up to 300 km/h), upgraded lines (up to 230 km/h), and old lines (up to 160 km/h). The length of the lines and line sections with V > 200 km/h is currently 1538 km; a further 977 km on the upgraded lines allow speeds of 200 km/h. Given the size of the population living there, new high-speed rail in Germany is quite modest. There are just 19 km of new high-speed rail line per million inhabitants. In comparison, there are twice as many new high-speed rail kilometres per inhabitants in France, and three and a half times as many in Spain. This also helps to explain why the French and Spanish are so proud of their high-speed railway networks – new lines and high-speed trains are a sign of national achievement that is visible to everyone.

5.2. CHANGING TECHNICAL SPECIFICATIONS

The recently commissioned second section of the new line (Nuremberg – Ebensfeld – Erfurt – Halle/Leipzig) is an example of how technical requirements can change even during the planning and construction periods. Pre-planning began shortly after German reunification and is based on DB's July 1991 version of the "New line" DS 800.02 guidelines, which now takes V = 300 km/h into account. For traffic reasons, the line is intended for mixed-traffic operations with passenger and freight trains. In the Bavarian section of the line, a track spacing of 4.70 m was used (based on the "expanded standard clearance gauge" – (Erweiterter Lichtraum, or ERL). DB abandoned this clearance gauge one year after commissioning the new Hannover – Würzburg line (1991) because no-one used it. In the sections of the new line that are further north, the track spacing was reduced to 4.50, in line with the subsequently updated guidelines and TSI Infrastructure.

Two-track tunnels – recognised as state-of-the art at the time – were used (Fig. 13) in the Ebensfeld – Erfurt section like the new Ingolstadt – Munich section.

On 1 July 1997, the German Federal Railway Authority (Eisenbahn-Bundesamt, or EBA) issued guidelines entitled "Fire and disaster protection requirements for the construction and operation of railway tunnels". These guidelines stipulated construction of two single-track tunnels with cross passages for mixed operations with passenger and freight trains in long tunnels. The two-track tunnels in the Ebensfeld – Erfurt section were grandfathered, but the EBA required a safe operational solution that would rule out simultaneous use of the tunnel by freight and passenger trains. That is why only twin-tube tunnels were built in the Erfurt – Halle/Leipzig section (Fig. 14). They are significantly more expensive than two-track tunnels. Tunnel equipment, including emergency lighting, escape routes, etc., is detailed in the TSI entitled "Safety in train tunnels", which came into force on 1/1/2015.

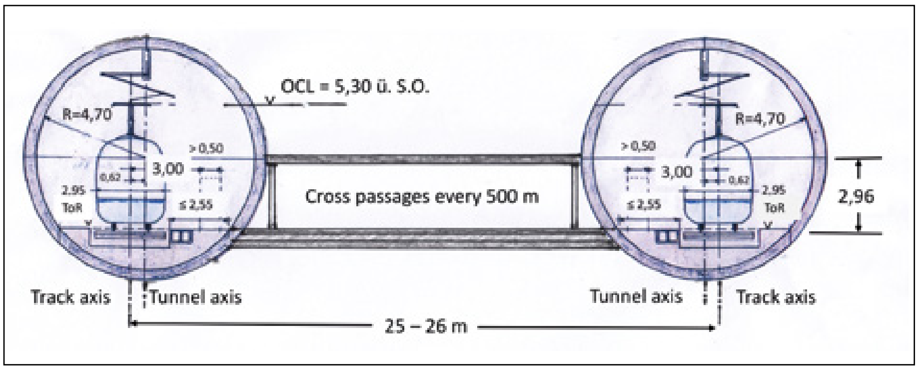

FIG. 14: Standard cross section of the twin-tube tunnel for the new DB lines, 2 x 60 m², 300 km/h

5.3. PROTRACTED LARGE PROJECTS

In Germany, the time between preliminary evaluation and commissioning in a large railway project is very long. The overall Nuremberg – Leipzig line was commissioned in December 2017, 27 years after its preliminary evaluation. In comparison, the new Cologne – Rhine/Main line was conceptually designed in the 1970 DB expansion programme as a new Cologne – Groß-Gerau line, but the large-scale alignment variant (via Koblenz or another station?) and the technology remained under discussion for a long time. In 1989, the German federal government decided on the alignment variant. 31 years passed between its initial conceptual design in 1971 and its commissioning in 2002. The Hannover – Würzburg line was part of the 1970 expansion programme as a new Hannover – Gemünden line. The preliminary evaluation began in 1971. The decision for the Hannover – Göttingen – Kassel alignment variant (put forward by the federal state of Lower Saxony) did not come until 1976. 20 years passed between the preliminary evaluation and the completion of its entire length in 1991. The Hannover – Berlin high-speed railway line moved quickly: DB/DR exploration in 1988, ministry agreements between the Federal Republic of Germany and the German Democratic Republic in June 1990, commissioning in 1998 – just ten years after the preliminary evaluation began.

At present, DB constructs the Stuttgart to Ulm dedicated passenger line and new tracks in the Rhine corridor between Karlsruhe and Basel, where some newly-built sections are still put into operation. Some more projects in Germany are in the pipeline, as a link from Frankfurt to the HS line's section Würzburg-Fulda for creating more capacity and shortening journey time between Frankfurt and Berlin. In 2017, DB Netz AG presented its "Network conception 2030". Besides providing more freight traffic capacity along two north-south axes (the Rhine Corridor and the East Corridor via Halle), several improvements for passenger traffic are provided for. Among them are the modification of several major nodes in which passenger and freight traffic must share tracks. The long planning and constructions times are to be shortened to about 15 years by means of citizen participation, building information modelling (BIM) and simplification of plan approval procedures.

Expanding the high-speed rail network – a matter of decades.

FIG. 15: DB AG's ICE 4 on a new line

5.4. NEW TRAINS

Older models of high-speed trains, especially the ICE 1, are now being gradually replaced by ICE 4 (Fig. 15). They are multiple-unit trains for 250 km/h with distributed drives. The ICE 4 cars are longer and narrower than the previous ones; however, DB AG promises more comfort in the trains, and advanced interior fittings are to contribute. ◀

Quiet, clean, fast: use of MTU hybrid drives on the Lake Constance belt railway

MTU Hybrid PowerPacks combine the advantages of diesel and battery-powered rail traction. They can be installed in new or existing rolling stock without the need for additional changes to operations, infrastructures or time schedules. Even on non-electrified routes, they allow quieter, cleaner, faster and more cost-efficient rail travel. The use of hybrid drives on the Lake Constance belt railway could signify a breakthrough for this innovative technology.

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PREFACE

The Lake Constance belt railway (in German: Bodenseegürtelbahn) is the only rail link between the east and west of the lake. The line is used not only for regional services, but also for the international Ulm – Basel connection, and in Friedrichshafen it links with the Württemberg Southern Railway (Südbahn) towards Ulm. Electrification of the Südbahn is already in progress and scheduled for completion by 2023.

Electrification of the Lake Constance belt railway, however, has been a subject of constant debate for some years now. Since electrification has not been taken into account in the Federal Transport Infrastructure Plan for the period up to 2030, financing and realization are still open to question. The undertaking would also bring certain challenges in the light of, for example, two low tunnels in the town of Überlingen. The financial expenditure necessary to deal with them has not yet been calculated. Furthermore, the erection of overhead lines in such close proximity to the shore of Lake Constance would drastically alter the rural landscape and the touristic character of the location. The project is therefore meeting with resistance from some local residents and communities.

As an interim solution for improving service on the belt railway, MTU Friedrichshafen, in discussion with the Lake Constance Railway interest group, has proposed the fitting of hybrid drives to the existing fleet in regional and long-distance service. Diesel-based hybrids such as the MTU Hybrid PowerPack offer the advantages of both diesel and battery-driven rail travel and are quieter, cleaner, faster and more cost-efficient than the straightforward diesel drives currently in use. An electric drive, for example, enables very low-noise, emissions-free operation in urban areas and around stations. Nitrogen oxide (NO_x) and particulate emissions fall impressively by comparison with conventional fleet, and improved acceleration capabilities allow the planning of more stops and render the service less prone to delays. Fuel consumption and in turn carbon emissions likewise fall by up to 25 %. All these benefits are available without the need to change existing infrastructures.

FIGURE 1: An IRE train with tilting technology on the Lake Constance belt railway

MTU's Hybrid PowerPack is evolved from its conventional rail PowerPack. PowerPacks are compact drive systems with diesel engine, transmission, cooling system and automation unit integrated on one base frame. In the hybrid version of the PowerPack, the drive is enhanced by an electric motor, frequency convertor, intermediate circuit, on-board convertor, and battery for storing energy harnessed during wear-free electrodynamic braking. This technology was already presented by MTU in a previous article published in this journal [1].

Specific application of this concept on the Lake Constance belt railway has been examined in simulations and verifications carried out by MTU on its own systems test stand. The subject of the study was the IRE service between Friedrichshafen and Singen.

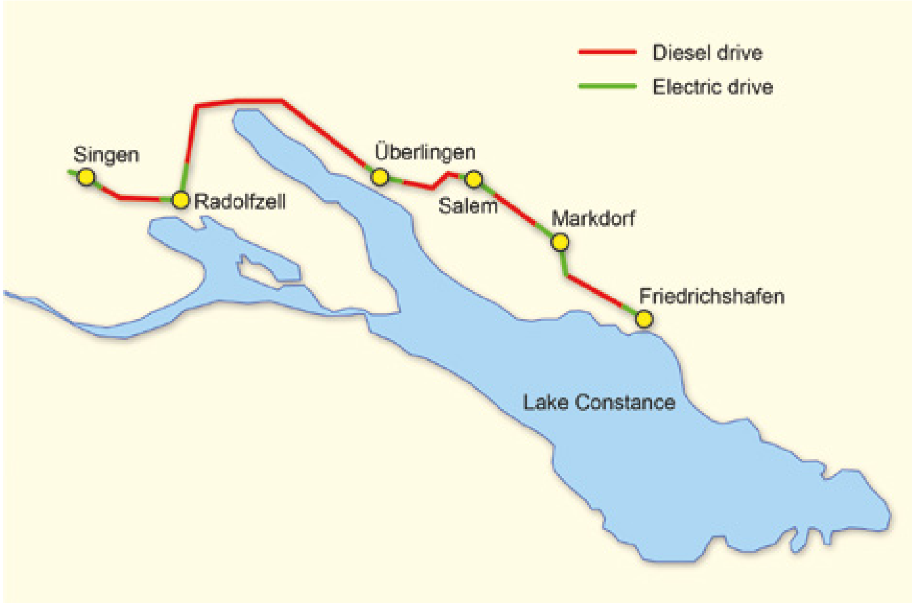

FIGURE 2: Deployment of a VT 612 Hybrid on the Lake Constance belt railway with electric-only phases

TEST STAND SIMULATION AND VERIFICATION

MTU Friedrichshafen is unique in its ability to simulate a complete vehicle drive such as the Hybrid PowerPack on a selected route and make reliable predictions on operation and fuel consumption. Furthermore, the company has a state-of-the-art Hardware-in-the-Loop (HiL) test stand that enables travel of the rail vehicle over the route to be simulated according to a given time schedule. In this set-up, the real drive is incorporated into a virtual rail vehicle and subject to real conditions and loads. Parameters such as fuel consumption, drive dynamics and battery loads can be measured in the HiL set-up and compared with the previous computer-generated simulation results. In this way, MTU is able to verify its fuel-saving predictions and continually optimize its simulation tools.

SIMULATION IRE FRIEDRICHSHAFEN – SINGEN

Simulation of conditions on the Interregio service was carried out using the technical data from an existing Bombardier VT 612 DMU that is used on the Lake Constance belt railway. The special feature of this train is its tilting capability, which allows it to negotiate curving track at speed. Two vehicle configurations were simulated: an existing VT 612 and a virtual VT 612 repowered with an MTU Hybrid PowerPack.

Two scenarios were considered in the test: In the first, the VT 612 Hybrid rail vehicle and the existing rail vehicle were run as per the current timetable (status 26.01.2018) and compared in order to draw conclusions about time schedule feasibility and fuel consumption. The second scenario looked at the feasibility of introducing a new time schedule with additional stops. The new time schedule was taken from a study carried out by SMA & Partner AG [2], whom the Lake Constance Railway interest group had engaged in 2013 to examine different timetable concepts, also taking into account possible electrification of the line. The study showed that operation of an hourly IRE service on the Lake Constance belt railway with additional stops in Markdorf and Salem could be recommended.

In both scenarios, electric-only mode for low-noise, emissions-free rail travel was taken into account around planned stops. Route sections travelled in electric-only mode are shown in Figure 2.

To determine fuel consumption, the State of Charge (SOC) of the battery was taken into account in the energy balance. SOC at the end of the journey must correspond to SOC at the beginning. If despite smart energy management and re-charging where appropriate en route the end SOC was not absolutely equal to the initial SOC, the battery was re-charged up to the required level using the diesel engine. The fuel required to do so was also taken into account in overall fuel consumption.

The aim of the simulation was to directly compare the VT 612 with the VT 612 Hybrid on the Friedrichshafen – Singen service of the Lake Constance belt railway based on the current time schedule (Scenario 1), and to determine the feasibility of the new timetable with additional stops in Markdorf and Salem as per the study made by SMA & Partner AG (Scenario 2). A statement on fuel consumption was also to be made. It is emphasized again that the hybrid train switched to electric-only mode around stations and in urban areas, as shown in Figure 2. Phases of »

	Scenario	Driving time [min] Friedrichshafen → Singen	Fuel consumption [%]	Remarks
Existing VT 612	1	46:04	100	
VT 612 Hybrid	1	46:00	84,3	With electric-only drive phases
VT 612 Hybrid	2	56:00	79,4	With electric-only phases Additional stop in Markdorf + Salem

FIGURE 3: Simulation of IRE service on the Lake Constance belt railway

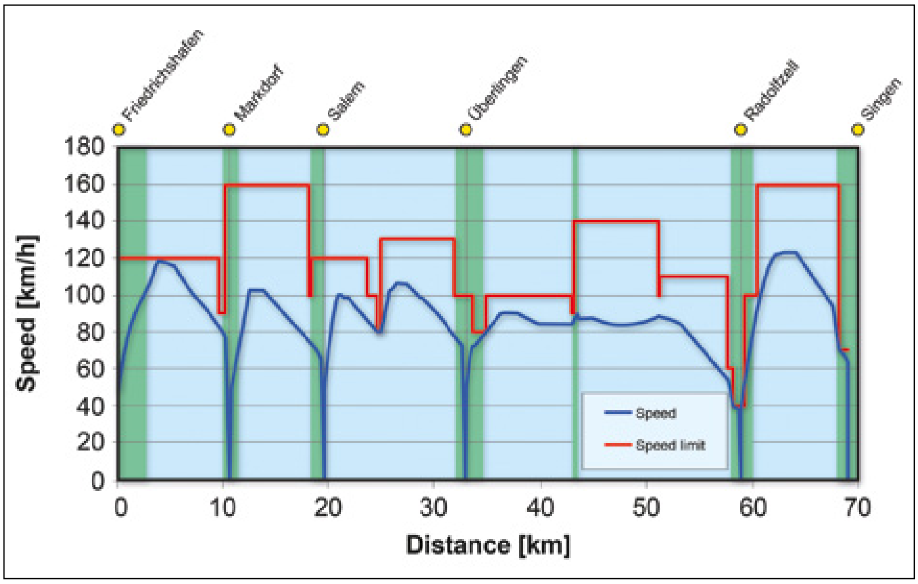

FIGURE 4: Simulation results for IRE service using VT 612 Hybrid; Scenario 2

travel in electric-only mode caused a slight reduction in the fuel saving possible in relation to the existing rail vehicle. However, this is seen as a justified compromise in view of the benefits of phases of emissions-free, quieter travel.

The results for both scenarios are shown in Figure 3.

The simulation results for Scenario 1 show that with a hybrid rail vehicle a fuel saving of 15.7 % in relation to the existing VT 612 vehicle can be achieved, including phases in electric-only mode. The travel time in this case is 46:00 min. The fuel saving can be principally attributed to regenerative braking. The energy thereby harnessed is used entirely for travel in electric-only mode. The results for Scenario 2 show a fuel saving of 20.6% in relation to the existing rail vehicle from Scenario 1. The time scheduled for Scenario 2 is 56:00 min. So with the hybrid rail vehicle, the new Scenario 2 time schedule with additional stops in Salem and Markdorf can be realized with lower fuel consumption than for Scenario 1 and including electric-only mode around each stop.

Evaluation of the simulation results even shows that potential still exists for a further reduction in the travel time (Fig. 4). The blue line shows the vehicle speeds required for keeping to the time schedule. The red line shows the speed limit for taking curving track at speed. The route sections passed in electric-only mode are highlighted in green. The speeds necessary along the route for keeping to the timetable remain for the most part well below the maximum speed limits. This means that a reduction of the travel time is perfectly feasible, still leaving sufficient operational reserve.

The simulation results shown were verified on the Hardware-in-the-Loop (HiL) test stand and could be confirmed. Besides timekeeping, the most tangible improvements outside the vehicle are emissions-free travel and quieter operation around stations and in urban areas. Measurements at the test stand and on a demonstrator showed that vehicle noise in the vicinity of stations can be reduced by around 75 % (20 dB(A)). This improvement might even be perceived by passengers inside the vehicle.

Based on the simulation results, it is possible to calculate the annual savings in CO_2 (132 tonnes) and NO_x (1.05 tonnes) per vehicle based on 2,500 hours runtime per year. Extending this to the entire VT 612 fleet in service in Baden-Württemberg, which amounts to 41 vehicles, a total of 5,412 tonnes of CO_2 and 43 tonnes of NO_x could be saved per year. Rebuilding the rail vehicles with MTU Hybrid PowerPacks could therefore make a very significant contribution to air pollution control on Baden-Württemberg's railways.

REBUILDING THE VT 612 WITH A HYBRID DRIVE

The VT 612 is an ideal candidate for conversion to a hybrid drive. As a high-floor vehicle, it has more than enough space underfloor for housing all Hybrid PowerPack components. Since the Hybrid PowerPack's components are not heavier than the current drive system, it can be installed without any shift in the centre of gravity. The feasibility of the rebuild was also confirmed by DB Systemtechnik, the Deutsche Bahn subsidiary. Rebuilding tilting VT 612 railcars with hybrid drives would give them a new lease of life as fast, eco-friendly trains, and their tilting systems – to which they owe their faster travel times – would remain available in the future.

The rebuild concept proposed by MTU provides for installation of a Hybrid PowerPack in each car. The installation scope would comprise the following components:

→ Hybrid PowerPack (comprising diesel engine, electric motor, transmission, cooling system)
→ Batteries (3 MTU EnergyPacks with ca. 90 kWh capacity overall)
→ Water-based battery cooling

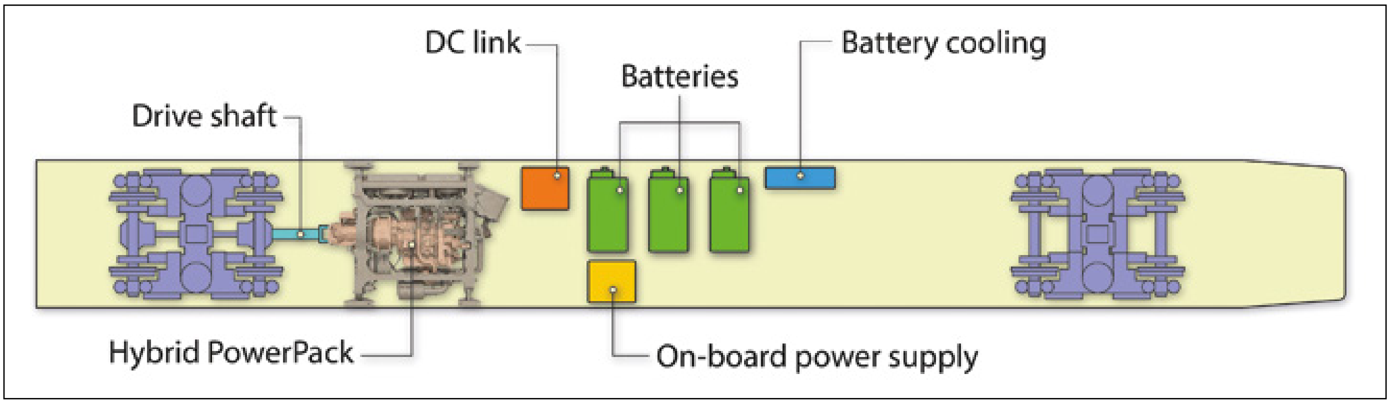

FIGURE 5: Rebuild concept for VT 612 Hybrid

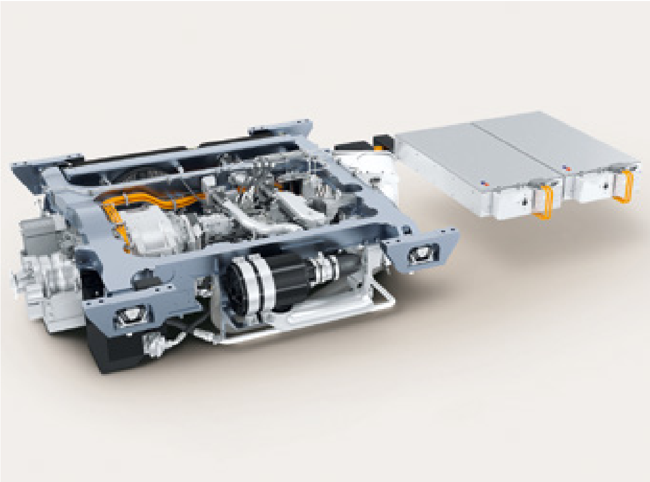

FIGURE 6: MTU Hybrid PowerPack

- → Intermediate DC circuit
- → Power electronics and filters for on-board power supply

The Hybrid PowerPack comprises an MTU 6H 1800 R85L diesel engine, an electric motor, and a ZF EcoWorld power-shift transmission with integrated reversing function. The diesel engine delivers 390 kW and the electric motor delivers 300 kW continuous power.

The Hybrid PowerPack is arranged as a parallel hybrid, with the electric motor sitting on the input side of the transmission upstream of the diesel engine. As a preference, the electric motors are configured for electro-dynamic braking in order to harness surplus energy for battery storage or on-board power.

SUMMARY

The simulations show that an MTU hybrid drive will have no difficulties meeting either the current time schedule in place on the Lake Constance belt railway service or that planned for the future. Rebuilding the rail vehicles with Hybrid PowerPacks would achieve significantly cleaner, quieter and more economical rail travel even without overhead electrification, and with no compromises with respect to travel times. The installation alone of state-of-the-art, EU Stage V-compliant diesel engines in the VT 612 railcars could reduce particulate and NO_x emissions by around 90%. The further benefits offered by a hybrid drive would profit the environment, passengers and operators alike. Electric-only mode in urban areas and around stations lowers the noise level by as much as 75 %. Regenerative braking considerably enhances the ecological soundness of operations while improving their cost-efficiency. In this way, up to 20 % fuel savings can be made.

All in all, deployment of Hybrid PowerPacks on the Lake Constance belt railway could herald a breakthrough for this innovative technology in Germany. ◀

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The treasure of the Data Lake – Predictive maintenance for vehicle fleets

Effective asset management of vehicle fleets in rail requires an efficient and comprehensive IT landscape as a basis. The core of an associated architectural concept is a data lake that collects and provides real-time diagnostic data gathered on the vehicles. It is the technical basis for the application of algorithms for condition-based maintenance of rail vehicle fleets.

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BASIC PRINCIPLES OF DATA LAKES

Data Lakes differ fundamentally from classic concepts of Business Intelligence, such as Data Warehouses, primarily by the type of data retained. In data warehouses, mainly transactional data is stored whose structure is defined upfront and which has already undergone pre-filtering before persistence. In a data lake, however, all data is persisted regardless of its structure or relevance for known use cases. Data Lakes have the following basic properties [2]:

- → Data Lakes collect and store data, regardless of type, format or data volume, while they are to be stored in a structured manner in classic data warehouses.
- → Data Lakes provide large amounts of data. Therefore, it is important to keep costs low while maintaining a high access rate. Since data stored in structured form in data warehouses must be immediately accessible at all times to enable fast access, high persistence costs are generated. Data Lakes, on the other hand, store raw data which, depending on the frequency of accesses, can also be stored with reduced access speed.
- → At Data Lakes, all data is stored centrally and heterogeneously at the same time. This means that data, which is very different from the format, can be linked together in analyses without having to request potentially different systems beforehand. Existing Application Programming Interfaces (APIs) provide a wide range of usable use cases. It is easy to add different tools to the data stream as services, for example, or to store intermediate results in the Data Lake for further use by other tools.
- → Data Lakes keep all relevant data central and unstructured, regardless of formatting. The analysis tools are always conceptually independent of the format and structure of the data. This allows new analyses or new data sets to be integrated easily and quickly.
- → In modern implementations of data lakes and the service landscapes required for this, the concept provides for the rapid interchangeability of tools and microservices. The user can test generally available tools with practically no initial effort and, if required, can transfer those to productive use in just a few steps.

FIGURE 1: Vehicle fleets in rail transport as an object of asset management

SERVICE-ORIENTED AND CLOUD-BASED ARCHITECTURE FOR DATA LAKES

Instead of using solutions based on individual or a few applications with a defined range of functions, Data Lakes reliy on solutions consisting of a flexible combination of different micro services around a central data store. The software architecture must be detached from classical patterns such as a layered hierarchy and the development must lead to a data- or data-flow-centered architecture. This makes it easy to add or replace services at any point and keeps the architecture flexible for future developments.

When using data lakes, primarily event-driven architectures are common. By con-

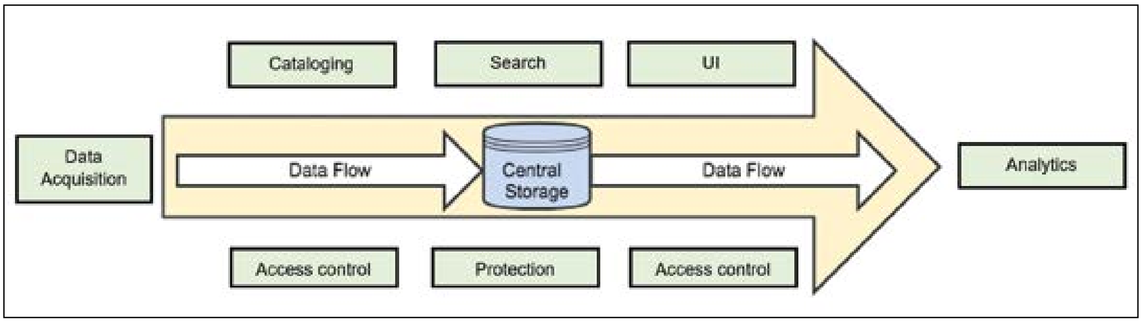

FIGURE 2: Overall concept of the data-driven architecture. The microservices are structured around the data stream

trolling the events based on the underlying data streams, this architecture can be called Data-Driven Architecture (cf.[5]). The software therefore builds itself around the data stream as shown in Fig. 1. The data stream therefore represents the basis for the achievement of objectives, whereby each individual problem can be regarded as an independent architecture. The desired objective is broken down top-down into required services and newly formed into a specific solution. Right from the start not only services for data manipulation are considered, but also accompanying services for areas such as logging and security.

The implementation of data lakes on company-owned hardware does no longer make sense for most projects from a financial point of view and therefore only makes sense for particularly critical applications (e.g. banks, medicine, military) if commercial cloud solutions with appropriate security options cannot be found or are not applicable for compliance reasons.

CHALLENGES AND SOLUTIONS OF CLOUD-BASED ARCHITECTURES

The use of services in a cloud creates new challenges that need to be addressed in advance:

Information security of the customer data available in the cloud is in most cases much higher in the Amazon Web Service (AWS) Cloud than on self-operated servers. The large number of system administrators deployed worldwide for the AWS Cloud, some of whom specialize in information security, provides significantly better information security than would be the case with conventional IT infrastructures operated by companies themselves.

Handling security vulnerabilities: Due to the high number of users in the global internet of things (IoT), security gaps that allow access to external data quickly become financially and legally problematic. The Linux base and the simple reporting of security problems allow newly discovered vulnerabilities to be resolved quickly and globally: The globally uniform system and the uniform administration of software components close security gaps within a few hours.

Protection against unauthorized access by third parties: Authentication measures serve to protect sensitive data against unauthorized read access (data theft) on the one hand and to protect data against unauthorized manipulation (data modification, computer sabotage) on the other. Authorization measures are aimed at ensuring that analysts and solution architects only have access to the data relevant to their projects. This is supported by the targeted allocation of authorisations to the respective architects. In addition, organization-related boundary conditions are contractually secured. One example of this are compliance guidelines, such as certification of cloud providers according to standards like DIN EN ISO/IEC 27001.

Software maintainability: The AWS basic system is stable against updates and changes without interfering with customer projects. Customer projects run in self-contained environments (sandbox). The provider of the cloud system has the freedom to use, exchange and extend any hardware components without expensive downtimes or waiting times for the user. Software updates and time-consuming hardware upgrades are obsolete for the user.

Legal framework: Sending data across national borders is often a legal hurdle that prohibits the use of cloud services. To counteract this, cloud providers have provided »

FIGURE 3: Using cloud solutions brings new challenges

for the possibility of binding to regions that ensure that data does not leave certain predefined regions.

Calculability of costs: An AWS solution is about 90 % cheaper than the operation of "classic" infrastructures. This value is also evident in one of our customer projects, where about 98 % of the costs were saved on the development system and the effective savings for the live system were interpolated to be at about 91 %. AWS provides a billing calculator that provides an estimate based on past months and previous monthly costs.

SAMPLE IMPLEMENTATION STEPS FOR AMAZON WEB SERVICES

As an example implementation of a data lake, the cloud environment AWS was used as described below. During implementation, four functionalities were clearly separated, which are described in more detail below:

- → Data acquisition including pre-processing (ingestion),
- → central data storage,
- → Cataloging of data
- → Preparation of concrete analyses

DATA ACQUISITION (DATA INPUT) FOR DISTRIBUTED DATA SOURCES

In order to be able to ingest sensor data from vehicle fleets, the receiving system must be able to accept and store a large number of distinct data from many sensors. On the sender's side, however, data must be collected, buffered and regularly transmitted to the Data Lake. To do this, a periodic Internet connection must be ensured. For the frequency of data transfer, an individual taring between the local data collection and the frequency of synchronization to the cloud must also be found. Data transfers at low bandwidth should preferably rely on the collection of several data sets and transfer with a stable connection. However, this requires more memory in the local device. With higher bandwidth and stable connections, the data can also be transferred more frequently. This, on the other hand, leads to an increased load on the receiver. A project-specific optimum must be found here.

Finally, it should be taken into account that the order of data sets should already be defined during ingestion, even if the structure does not have to be fixed from the outset. To simplify later evaluations considerably, data of the same type for which the uniformity is to be foreseen should be grouped logically. This unifies the data accesses of the evaluating processes and thus minimizes the effort.

From a specific project of a customer we know that the current data load of 67.54 MB/h will increase tenfold by 2020 due to an increase in the number of equipped vehicles and a simultaneous tripling of the number of sensors to approx. 2GB/h. The distribution of the fleets is Europe-wide with the focus on Central Europe.

CENTRAL DATA STORAGE

In order to efficiently persist the collected sensor data of vehicle fleets, the receiving system stores the data in a central location. In AWS, data is stored centrally in any size and in an automatically growing storage unit, a so-called bucket. The data is stored in objects, a logical data unit, comparable to files in a classic file system. To make searching through data easier, the objects are indexed based on their specific prefixes and optimized for fast access. Since the implementation is based on RESTful and therefore each data record transmitted by sensors sends a PUT request, a new object is created for each data record. This creates an immense number of objects in the long term. This is irrelevant in terms of costs and storage space. For an analysis based on large amounts of data with low reaction times, however, a cataloging of the data is still necessary.

CATALOGUING FOR VARIOUS APPLICATIONS

The flexible NoSQL database DynamoDB offers an optimal possibility to catalog data without having defined a schema and still get extremely fast access speeds. A DynamoDB table has a primary key, which consists of a partitioning key and an optional sort key. The partitioning key determines the automatic partitioning of the table and should therefore be very well selected (see [9]). An entry also supports update commands. DynamoDB offers a very flexible memory, which can be written and read in different ways.

New data arriving in Simple Storage Service (S3) can be automatically analyzed as a trigger for cataloging and added to corresponding catalogs. Since the analyses are usually very individual, a pipeline must be created so that the new data arriving in S3 can be processed. This can be achieved with minimal effort using the Microservice Lambda, which makes it possible to execute small programs in the AWS landscape without any further integration effort. Optional filters can be set for the triggers, so that different prefixes start different lambda functions.

- → Read: The respective lambda function receives the bucket and the object name of the newly arrived object and can examine this import and the content according to previously defined criteria and extract the corresponding values.
- → Write: This data can then be written to a DynamoDB table, regardless of whether the data record already exists, i.e. whether it has to be updated or whether it is a new data record.

This type of cataloging is the comparatively most complex, but at the same time, the flexibility exceeds that of other technologies by far. The cost factor is also considerably lower here. The costs for DynamoDB tables are calculated according to provisioned capacities for read and write accesses. This is understandable, as an increase in capacity in the background is a real hardware replication. This allows tables with costs of less than one euro per month for the minimum configuration and a separate table can be provided for each application case. The requests for large amounts of data via the primary key or only a part of it can be retrieved extremely quickly, whereby retrieval times in the low two-digit millisecond range are not uncommon.

PREPARATION OF CONCRETE ANALYSES

The creation of analyses on the catalogued data is possible without great effort with the basis shown. This is done in several consecutive steps:

- → *Top-down analysis* of the problem to be solved, as there are various microservices for a wide variety of applications. As a result, individual use cases can be assigned to the use cases.
- → *Selection of suitable microservices:* Depending on the target platform, the appropriate microservices can be selected. There are specific services that enable the further use of existing programs that work on relational databases, for example. Other microservices support machine learning or the visualization of complex interrelationships in informative dashboards.
- → *Bottom-up aggregation* of specifically configured microservices. For this purpose, services already configured for similar analyses can be reused, or additional instances with slightly modified configuration can be created.

SUMMARY & OUTLOOK

All in all, Data Lakes offer an optimal solution from the initial setup of a collection of raw data from various sources without large upfront effort or high costs to the data storage of many fleets of different vehicles worldwide and the provision of data catalogs for various analyses of various kinds. The collection of measurement data in persistent online data stores such as AWS buckets can be implemented within minutes and is operational from this point in time so that data can be collected and archived. Even if no specific use cases are known at the time of implementation, it is recommended to persist all data on low-cost cloud storage, so that it is already available for possible evaluations at later points in time. Since there is often no reason to process data without use cases, favorable options for persistence of the data can be used. To avoid vendor lock-in, consider designing Data Lake to be adaptable to alternative platforms. Alternative options for data storage include the storage services of Google Cloud Services or Microsoft Azure. Of course, the use of a second service also doubles the total costs. ◀

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Digital twin serving rail infrastructure

How turnkey rail infrastructure projects are benefiting from applying Building Information Modeling (BIM), how Siemens Mobility is pursuing virtual planning of projects with project partners and customers such as in the Riyadh Metro Project, and what added value this methodology is creating.

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ABOUT SIEMENS MOBILITY'S TURNKEY RAIL SOLUTIONS BUSINESS

Siemens AG is a global technology powerhouse that has stood for engineering excellence, innovation, quality, reliability and internationality for more than 170 years. The company is a pioneer in supplying infrastructure solutions. Siemens Mobility is an experienced provider of complete, turnkey solutions for rail systems, having already carried out more than 50 various and major rail projects worldwide. The organization is home to experts in project management and system integration as well as key products of rail infrastructure. These specialists develop and implement projects for all types of rail vehicle systems, from metros, trams and light rail vehicles and automated people-movers to Intercity and high-speed train units – all designed for maximum reliability, availability and efficiency.

THE CHALLENGES OF RAIL INFRASTRUCTURE PROJECTS

Projects to install new rail infrastructure and expand existing systems are growing steadily more complex. The rising number of project participants and stakeholders presenting a broad range of specific requirements, planning teams in different locations and time zones having to coordinate and integrate their civil and rail engineering and planning, and the ever increasing time and cost pressures exemplify this problematic complexity.

There are an enormous number of interfaces and requirements involved, especially in large rail infrastructure projects, and organizing them demands extensive resources and absolute precision.

AT THE VANGUARD OF DIGITAL PLANNING

Just as countless other sectors of the construction industry have already experienced, digitalization is driving a paradigm shift in rail infrastructure away from analog methods and embracing digital and integrated planning, encompassing everything from erection planning, installation and support for training to preparation and performance of repairs and maintenance, all based on digital processes and data models.

> Both the implementing company and customer benefit from the reduced risk of delays in planning as well as the prevention of defective planning and resultant need to revise planning during ongoing installation.

More than four years ago, Siemens Mobility began applying building information modeling (BIM) techniques as well to project planning and execution of complete turnkey solutions for rail systems. As one of the trailblazers of digitalization, Siemens Mobility uses BIM to create a digital twin – a virtual model of major rail projects planned for implementation.

This methodology focuses on achieving cost and time efficiency while also ensuring the highest quality standards.

Siemens Mobility's Turnkey Rail Solutions is using BIM in collaboration with construction partners to optimize project planning and execution. This involves the use of computer-generated 3D modeling and the information integrated into or linked with the models.

REFERENCE PROJECT RIYADH METRO

The Arriyadh Development Authority (ADA) – the executive arm of The High Commission

A simulated view of the outside of the depot, for which the path of sunlight can be simulated over time for the Development of Arriyadh in Saudi Arabia – is currently building one of the largest metro projects in the world, with six rail lines totaling 176 kilometers in length. The system will be the backbone of the public rapid transit network serving Saudi Arabia's capital city. The order placed with Siemens Mobility covers supply of 67 Riyadh Metro model rail vehicles based on the Inspiro Platform series, line electrification, the signaling and communication systems for driverless service on Lines 1 and 2, as well as system integration and project management. Siemens Mobility is part of the BACS consortium led by U.S. company Bechtel along with Almabani General Contractors and Consolidated Contractors Company.

The Riyadh Metro Project (RMP) kicked off by defining the information requirements and project-specific BIM objectives of the customer. The BIM management team of Siemens Mobility's construction partner Bechtel then used this information as the basis for elaborating in detail the BIM process for all project participants.

The BIM execution plan that defines the BIM process for a specific project basically provides the answers to the agreed requirements. In this key, central document, Turnkey Rail Solutions defined for all project participants involved in the infrastructure design the roles and scopes of responsibility, the programs and file formats to be used, what applications are to be integrated into the BIM process, the data-exchange process along the chain of project phases, the quality review, inspection and testing criteria, procedures for coordination and collaboration, and much more. This was necessary in order to ensure smooth BIM implementation over the entire project cycle.

BIM creates full transparency for everyone participating in the planning of infrastructure projects.

Siemens Mobility's construction partner also generated the model element plan, which defines in an overview who is to generate what model content for the project by when and to what level of development (i.e. geometry, information and coordination). In this project BIM standard, the construction partner also defined the details for modeling agreements and documentation standards.

Model-based planning is one of the project's centerpieces, enabling comprehensive integration of all rail infrastructure systems such as rail electrification, the depot and workshop equipment, line signaling and communication technology, and platform screen doors.

The Control Center of the Riyadh Metro Project for Line 1 was fully planned digitally. Once that design process was completed, actual construction started

CLARITY DRIVES THE EFFICIENCY OF WORKFLOWS

Siemens Mobility's infrastructure planning engineers used project-specific BIM software to share their model-based information with Siemens Mobility's suppliers and the construction partner. The program ProjectWise is used in combination with Aconex, served and continues to serve as a shared data platform accessible project-wide ensuring that each piece of information is retained only once and in its most recently valid version. In this "single source of truth", data are referenced rather than duplicated, significantly improving information management, increasing the reliability of data, and eliminating any use of superseded, obsolete data. This provides full transparency for all project participants. Photo-realistic displays and animated videos of the planning progress generated on the basis of the 3D planning information ensure transparency, enhance understanding, and support the iterative process.

BIM enables earlier design validation of rail infrastructure technology and engineering as well as civil construction.

The permanent availability of data accelerates collaboration across national borders and company boundaries. These aspects are particularly beneficial in the RMP: Just Siemens Mobility's unit alone had colleagues based in 13 different cities working to design the rail infrastructure, coordinating and agreeing across national boundaries and different languages, time zones and work capacities.

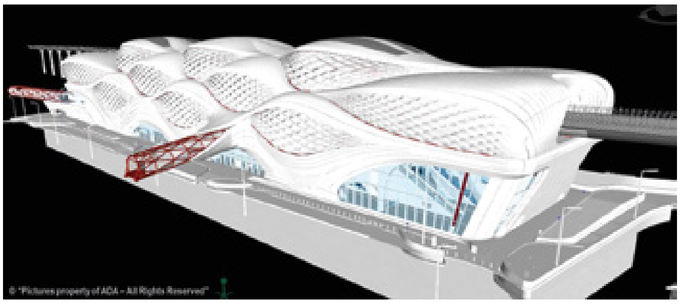
In addition to the geometrical properties of system components, for example of frequency converters, the participating planning engineers also integrated non-geometrical information and requirements of their systems such as zones and clearance spaces that are essential for installation and maintenance. Once work on a subarea of a model (work in progress) was approved for release, this information was then available to all partners within the project (shared areas). In turn, these partners reviewed the completed work for impacts on their own work scopes.

In interdisciplinary collision reviews, the design coordinators conducted collision tests with all other draft components. Such reviews examined for example the civil structures, technical building equipment systems and Siemens Mobility's systems such as the signaling equipment and traction power supply grid to identify any conflicts between the systems themselves or with the civil structures.

In this way, structural implementation of the overall project as well as individual subareas can be digitally tested at any time.

As a provider of turnkey infrastructure solutions, Siemens Mobility's unit was involved early in the RMP through BIM, helping to prevent planning errors and leading to quicker validation of draft planning such as for spatial requirements of infrastructure equipment, free clearance profiles, and preventing collisions.

The RMP offers a basis for further infrastructure projects using BIM methodology: The stock of digital objects available in the component library continues to grow. Existing digitally modeled components can be directly used for the next digital twin. This »



A view of the digital model of the King Abdullah Financial District Station on Line 1, which can be viewed in the computer program from all sides

accelerates digital planning from one project to the next.

Siemens Mobility Turnkey Rail Solutions sees particular potential for BIM in integrating the necessary management processes. BIM supports the management of interfaces, requirements, configurations and project documentation. This improved management leads to accelerated project execution. And although project execution in Riyadh is still underway, the added value created by the BIM method is already clearly evident today – for both Siemens Mobility and the customer.

BIM provides the basis for simpler and efficient interface management, and contributes significantly to accelerating project execution.

DIGITAL SCAN OF THE INFRASTRUCTURE CREATED

Siemens Mobility Turnkey Rail Solutions is utilizing other digital solutions as well for the Riyadh Metro Project that further optimize project execution. Siemens Mobility-owned track measuring vehicles and 3D laser scanners are deployed to efficiently compare the progress of as-built construction and installation against the design target data. These units travel along the existing sections, scanning and thereby digitalizing the as-built environment. The object-specific information collected by this measuring system, whether on track positioning, platform edges or technical spaces, is compared with the digital design, thereby directly revealing any deviations from planning.

This produces a 100%-accurate database of the existing as-built status. Particularly when projects aim to expand existing infrastructure, such transparency prevents costly conflicts when equipping existing civil structures with new infrastructure equipment. Besides the hardware procurement, Siemens Mobility is banking in this context on developing the expertise of its own personnel to cover planning of measuring campaigns, kinematic and static imaging, and evaluations such as review for collisions.

Photo-realistic displays and animated videos of the planning progress ensure transparency and enhance understanding.

PROMISING OUTLOOK

Siemens Mobility's Turnkey Rail Solutions has ceaselessly invested in implementing and further developing digital methods to keep pace with steadily growing deadline and cost pressures and the increasingly stringent demands of complex rail infrastructure projects. These efforts are now empowering Siemens Mobility to better assess the sometimes extremely demanding detailed requirements early, already in the project bidding phase, and estimate costs more reliably, thereby minimizing risks.

In previous projects utilizing BIM methodology, Siemens Mobility' experts identified a shifting of effort into the early project phases.

Siemens Mobility' experts see opportunities in doing so, particularly in the assessment of design modifications in terms of impacts on costs and in early application when the leverage for such optimization can still prove very effective.

Yet, BIM doesn't end when construction work on an infrastructure project has been completed: By developing a digital twin of the as-built infrastructure and applying that model over its entire lifecycle, these sets of digital data can be used to optimize asset management.

The BIM method harbors major potential for significantly shaping the rail infrastructure sector in the coming years. ◀

Ground Penetrating Radar – Basis for effective Track Maintenance

This article describes the capabilities and functionality of Ground Penetrating Radar (GPR) for higher speeds. GPR is a train-borne technology for a continuous inspection of the geotechnical conditions of railway tracks. The basic principles of the GPR technology are explained with particular reference to all relevant railway specific tasks, namely the identification, qualification and quantification of ballast fouling by using a fouling index, the determination of the quality of track drainage and its quantification through a drainage index, and the calculation of the track modulus (TM).
Special emphasis in the context of GPR investigations is placed on the mapping of sections with clay fouling/mud spots inside the ballast bed or at its base and, respectively, inside intermediate layer, formation or subsoil. In the past, such weak-spots have caused derailment; they could represent a risk for rail-traffic [11, 13, 14, 15, 16]. Besides, their late detection implies exceedingly high maintenance costs.

1. INTRODUCTION

Many countries allocate large amounts for the modernization and upgrading of their railway networks in order to meet the demands of increasingly dense rail traffic with higher axle loads at ever higher speeds. However, this can only be achieved if all relevant key figures and geotechnical conditions of the respective tracks can be reliably evaluated. On this basis only the necessary investments in track maintenance, modernization and support can be defined in the appropriate size and can be placed correctly. This is particularly true when budgets are tight.

The demands exerted on the track in terms of safety grow with increasing speed.

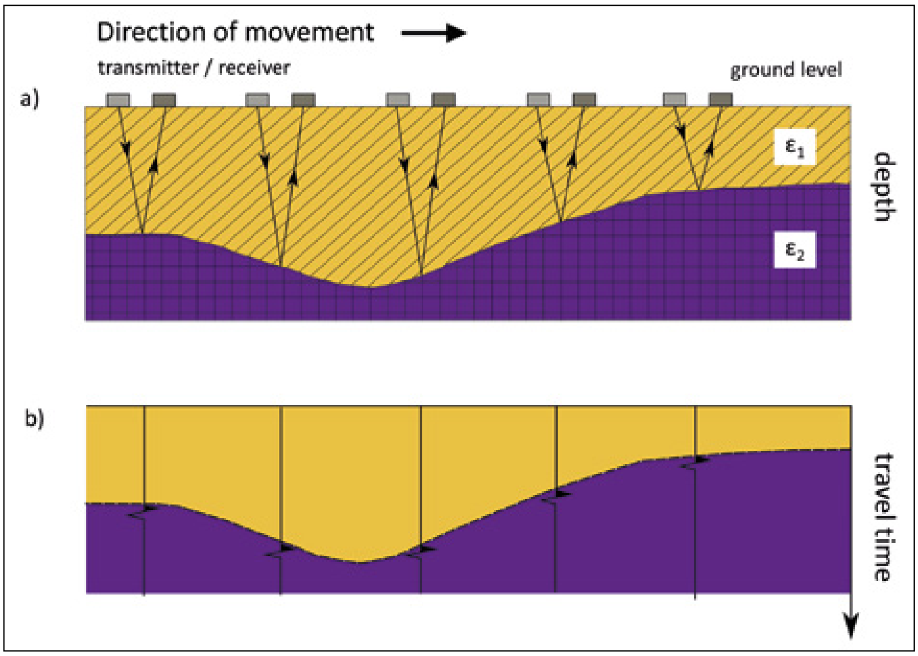


FIGURE 1:
a) Trajectories of radar waves, which are reflected at the layer boundary between two media with different dielectric constant (ε).
b) Due to the different travel time of the reflections, the layer boundary is reproduced in the radargram (reference: Ground Control and IEV)

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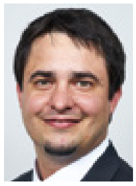

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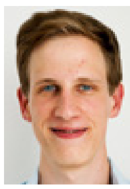

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FIGURE 2:
Figure 2: Antenna mounted on the train buffers of a maintenance vehicle
(reference: Ground Control)

Therefore, failing to detect track damages or obtaining inadequate information on track damages represents a hazard for every kind of railway traffic. For this reason, a decision guidance that facilitates a systematic and efficient renewal of the tracks is important. The more intensive the rail traffic and the higher the traffic speed, the bigger the requirements in terms of an efficient and reliable track inspection.

The mapping of clay fouling or mud sections is of special importance. Fine-grained soil material such as silt or clay wells up from the formation and reaches the ballast base or even penetrates the ballast layer itself. As a consequence, track drainage and track stability (i.e. bearing capacity) are strongly reduced. This results in lasting deformations that require complex maintenance work and high costs. If weak-spots are not identified or not detected in time, clay fouling can, in the worst case scenario, lead to derailment [10, 13, 14, 15, 16].

During the past 25 years Ground Control GmbH, which is placed in Munich, Germany, has surveyed more than 100,000 km of railway tracks in many countries in Europe and all over the world. Recently, with information obtained from GPR results and other data (i.e. track geometry and track dynamics), a continuous and complete assessment of the track's structural condition is possible.

2. MEASURING PROCESS

The GPR method is an electromagnetic reflection method: Radar pulses are transmitted into the subsoil by a transmitter antenna. The energy of the electromagnetic waves is partly reflected at interfaces between layers with different dielectric properties and retransmitted to the receiver antenna. Based on the measured travel time of the signals and knowing the propagation speed of the waves in the medium, depth and surface of the layer can be computed.

In order to define the depth of the reflector from the surveyed travel time, the propagation speed of the radar waves in the subsoil has to be determined. The speed of electromagnetic waves in the subsoil is related to the water content of the individual material. Therefore, it is generally not possible to refer to reference values for certain rock or soil types. Thus, the radar wave speed has to be calibrated for each project area.

The penetration of electromagnetic waves mainly depends on the electric conductivity of the soil and the applied antenna frequency. By using low frequency antennae on low conductive subsoil, the largest investigation depth can be achieved.

PERFORMING SURVEYS WITH MODERN HIGH-SPEED-GPR

Today's GPR surveys are carried out with train mounted systems at speeds up to 160 km/h. As a general rule, the antennae system is fastened at the carrier vehicle's buffers. A precise positioning is achieved by an integrated Differential Global Positioning System (DGPS) and Doppler radar.

The characteristics of modern GPR systems are:

- → The equipment can be installed and run on a wide range of track-bound vehicles (including regular trains or vehicles on Hy-Rail).
- → They are fast enough to be integrated into the regular traffic schedule. Hence, expensive track closure is no longer necessary.
- → DGPS and Doppler radar are used for an accurate (i.e. precision within a meter) positioning of the antenna independent of the speed and length of the track surveyed.
- → Measurement data resolution and data quality are equally high, no matter what length and what speed.
- → All GPR components are effectively shielded against interferences from signalling and communication systems.

3. GPR TASKS

In contrast with punctual boreholes and trenches, modern GPR systems provide continuous information about the geotechnical condition of the track, performing the following tasks:

- → Continuous mapping of track-bed-thickness and layers below (i.e. intermediate layer, protective layers).
- → Distinction between clean and fouled ballast and calculation of Fouling Index.
- → Mapping of mud spots or clay fouling sections inside ballast bed, at its base or inside substructure layers respectively.
- → Detection of sections with drainage problems and calculation of "Wet Bed Index".
- → Mapping of areas with insufficient bearing capacity (e.g. settlements) and evaluation of the dynamics of track settlement.
- → Control and evaluation of the quality of maintenance/renewal/construction work (quality of cleaned or exchanged ballast, thickness of a new ballast bed, quality and thickness of soil layers).
- → Estimation of track condition based on track modulus (TM) calculation.

Additionally, GPR data allow for the definition of a sustainable, cause-based and therefore effective track renewal recommendations and programs. Optionally, GPR offers the possibility to accurately map cables, pipes and other objects in the track substructure, creating the possibility to provide a complete picture of the entire system.

3.1. CLAY FOULING – STRONG EFFECT ON TRACK STABILITY

Clay Fouling is one of the main reasons for the reduction of the load bearing capacity of the track in a relatively short period of time. Several derailments in the past were caused by mud spots [10, 13, 14, 15, 16] even when the limit values for track geometry failures according to [2] have not been exceeded [13, 14]. It is therefore and because of safety reasons, of particular importance to detect clay fouling areas reliably, in their precise dimension and as early as possible. The recognition of the problem should be irrespective of whether the clay fouling exists in the substructure, at the base of the ballast bed or in the ballast bed itself. Clay fouling can rapidly deteriorate the stiffness of the track and its quality. The track's lateral stability is massively reduced; longitudinal errors along the rails arise.

Clay fouling is also a serious deficit from an economic point of view. Its timely identification allows for avoiding slow speed sections, thus sparing time and money for maintenance procedures. Detecting clay fouling before it reaches the ballast bed enables cost effective renewal. Otherwise it will be very expensive. There is no option for ballast cleaning; a sufficiently compacted protection layer built of the appropriate material is essential; the installation of composites does not prevent clay fouling from entering the ballast bed (see Fig. 3).

Save few exceptions, clay fouling spots are not visible at the track surface, and since drillings and trenches do only provide punctual results, reliable information is only achievable through GPR measurements (see Fig. 4).

A frequency analysis of the measured data results in a typical change of the signal spectrum in the area of clay fouling. Based on the GPR results, borehole program can be implemented which can be used for further analysis. GPR surveys to detect ballast fouling have been carried out for years in Switzerland, Austria, the Netherlands and France among others.

FIGURE 3: Geotextile or composite does not stop fine particle migration to the surface (reference: Ground Control)

3.2. TRACK MODULUS (TM)

Examining the geotechnical conditions of railway tracks requires an index which informs about state and quality of the tracks in a quantitative manner. The challenge has been to define the track condition continuously. This has been achieved by combining TM with the results of continuous GPR-measurements.

It is possible, based on [3, 4, 5, 6, 7], to estimate quality and bearing capacity of the railway track. Therefore, the TM describes the relation between vertical load and elastic deflection of the sleeper-bearings.

On the one hand the TM can be calculated based on the measured deflection under load [18, 20], on the other hand according to the soil properties [8, 9, 11]. The measuring principle for determining the load deflection is described in detail in [12] and [17]. The properties of the system components, such as the area of influence of the sleepers under load, can greatly affect the TM. Hence, around turnouts, the area of influence of sleepers deviates from the standard track. This is because an increased area of influence causes an increase in the distribution of the load, reducing the deflection of the rail. Notwithstanding, to simplify the calculation of the TM, the influence area of sleepers around turnouts are assumed to be constant assuming the values of the standard track. Depending on the type of sleepers installed, the value of the TM can increase sharply around turnouts (Fig. 5). In addition, cavities under the sleepers increase the deflection of the track under load which in turn influences the calculation of the TM, decreasing its value.

An additional and new approach for calculating the TM is based upon the soil properties which can be described by the Poisson's Ratio or the material density of the soil. The soil properties derive from the GPR data. This method's advantage is to be completely independent from superstructure conditions. The individual layers are assigned soil values according to condition and bulk density. Averaged soil properties are calculated according to [1, 19]. The TM can be estimated according to [9] and [11]. Previous studies »

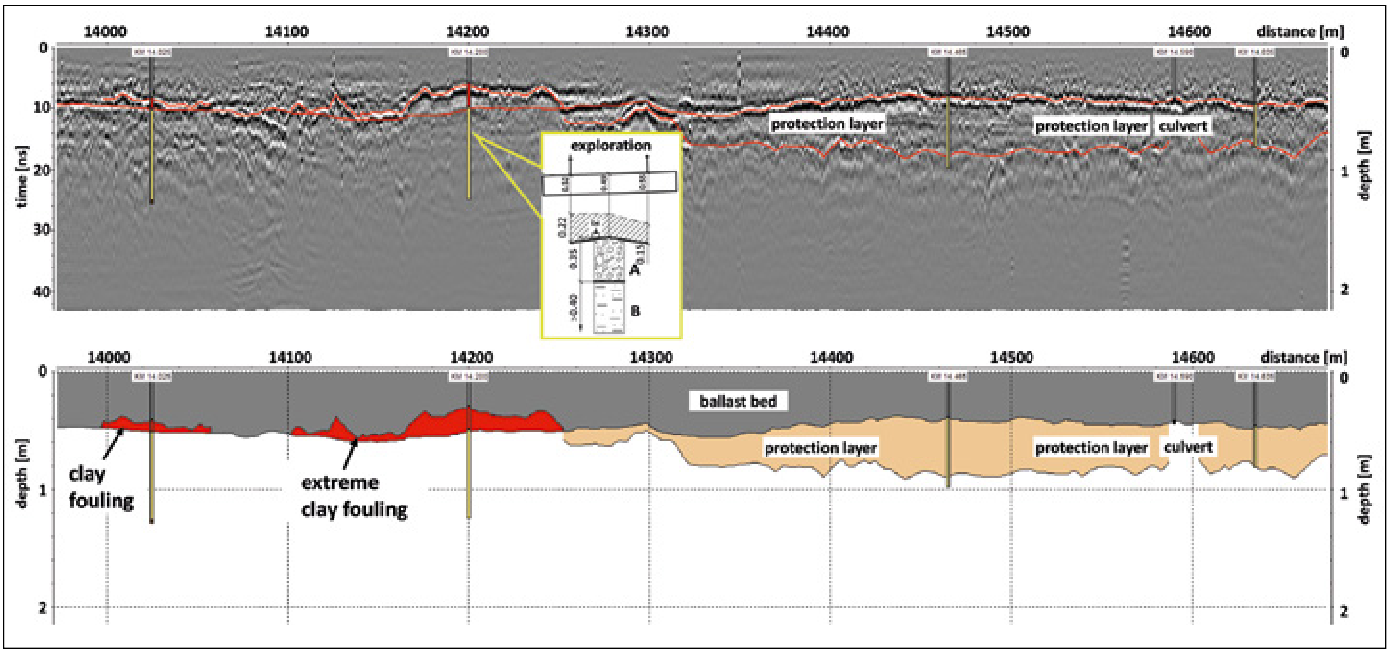

FIGURE 4: Visual analysis of GPR data depicting clay fouling along a track (reference: Ground Control and IEV)

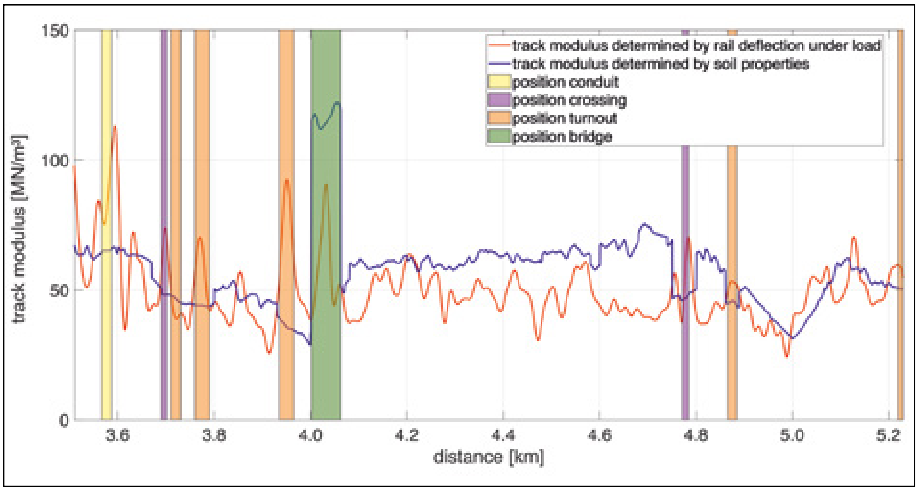

FIGURE 5: TM calculated from measured displacement under load (red graph) and soil properties (blue graph) (reference: IEV)

to characterize the underlying geotechnical characteristics of the track substructure/subgrade which results in significant cost reductions.

indicate that this method has significantly lower value variations along the track axis compared to the approach based on the use of track displacement data (Figure 5).

The example in Fig. 5 shows two track moduli based on the measured displacement under load (red line) and the soil properties (blue line). Around the turnouts a significant increase of the TM is visible if the calculation is based on the measured deflection. By dividing the TM into quality classes according to [3, 4, 5, 6, 7], the condition of the track can be satisfactorily estimated (Fig. 6).

3.3. TRACK ANALYZER – CONTINUOUS PRESENTATION OF ALL MEASUREMENT AND TEST RESULTS

Results from GPR surveys, along with all identified soil parameters and indices calculated, can be displayed in comprehensive track analysis software called "Track Analyzer". In order to provide all information for infrastructure managers, track geometry and track dynamics data are also integrated and displayed in the software (see Fig. 7) which also offers the flexibility to incorporate other tasks and aspects as required by the user.

The Track Analyzer provides infrastructure managers continuous information about the geotechnical conditions of the track with regard to all relevant issues. Moreover, it provides a better understanding of the substructure/subgrade conditions and their influence on the superstructure. This allows for a significantly increased track quality, providing higher route availability and safety.

A big advantage of the GPR method is the minimization of the need for intensive direct outcropping (probing, drilling, scooping)

4. SUMMARY

This paper describes a modern train-borne technology for the inspection of the geotechnical conditions of railway tracks. It is based on High Speed GPR and on classical procedures for providing continuous information about geotechnical parameters and indices. A new quality of GPR measurements is to provide quantitative indices in addition to qualitative results to fulfil the requirements of the railway engineers in the best possible way.

Special attention is paid to the detection of mud spots and clay fouling sections as a risk for derailment [10, 13, 14, 15, 16]. To date track inspection with GPR is more appropriate than any other inspection method to detect, map and qualify areas with geotechnical problems.

The Track Analyzer software combines GPR results with track geometry and track dynamics data. This allows for cause-based track renewal and targeted investment and provides significantly more reliable results than conventional methods. This approach is especially relevant for limited budgets. ◀

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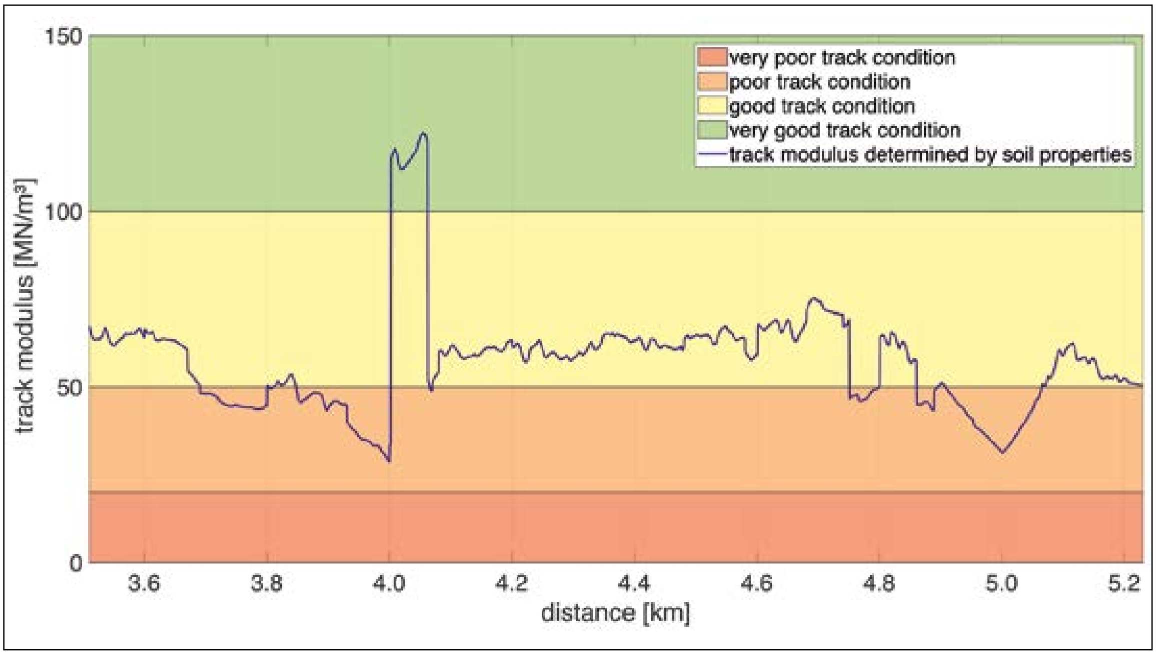

FIGURE 6: TM divided in different quality classes

(reference: IEV)

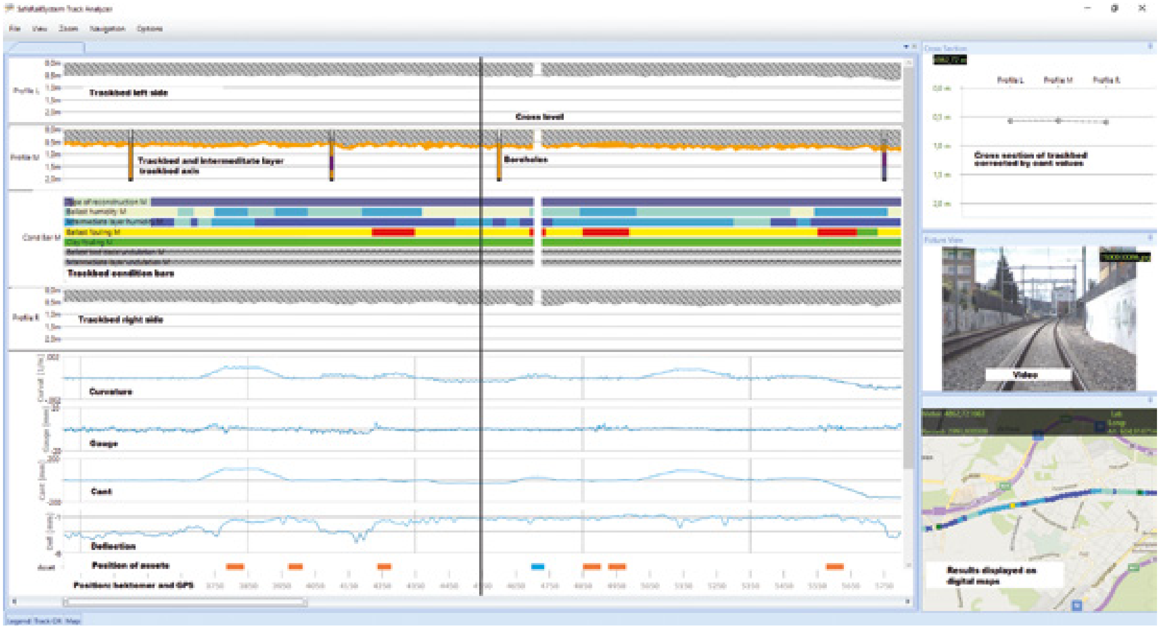

FIGURE 7:
Track Analyzer
(reference: Ground Control)

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How Distributed Acoustic Sensing supports condition based maintenance strategies

Current technological developments are opening up new opportunities for the railway industry in a whole range of application areas. Most notably, these include networking, digitalization and the Internet of Things (IoT). This trend is also having a growing impact on processes and strategies for maintaining rolling stock and infrastructure: Traditional maintenance philosophies, which are based on fixed intervals or, in the case of vehicles, on mileage, are increasingly being replaced by predictive condition based maintenance (CBM).

▶ This involves planning and controlling maintenance measures based on the actual condition of the equipment, systems and components (assets). Unexpected events due to faulty components and unnecessary work on fully intact elements can thus be reduced. This is possible thanks to the ever increasing amount of reliable data about the condition of the asset that is available in real time.

Continuous acoustic condition monitoring of the infrastructure based on Distributed Acoustic Sensing (DAS) is a key building block of future solutions. This technology can considerably increase the availability of rail networks since it continuously delivers very precise information about the condition of the infrastructure and any changes, thereby fulfilling a key prerequisite for the use of CBM solutions.

The sensor technology and inspections form and remain the basis for condition-based maintenance of the track. These include track recording vehicles, fixed measurement points, sensor technology on standard trains, track-side sensor technology, selectively deployed manual measuring instruments and self-monitoring infrastructure systems. Data from these sources must be consolidated and, if applicable, combined with information about rolling stock and system-side infrastructure data, such as a system directory, or inputs from other sensors.

DAS enables a sensor solution to be created which fulfils several of the specified requirements: this technology allows railway networks to be monitored continuously, in real time and with respect to a huge number of different events. Frauscher has developed its own DAS solution for the railway sector: Frauscher Tracking Solutions FTS. The manufacturer's team tested the technology and, through intensive development, eliminated constraints with respect to use for rail traffic. To create this, in-depth knowledge of DAS as well as requirements and standards in the railway industry was required.

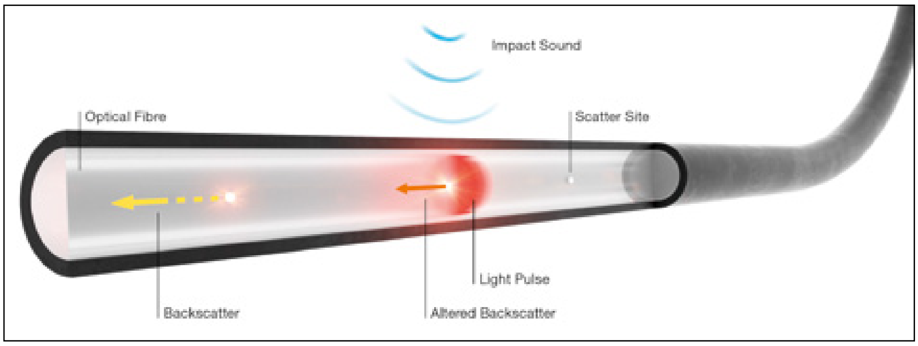

FIG. 1: Distributed Acoustic Sensing (DAS) allows for the detection of vibrations and sound waves caused by trains, component defects, people or other sources

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1. DAS FUNCTIONAL PRINCIPLE

DAS-based systems use laser pulses sent in a glass fibre to detect events on or in the vicinity of the track: part of the laser pulse is reflected back out of the fibre to the transmitting unit. The sound and vibration waves impacting on the cable result in significant shifts in the reflection (Fig. 1). The maximum frequency range of the vibrations detected in this manner is 1.25 kHz. Using specifically developed algorithms, the acquired data can be used to calculate specific signatures in real time. These describe highly precise locations and types of processes in the vicinity of the track.

One of the advantages of installing a DAS system is that the fibre optic cables it requires are often already laid next to the tracks. These are normally used for communication purposes. As the optical fibres used require practically no maintenance, the system can be rolled out to large sections of the route extremely economically and efficiently. In practice, a single DAS unit can effectively cover up to 40 kilometres of glass fibre in each direction, so 80 kilometres in total. [1]

2. CONTINUOUS MONITORING OF WHEEL-RAIL INTERACTION

The ongoing analysis of infrastructure using FTS is based on continuous monitoring of wheel-rail interaction (Fig. 2). On the one hand, this enables the detection of changes that arise slowly over the course of time. To do so, the system compares the relevant signatures that are captured each time a railway vehicle passes a spot. On the other hand, events that occur suddenly can also be reliably detected.

2.1. TREND ANALYSIS FOR LOCALISATION OF CONDITION CHANGES

The wheel-rail interactions quality is the most important factor when it comes to the service life of both system components and the rolling stock. This quality is derived from various parameters such as the roundness of the wheel, the surface of the rail and the track design. Even slight deviations from the ideal parameters result in increased signs of wear and tear over a certain amount of time. Ultimately, these can also lead to critical operating conditions. Which is why continuous detection and thus early recognition of changes in condition along the entire route is extremely useful.

This is where the FTS come into play: by evaluating the signatures in the laser signal feedback, it is possible to determine whether a sp ecific anomaly in wheel-rail interaction comes from the train or from the infrastructure. This is possible because the FTS system uses a glass fibre as a permanent sensor along the track, thus allowing the wheel-rail interaction for each individual axle on all train journeys to be permanently monitored along the entire route. Changes are detected in real time and the method does not depend on a fixed measurement point.

If a notification is triggered by an out-of-round wheel, for instance, then this pattern will be part of the train signature and be detected in association with the moving train. This allows the event to be clearly attributed to vehicle damage.

By contrast, if there is a change to the infrastructure, several axles will have a noticeable signature in one specific position. The system uses this to determine an indicator. Based on this, trend analyses are formed for individual, ten-metre long infrastructure segments. Warning or alarm notifications can now be created and transmitted through defined, user-configured threshold values. These indicate the type of change as well as the location. With good georeferencing for the fibre optic cable, the position identified via FTS can be localised to an accuracy of up to five metres and made available via machine-readable interfaces.

Frauscher offers powerful interfaces for employees in railway infrastructure companies. In particular, these include, a graphical user interface with map view and heat maps, and depiction of the infrastructure condition in definable categories. The zoom function can be used to display the entire route or a position with relevant localisation in route kilometres or GPS data, the actual condition and the change in condition over a specific period. Filters can be set for even more detailed analyses and evaluation.

FIG. 2: By continuously monitoring the acoustic signature of the wheel-rail contact, the FTS support condition based maintenance strategies

2.2. EVALUATION OF CHANGES IN CONDITION AS A PROCESS

To determine the relevance for a specific railway operation, simply identifying a change in condition is not enough. The trend analysis must also be correlated with the trains and their speeds. After all, identical technical non-conformities will result in indicators with completely different frequencies and intensities when a heavy, long freight train and when a lighter, short passenger train travels over a position with a fault.

Therefore a basic condition must first be defined for the infrastructure and stored in the FTS. The trend analyses can then be applied to this. To do so, the system structure (primarily bridges, tunnels or points) must be logged in the system and the sensor must be calibrated accordingly. Data that needs to be entered includes rail joints or transitions from a point, for example. They create similar patterns to those of a rail defect, but must be evaluated and examined differently.

It may also be necessary to filter out ambient noise from stationary systems such as pumps and generators, so that this does not have a negative effect on the detailed analysis of the wheel-rail interaction signature. These adjustments are currently carried out manually during the installation and commissioning process. However, Frauscher is developing tools to automate these processes. These steps form part of the technology's path towards serial production.

Once the basic condition has been defined, then, depending on the model, the operator will receive regular reports or warning and alarm notifications via defined interfaces. The DAS systems that are currently available are not yet able to classify and quantify the changes detected with sufficient accuracy. Maintenance personal therefore take on the task of evaluating suspect positions through inspection actions during the development and installation phase. A visual inspection is often enough to identify the cause of the warning, classify the change and take the necessary action within a defined period.

Based on experience with several installations and Frauscher's collaboration with operators, there are essentially three relevant classifications:

- → No detectable or only minimal damage
- → Non-critical damage
- → Critical damage

What is important is that this evaluation and classification is understood and followed as part and parcel of the maintenance process. Defining the threshold values and determining the sensitivity of the system is a key step in this regard. Experienced specialist staff who evaluate and process the notifications, can shape the system to suit their own needs. This allows CBM concepts to be applied even more efficiently for practical support and to build expertise (Fig. 3).

The high sensitivity level of the system »

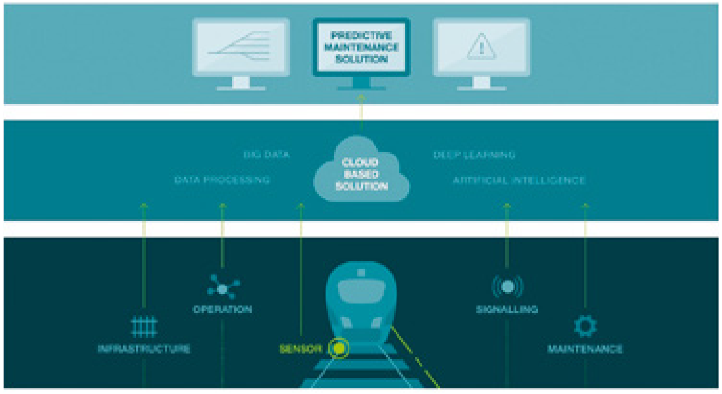

FIG. 3: When developing advanced maintenance solutions, various levels within a railway network have to work together closely

means that a range of errors can be detected at a very early stage. However, this also increases the risk that positions that are not relevant for maintenance will be displayed. This is where empirical values are really needed, so that the optimum setting can be tuned for the operator. It is crucial to involve the maintenance personnel in this, whether through the operator or the service contractor. After all, only experts on the ground can evaluate the condition of the infrastructure and determine the necessary measures. Maintenance employee experience thus remains essential for training the algorithms and evaluating the results: the maintenance personnel must use their knowledge of routes and systems to determine whether a notification is in fact relevant or not.

Not detectable or only minimal damage

In this case, no maintenance measures are needed. There are three main reasons why the system has indicated a potential fault in this case: First, there may be a structural factor in the infrastructure or a factor in the environment of the trigger. In this case, the influencing factor can be filtered out in future. Secondly, it could be that a visual inspection reveals no detectable fault, but there are already signs of wear. In this case, the user would add information to the system stating that this section is to be kept under observation or specifically monitored over a certain period of time – for example by adjusting the threshold value. If the system continues to exhibit a fault, it is advisable, to apply analysis methods that go beyond a visual inspection of this point or use other measurement data as a comparison. Thirdly, this could be due to a minor surface fault on the rail, for example, which does not require any action, since scheduled surface processing measures are due to be carried out (Fig. 4). In this case, the fault message can be acknowledged.

Non-critical damage

In this case, the system has identified a relevant fault, but it does not need to be corrected right away (Fig. 5). The main advantage of this is that early detection allows the necessary measures to be planned in good time, so these can be put into effect during quiet periods or efficiently combined with other measures, thus reducing the number of expensive individual activities.

Critical damage

If such changes are detected, then measures must be initiated immediately in order to resolve the safety-critical operating condition and minimise any expensive subsequent damage. Experience shows that such critical conditions can develop over just a few days or can even be triggered by acute, short-term factors. Examples include ballast voids due to washout, rail head cracks and broken rails.

Critical conditions can arise during the analysis cycles even if the rail network is monitored regularly, with track recording vehicles, for example. Continuous monitoring of the wheel-rail interaction enables quicker intervention and minimises personal injury and damage to property.

2.3. EMPIRICAL RESULTS

In addition to various applications which can be used in real time on the basis of train localisation, over the last two years Frauscher has been taking a closer look at infrastructure maintenance. In particular, at the potential that continuous monitoring of the wheel-rail interaction has to offer in the following scenarios:

- Rail monitoring
- Rail fastening and sleeper monitoring
- Track substructure and superstructure monitoring

Practical application has shown that the data that can be provided via the FTS system already offers a range of interesting options: it helps users to plan and control maintenance measures in good time. To do so, Frauscher implements technology such as machine learning, pattern recognition and artificial

FIG. 4: Changes in the track's surface can be detected, evaluated and considered when planning maintenance works

FIG. 5: Detecting small defects allows for a targeted monitoring in order to generate alarms when their condition deteriorates

intelligence. However, in order to move to the next level, a solid base of empirical values and a library of signatures from a variety of sources of damage are needed.

The company is working very closely with the operators of several installations selected from approximately 30 projects that are currently ongoing worldwide. They are jointly considering the evaluation, interpretation and derivation of measures. Specific issues and ideas for further development of the evaluation software and logic are directly incorporated into Frauscher's development processes using agile methods.

Rail monitoring

All types of rail damage that cause vibrations or a noise spectrum that deviates from the norm are detected. This ranges from surface damage such as rail corrugation, squats, rail head cracks, wheel burns or corrosion and dents to cracking and fissuring or even broken rails.

Unsurprisingly, the algorithm for detecting rail damage also detects rail joints. After all, the signature of a gap as in an isolation joint could be exactly the same as that for a break in part of the rail. In this case, depending on requirements, these rail joints can be suppressed or specifically monitored with their own threshold values (Fig. 6, 7). The sensitive sensor system can detect broken rails, as a train passes over them, with high probability. However, due to the many different forms and physical basic conditions, a warning system with a 100 percent detection rate and zero error rate cannot be achieved.

In addition, there are still no empirical values for broken rails which can be traced back to warping and thermal effects, without the effect of the train. Noises that arise due to warping (thermal popping) were detected during tests designed to identify and localise landslides and rock fall. These are hard to classify or uniquely identify using the currently available hardware and software. It is to be assumed that a rail that breaks for thermal reasons generates a similar, if more intensive, signature and it is not possible to clearly distinguish this from the "thermal pop".

Therefore, it is important to consider whether continuous monitoring of the tracks with appropriate trend analyses does not provide more information about the safety of the route than a warning system for broken rails. Last but not least, broken rails should generally be reduced by as-required maintenance measures.

Rail fastening and sleeper monitoring

In several installations, positions were detected that exhibited increased vibration due to damaged or missing rail connections or broken sleepers. These are typically faults that do not necessarily require action to be taken right away. Instead they are classified in such a way that these tasks will be carried out during upcoming scheduled on-site maintenance.

FIG. 6: Rail joints are specific points, which can be monitored via FTS by storing their base signature in a first place

FIG. 7: If the condition of the rail joint changes, its acoustic signature will do the same

Track substructure and superstructure monitoring

The FTS system is able to localise weaknesses in the substructure and track superstructure, such as ballast voids under sleepers, cavities or compacted areas. The condition of the track bed may, under certain circumstances, also lead to a critical situation in a relatively short period of time, particularly in mountainous regions, where heavy rain or mudslides can also make the track position unstable. Practical examples also exist for these scenarios, where FTS localised critical positions where ballast voids under sleepers were later identified.

3. SUMMARY

Continuous monitoring of wheel-rail interaction based on FTS opens up numerous possibilities for the user in terms of timely detection of weaknesses and changes in condition on the route. Thus, targeted and as-required maintenance measures can be defined, planned and efficiently controlled. This is a paradigm shift in terms of maintenance strategy, similar to that which is emerging for vehicles. Before, fixed periods, based on theoretically calculated average loads, were key to the strategy. Now, the actual wear and condition of the specific component (rail surface, fastening, sleeper, substructure or track superstructure) are the trigger for maintenance, repair or servicing work.

These new options for monitoring infrastructure will not replace existing measurement systems, instead they will enhance them. They will change the maintenance processes, mainly through the high-precision and early detection of continuous changes. By determining individual threshold values, necessary work can be planned and carried out preventively, before critical damage arises.

In addition to such continuous changes, the FTS is also able to detect vehicle faults and short-term, sporadic influences on trackside infrastructure. This includes natural hazard management such as falling rocks and trees, catenary flashover or protecting infrastructure from vandalism, cable theft or unauthorised access to track systems.

Even in times of advancing digitalisation, employee experience forms an indispensable basis for railway operations. Manufacturers and operators must work together to develop systems for CBM concepts and individually calibrate them, so they become helpful tools which raise efficiency while reducing ongoing costs. ◀

Literature

[1] Rosenberger, Martin. Lancaster, Gavin. Real-time track monitoring for sustainable maintenance strategies. ETR International 1/2017. P. 20-23

Smart Tamping – Fields of Application of the Turnout Tamping Assistance System

Plasser & Theurer's development of the turnout tamping assistance system "PlasserSmartTamping – The Assistant" has been an important step towards the further automation of tamping machines. The assistance system provides automated support for tamping works in turnouts and crossings. It recommends specific actions which must be confirmed by the operator before they are carried out. As a result, operators increasingly monitor processes, intervening manually only in exceptional cases. A new recording module allows for a completely new form of tamping documentation. It increases transparency, working quality and process reliability. For the first time, the turnout tamping simulator – not a tamping machine – was used to develop all of the software modules of the turnout tamping assistance system. In an extended hardware-in-the-loop application, the turnout tamping assistance system was developed and tested using the simulator.

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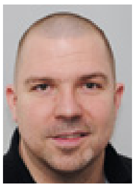

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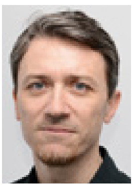

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1. THE DEVELOPMENT

In modern track maintenance, the conventional distinction between track inspection vehicles and track construction and maintenance machines has increasingly been blurred. To optimise processes, track construction and maintenance machines are fitted with the latest sensor technology, turning them into "smart machines". Inertial track measuring systems, used up to now only on track inspection vehicles, have increasingly been installed on tamping machines. This makes it possible to use tamping machines for separate track measuring runs to calculate the required track geometry correction values.

The use of inertial track measuring systems optimises the track geometry quality. In addition, laser scanners and light section sensors make it possible to create a "digital track twin", which provides the data base of the turnout tamping assistance system.

2. THE OBJECTIVE OF THE TURNOUT TAMPING ASSISTANCE SYSTEM

Turnout tamping (Figure 1) requires considerable knowledge of several areas of expertise (track surveying, machine technology, track technology, regulations). The most important tasks include:

- → In the main tamping cabin: Controlling the tamping unit including the turntable, opening width and tilting motion of the tines
- → In the co-tamping cabin: Controlling the lifting and lining unit, the parts of the tamping units in the diverging track and the additional lifting unit

The turnout tamping assistance system complies with level 3 of the standard SAE J3016. The standard defines terms related to on-road motor vehicle automated driving systems and has been applied correspondingly. On the automation level 3 the system recommends specific actions which must be confirmed by the operator before they are carried out, with the operator as fallback. The design of the turnout tamping assistance system also allows for higher levels of automation. However, for reasons of liability, automation options such as remote control or robot operation are not offered.

The turnout tamping assistance system

offered to machine operators and infrastructure managers consists of four product parts in modular design:

- → recording module for recommendations and operations
- → operation assistant for the lifting and lining unit
- → operation assistant for the additional lifting unit
- → operation assistant for the tamping unit

The modular design makes it easier to put the turnout tamping assistance system into operation for the first time. In a testing phase, recording modes can be used to verify the accuracy of the recommended measures (comparison of the actual taming operations and the actions recommended by the assistance system). Upgrading to a higher level is possible if it has been taken into account in the design of the machine. The modules are activated step by step to allow staff to familiarize themselves with the assistance system and to coordinate the work processes.

FIG. 1: Operators of turnout tamping machines must meet high requirements

3. THE RECORDING MODULE "DIGITAL TRACK TWIN"

The first step is to develop the digital track twin. When selecting the hardware components of the turnout tamping assistance system (one rotation laser, four light section sensors and one colour camera), it was ensured that the hardware can be exchanged and that the software can be adapted modularly. When designing the hardware components, a particular focus was placed on meeting the accuracy requirements. In addition, it was ensured that the system is highly robust and easy to maintain.

The recording module of the turnout tamping assistance system connects the digital twin of the track with the working parameters of the machine. As a result, the quality control of tamping works reaches a new transparency level. Infrastructure operators can easily access all parameters relevant to quality and work (such as the tine position, tamping depth or squeeze time) digitally and immediately when connected to the Internet.

In the future, the recording document will also include the rolling marks of the rails and the position of the aluminothermic welds. As the software is developed in-house, we can meet our customers' requirements flexibly (Fig. 2). For instance, it will be possible to export the "digital twin" for use on the tamping simulators. »

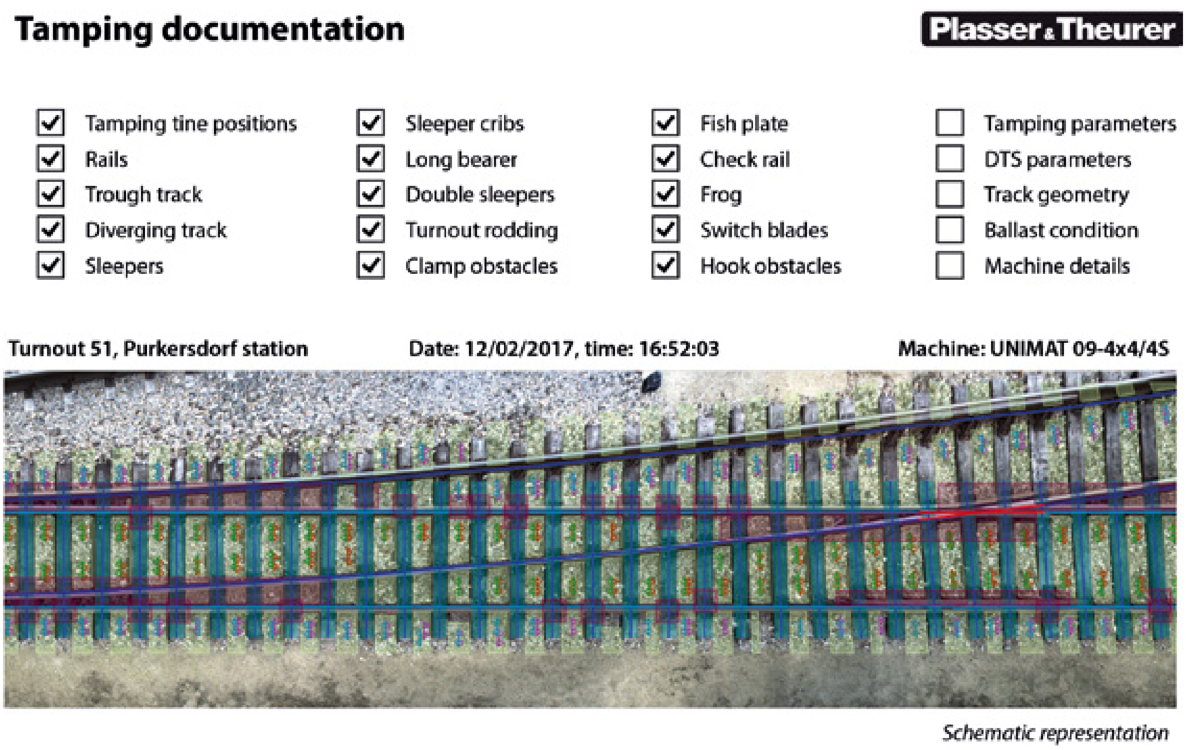

FIG. 2: Tamping documentation using multi-layer technology (schematic representation)

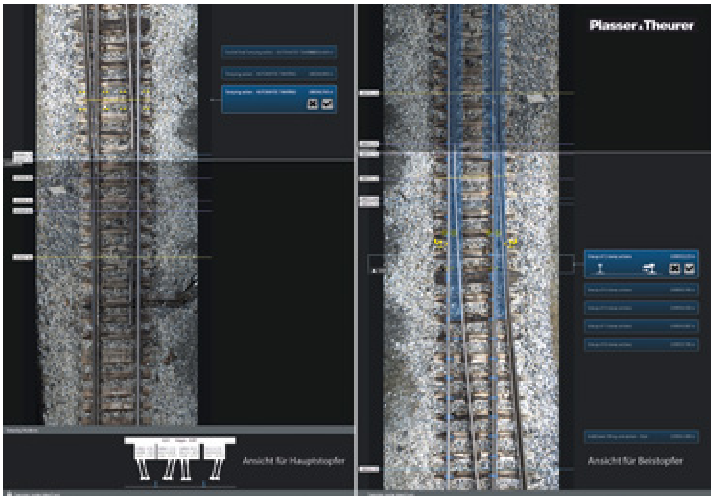

FIG. 3: Overview of the control recommendations

4. OPERATION ASSISTANCE

Based on their position at the time of recording, the individual scans and recordings are merged to form a 3D image of the reality, showing the exact position. At the same time, the position of the machine and every individual work unit is continually updated. As a result, a 3D image of the relevant machine parts is imported into the overall model, providing the basis for every decision of the assistant. The data is processed with the lowest possible latency and highly parallel data processing to ensure fast operation. The system recommends the respective actions several metres ahead of the tamping unit (Fig. 3), to provide the operators with sufficient time to analyse and modify the recommendation, if necessary. The recommendation of the assistance system is checked directly at the tamping position before the tamping unit is lowered. At the same time, the configuration of the lifting and lining unit (hock and tongue position) for the transfer to and the lifting operation at the next tamping position is checked prior to transfer travelling. At this point, the operator can take action at any time and further adjust the settings. The operation of the additional lifting unit is checked in a similar way.

Position for every sleeper crib	
	Tamping units
	Lifting and lining unit
	Clamp disks
	Hooks
Angle for every tamping/lifting operation	
	Turntable
	Tamping tine
	Additional lift
Activation of thrust flaps	

FIG. 4: Position sensors, angle sensors and actuators operated by the assistance system

To allow for tamping recommendations, the track sections requiring actions must be located in an automated process. To ensure this, different image processing systems are combined with artificial intelligence and connected systemically.

The basic tamping scheme was developed on the basis of regulations and specifications of German Federal Railway (DB), Austrian Federal Railways (ÖBB) and experience from practical operation. A specific adaptation to the infrastructure manager's requirements is possible.

Figure 4 shows a list of position sensors, angle sensors and actuators operated by the assistance system. The values of the lining adjustment, the lifting operation and the tamping parameters (multiple tamping, tamping vibration frequency, squeeze force, tamping depth) are not controlled by the assistance system.

The turnout tamping assistance system has been designed for two applications: In the first design version (the separate view), separate measures are recommended to the operators in the main tamping cabin and the co-tamping cabin. The second design version (the combined view) is the current development focus: Both assistance modules are merged into a combined view in the main tamping cabin, enabling the operator in the main tamping cabin to control the entire turnout tamping process by himself (Figure 5).

The application focus of the first generation of the turnout tamping assistance system is on turnouts that have not yet been fully ballasted. As a result, the surface of the sleepers is visible. Specific recommendations require a good view onto most of the turnout area, the sleepers and obstacles (such as switching contacts, turnout operating units).

In a next stage, we plan to fit the turnout tamping assistance system with sensors (eddy current sensors) for the detection of sleepers in ballasted areas (newly laid track).

Completed tamping works in turnouts can be duplicated using the machine control module turnout programming automation. In a combined application of the turnout tamping assistance system and the turnout programming automation it is, in principle, possible to scan turnouts in advance while they have not yet been fully covered with ballast, and to provide the turnout programming automation module with the recommendations to allow for their duplication. Turnout tamping machines with the integrated supply of new ballast generally allow for the use of the turnout tamping assistance system, as the turnout is not ballasted at the scan position at the front end of the machine.

The prototype of the turnout tamping assistance system was introduced to the expert audience at the trade show iaf 2017 in Münster. The positive feedback proves the great potential of the technology. In practical operation, the turnout tamping assistance system is currently prepared for series production for the work unit types "275", "475" and "4x4". ◀

FIG. 5: Tamping cabin with the assistance system "PlasserSmartTamping – The Assistant"