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Insights and propositions on innovation of railways

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Innovation in the railway field can take up to forty years or more to become fully established. Today's innovations already give us an insight into what the railway system of 2058 is going to be like.

It's still likely to be steel rail-steel wheel technology but will aim to be fully digitised with far-reaching automation of systems. It needs to be precise, responsive, proactive, robust and economic. Automation aims to open up opportunities for break-through, providing new types of passenger services. Through this it aims to meet or exceed the customers' expectations of the mid-21st century and to play a leading role in land transportation.

This paper does not summarise just a single project, but rather combines insights into innovation in the railway sector from around 30 years, which the author has gained as a researcher and practitioner. It builds on previous publications and continues the respective considerations. In part, it is based on research results of his group, but partly also reflects personal opinions. This means many of the following ideas can be seen differently with good reasons, hopefully providing an inspiring contribution to the discussion.

40 years: the innovation constant of the railway

Fleeting observers and daily users will most probably agree with the proposition 'that rarely is there anything new to be

noted on railways'. The station stops often consistently spread the charm of the seventies or eighties, if not far earlier and the vehicles sometimes remain in use for more than a quarter of a century. During this time, the neighbouring motorway experiences five generations of car model change. Is the railway really as incapable of innovation as it seems and is it facing its inevitable decline?

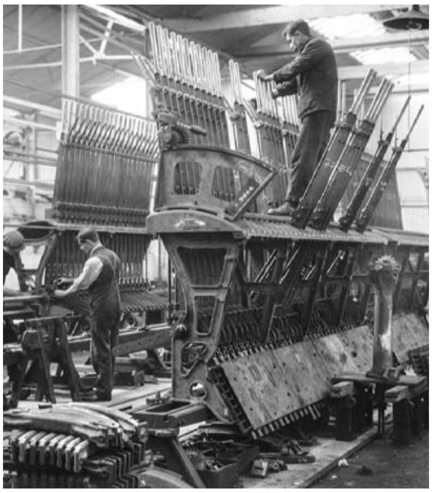
> "Innovation in rail has always spread slowly"

Innovation in rail has always spread slowly according to consistent human standards – since the beginning. Important pioneering achievements go back to the late 18th to early 20th century. For example, steel wheel on steel rail technology was introduced ca 1780, the steam locomotive ca 1800, the mechanical interlocking ca 1860, the electric train drive and the automated block ca 1880, the diesel locomotive ca 1910 and the high-speed railway around 1930.

In these and many other cases it took about four decades from initial use to general dissemination and adoption. To some extent an innovation constant of forty years can be concluded from this. Over the centuries, a transport system emerged which, apart from the basic principles, has nothing in common with the initial English coal mine tramroads.

Innovation intensity of the last forty years

These examples are historic and one could postulate that the innovation



Interlocking innovation: Mechanical interlocking, relay interlocking and solid state interlocking. Computer-based interlocking has followed, and cloud-based systems are beginning to emerge. *Photos Westinghouse archive*.

process has slowed down or even come to a standstill. In other words, is the innovation constant of 40 years still valid today? This can be established by looking back at the last forty years, the epoch since the mid-1970s.

Since then, passengers have the benefit of integrated timetables on many networks, air conditioning of the vehicles is the common standard, as well as dynamic passenger information systems, mobile phone, wireless connections and electronic ticketing in stations and in the trains of many railways.

General accessibility for disabled persons became a legal standard and has been introduced quite quickly, thanks to low-floor vehicles in city and regional traffic. In freight transport, intermodal transport concepts have spread.

In the vehicle sector, the high-speed railways have impressively demonstrated their capability for commercial speeds of up to 350 km/h over the past forty years. A little less convincing, but overall also positive, was the evidence of tilting trains. The first serious attempts to use three-phase current technology for locomotives began at the beginning of the seventies, this is today the undisputed state. It facilitated the development of standardised vehicle construction for high-performance locomotives, double-decker multiple units as well as trains for urban and regional transport. Finally, pneumatic suspension bogies and disc brakes are a matter of course in passenger transport.

The infrastructure includes new forms of track construction such as concrete sleepers, new rail grades, continuous welded tracks and slab track. The introduction of absolute track positioning and monitoring vehicles, allows the targeted track position to be clearly defined, the actual track position precisely recorded and position errors specifically eliminated. In databases, plans and factual information are available in digital format and often with time series. In maintenance, highly mechanised machines and the just-in-time delivery of new switches have arrived. At the same time, electronics has become established in the control and safeguarding of rail operations. Electronic signal boxes, signal box remote control as well as control and automation systems are widely used. The (more or less) Euro-compatible cab signalling according to ETCS Level 2 is operational.

> “The railway of 2018 can hardly be compared to that of 1978”

The railway of 2018 can hardly be compared to that of 1978. The industry finally broke away from post-war technology and took the step into the 21st century. The innovation constant of 40 years thus seems to continue to apply – the railway has remained innovative!

Challenges until 2058

Innovation will remain vital in the coming decades. Railways will be in the middle of the century, in an environment in which the competing transport systems have made great innovative progress. The automation of road traffic will revolutionise mobility and not only passenger transport, but above all freight transport. This will have repercussions on the commercial settlement structure and logistics systems, which will be even more dispersed and thus even more difficult to address by the railway industry. Car users will benefit from privacy in their own car while taking the time to work or rest, like a passenger on the train. In addition, the conventional internal combustion engine will be replaced by new propulsion systems, which are ecologically more advantageous. Trucks will be not only cheaper by not requiring a driver anymore, but also quieter and cleaner. This eliminates the important relative system strengths of rail transport.

It is foreseeable that the railway may struggle to survive in various current markets. Even with comprehensive innovation, it will not be possible to compensate for fundamental systemic weaknesses. For example, infrastructure and rolling stock will still be very expensive and durable. Just the infrastructure costs per train ride correspond approximately to the full costs of a bus including the driver! The network density continues to remain about 15 times smaller than that of the road and stations in rural areas can serve only a few passengers.

Comparative strengths

In this situation, the railway with its wheel-rail system must consistently focus on three systemic and absolute comparative strengths, which will distinguish it from the other transport systems for an indefinite period of time:

1. The train is the fastest means of land transportation; road traffic will unlikely to ever be able to operate at top speeds of 250 to 350 km/h. It is unbeatable for distances up to 500 km.
2. The railway offers the highest transport capacity on small surfaces; the space efficiency of the road

is far below and, moreover, the train can be relocated in the underground, if needed.

3. The railway is extremely efficient in carrying large quantities of goods over long distances. The smallest amount of personnel and energy is needed to move large volumes of cargo.

It is these strengths that the railway and its innovation must focus on; these strengths which are increasingly central to our society. Never before has mankind been as urbanised as today, with huge metropolitan areas that can only be opened up by rail systems in an efficient and city-compatible way. Never before has the exchange of people and goods between metropolitan areas been so important, but the capacity of the airspace is finite and the acceptance of aviation by the population is decreasing. Never before has the global exchange of goods been so intense.

Concentrating on the comparative strengths may therefore have some painful consequences for railways, such as the withdrawal from regional services and the abandonment of single-wagonload consignments. In contrast, the railways will be able to render their services even more essential in their strong areas – the connection of the metropolitan areas, transport services within metropolitan areas, and the transport of freight over long distances.

Focus of system development

In order to really exploit its three comparative strengths in this difficult context, innovations are required in the following four areas:

1. Performance

The requirements of passengers and shippers regarding punctuality and reliability will continue to increase. The more difficult the traffic situation on the roads and in the air, the higher the expectations will be of the railway. At the same time, improved flexibility in freight transport will become increasingly important.

2. Economic efficiency

Despite many political assurances, there is no real will in the majority of European countries for substantial funding to be made available to the railways. The maximisation of cost-effectiveness is therefore still required, by minimising not only the initial investment, but also the operating costs.

3. Adaptability

The railway is a rigid system with high fixed costs. The European transport market, however, covers highly populated corridors as well as low-demand regions. Demand fluctuates significantly in terms of time and, with conventional operation, leads to average utilisation of typically between 15% and 30%. At the same time, population distribution is changing due to intra-European migration, leading to growth in parts of the continent but also shrinkage elsewhere. As a result, the railway system must be able to adapt to the different demand patterns in terms of time and space.

4. Resource consumption

While the railways are more environmentally friendly than other transport systems, this will not be enough in the future because the other systems are catching up and resources are becoming scarcer. The energetic advantage of a factor 10 in rolling resistance currently results in about a factor of 3 in real operation; sometimes a bus is even more eco-friendly than a regional train. Rail vehicles have become heavier and heavier, but the average load-factor is still low. For each passenger, two to three tons of material are also carried along!

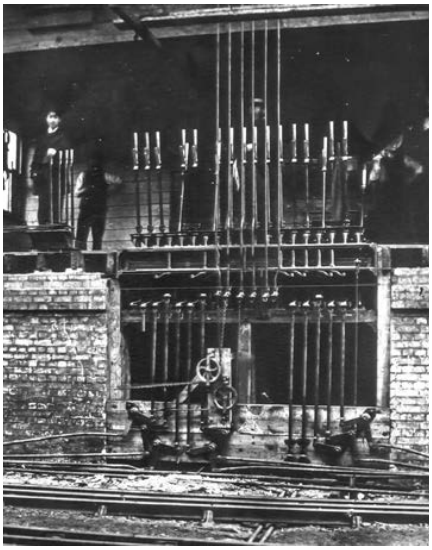
System innovation as a key and challenge

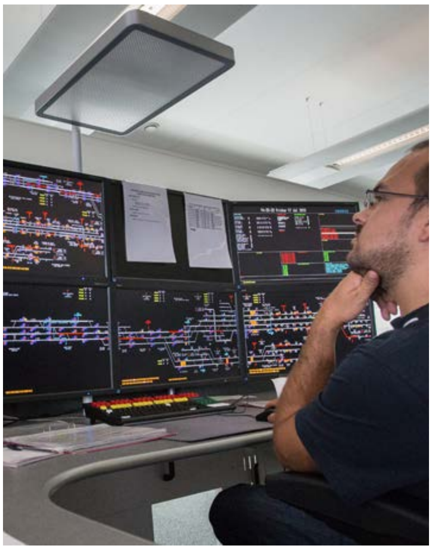
The railway is a system with a history of development of around a quarter of a millennium. Pure component innovations are still important, but they will not be able to give the system completely new properties. Breakthrough innovations – and such are required – can only be system innovations. This will be a challenge:

> "Breakthrough innovations can only be system innovations"

By definition, system innovation always affects the sphere of action of at least two actors and thus also the interfaces between them. For the target of system innovation, it follows that it must optimise the overall system. At the same time, the achievement of goals for individual actors can certainly deteriorate at the same time in several cases – system innovation

Control centre innovation: From the 'hole in the wall' at Victoria station, through panel technology, workstation based control is now the norm.
Photos Westinghouse archive and Network Rail.





Innovation in locomotive construction: SBB Cargo International Vectron freight locomotive for cross-border services. *Photo Steffen Schranil.*

can lead to winners and losers. This and the conditions of the railway system lead to three obstacles: actors in the innovation process, innovation processes and cash flows.

These obstacles are not new, but with the pronounced system character of the innovations they become particularly explosive and decisive in the pursuit for success.

First innovation obstacle: actors in the innovation process

The development of a railway system and the design of market-oriented transport services is the joint task of a large number of actors. The railway is a system with generically very distributed tasks and organisational fragmentation. This results in diverse, usually legally and financially delineated organisations.

Demand and policy

End customers: These are the users of the railway system and the final reason for running it, both in passenger as well as freight transport. Both groups want to get the best possible transport offer at the lowest possible prices.

Politics: As a primary goal, politics pursues a high-quality offer with the lowest possible need for financial support through tax funds. Further goals are the reduction of noise and pollutant emissions as well as energy consumption, universal access for disabled persons and affordable fares from a societal perspective.

Regulation: This sets the legal framework within the scope of policy frameworks. Primary objectives are safety, interoperability and fair competition between transport companies.

Services

Orderer: They order transport or infrastructure services which are desired as a public service but cannot be provided on a commercial basis. Since orderers are mostly political entities, they also have an interest in obtaining maximum transport performance with existing infrastructure.

Providers of transport services: Providers of transport services have an interest in producing these services at the lowest possible costs, while maintaining the highest possible quality, and in particular paying as little as possible for the infrastructure. Their goal is to optimise yields with the offer, be it through additional customers or through a higher willingness to pay by existing customers.

Operation

Service operators: The providers of transport services would like to produce these services with the lowest possible own costs. This entails low costs for the use of infrastructure and rolling stock.

Industry in the area of operation: This includes all suppliers of production-relevant system components. These can be, for example, in the field of dispatching software or of certain vehicle components. There is an interest in selling as many components as possible at high prices.

Rolling stock

Passenger coach and freight wagon owners: A vehicle owner aims at rolling stock that best meets the transport needs, at the lowest possible investment and maintenance costs.

Locomotive owner: The locomotive owners want to procure and operate their traction vehicles as cost-effectively as possible.

Rolling stock industry: The rolling stock industry has the interest to sell as many vehicles of the same type as possible at the highest possible prices.

Infrastructure

Infrastructure purchaser: Orders and finances the construction and operation of infrastructure facilities. Its goal is to have the (given) infrastructure capacity available with the lowest possible construction and operating costs.

Infrastructure supplier: The supplier builds the infrastructure. Their goal is to create the infrastructure as cost-effectively as possible.

Infrastructure operator: Maintains and operates the infrastructure. The infrastructure operator aims to utilise the infrastructure at the highest capacity in order to achieve the biggest possible earnings by track access charges. Furthermore, they want to maintain the infrastructure with the lowest possible costs.

Any railway specialist can confirm that the interplay of all these actors, with their different conflicting goals, is extremely complex, time-consuming and often grueling. Sometimes, therefore, one dreams of the long-gone monopoly structures before the railway reform. However, anyone who has experienced this – like the writer – knows that these times were equally stressful and inhibited innovation. Instead of complex interactions, the innovation was paralysed by a bureaucratic culture and lack of

Left, innovation in regional transport. Metre-gauge electric railcar of Aare-Seeland mobil, giving full access for handicapped people using a low-floor train entrance and elevated platform. Right, innovation in urban transport. TANGO low-floor trams of Baselland Transport allowing short dwell times and increased accessibility by use of more doors and a low-floor entrance. *Photos Steffen Schranil.*

innovation pressure. 'Back' is not a recipe for the future! Rather, all these actors are required to contribute to innovation if they really believe in railways. This requires a cultural change. Each actor must be aware that they can only survive if the railway survives as a whole.

Conclusion 1: Technical and operational innovation requires a cultural change in the cooperation of the actors; the maximisation of one's own interests must be replaced by the greatest possible strengthening of the railway as a comprehensive system.

Second innovation obstacle: innovation processes

Due to the structure of the railway system, as illustrated, with a large number of actors involved, as well as the strong role of state and society, there are major differences to the innovation in conventional companies in the manufacturing industry. These differences become particularly clear in system innovations and manifest themselves as a second group of barriers to innovation:

Research and development in commercial companies usually takes place in-house or, if carried out by third parties, under the clear control of the commissioning company. Every company depends on research and development in order to maintain an innovation advantage over its competitors. In contrast, rail transport and infrastructure companies have reduced their own research and development in the past and have switched to a functional tendering of supplies. This was further reinforced by GATT (General Agreement on Tariffs and Trade) public procurement legislation. Associated with this was a loss of knowledge, the balance between market requirements and the state of research and science becoming more difficult. Market requirements cannot be quickly and independently transformed into new products.

When introducing innovations in commercial products, the customer acquires the innovative product and profits directly from its benefits. Since railways only sell transport services as the final result of numerous production processes, a large part of the technical innovations in the system do not generate immediate added value for end customers and may not even be perceived by them. Examples are a new propulsion technology for locomotives or a new type of interlocking. The innovation is mostly used by the railway initially to improve the production of transport services – not to improve the transport service itself.

In terms of market penetration, an innovative company has a market advantage in the general economy, as its product has characteristics distinguishing it clearly and positively from products of other companies. In the case of the railways, first the transport service, as already mentioned, is only marginally improved for the customer by an innovation. Second, many innovations require full market penetration. Here, the innovative company cannot create a unique selling proposition because it also relies on the participation of its competitors.

From the perspective of the innovation leader in the commodity goods market, imitation of innovation by competitors is undesirable. However, this is often required on the railways, as system innovations only take effect if all system participants and thus also the competitors implement the respective innovation. By doing so, the willingness of industry to become leaders in research and development is naturally decreasing, since corresponding additional income cannot be generated.

"Close collaboration has brought benefits"

In the past, co-innovation has been common to railways and suppliers as well as between different areas within the railway companies. This close collaboration has brought benefits and has produced many important innovations. Implementation issues were already part of the development process. The railways were available as a test facility for prototypes together with the suppliers. For legal reasons, this is not allowed today and will probably not be possible in the future. There is therefore a lack of legal structures supporting system-compatible cooperation between supplier and railway in development. A central topic is the regulation of intellectual property.

Conclusion 2: The legal framework needs to be further developed with regard to the specific, coordinated forms of cooperation in the innovation process of railways.

Third obstacle to innovation: costs and yields of innovations

A system innovation should, therefore, lead to an improvement of the position of the railway in intermodal competition, in particular to a better economy. This results initially from lower costs and higher yields. What normally happens is that (1) costs are incurred first, followed by increased returns later on, and (2) the relative relationship between costs and revenues may vary greatly depending on the level of use or the level of dissemination of an innovation.

Costs

When determining the cost characteristics, initial costs for the development of the innovation, the preparation for the introduction, the training of the employees, etc., are to be provided, which are already incurred before the first device is put into operation.

With regard to the further cost trends, three cases can be distinguished:

Linear cost curves: Here, the unit costs per installed part are constant. Such cost curves arise, for example, with similar installation of mass components from other engineering areas in railway environments. No further economies of scale are to be expected due to the small additional number of units compared to the overall market. Each piece has the same installation costs under the same conditions. An example is the use of communication components in the train.

Degressive cost curves: Here, the costs per installed part decrease as the number of parts increases. Cost curves of this kind are to be expected above all in the case of innovations that have been specially developed for the railway sector and are being tested first in test applications or as prototypes. Subsequently, the systems are further developed and then installed as an optimised product in large quantities. Another possibility is the introduction of new products with only limited compatibility with existing systems, which initially causes additional costs due to incompatibility. As more new systems are introduced, it is more likely that only the new technology occurs in an environment and thus no costs for additional compatibility adjustments are required. An example of this is automatic coupling.

Progressive cost curves: Here, the cost per built-in part increases with the number of built-in parts. This cost trend curve occurs especially in systems where the favourable cases can be covered first and cases with complicated and expensive installation conditions have to be converted towards the end of the migration phase. Such curves can occur, for example, in the introduction of new components of the safety technology, if initially easily converted interlockings are adopted in simple stations and complicated cases will be converted later.

Revenues

For the benefits of an innovation, characteristic curves can be derived which are analogous to the cost curves:

Linear benefit: Each piece of equipment generates the same benefit. Such curves can be found, for example, in the introduction of similar additional equipment in vehicles with the same average customer frequency. Thus, the introduction of screens to inform travellers about connections always generates the same benefits per traveller.

Increasing marginal utility: Here, the benefit of a system increases with increasing equipment quota. These include especially, innovations where individual vehicles equipped with the innovative device must interact with other vehicles to generate benefits. As a special case, even a certain minimum equipment level is required to generate any benefit at all. An example is the use of intra-train communication, which only generates benefits when equipping a large part of the vehicles of a train.

Decreasing marginal utility: The marginal utility decreases as the number of installed systems increases. An example is the adaptive train control, which constantly defines a new speed target for the train, based upon the general operational conditions. This offers a significant capacity gain on highly loaded routes, but has only a minor benefit on secondary lines.

Transfer requirements

Finally, the economic viability of innovation results from the difference between the costs and the benefits of the innovative systems. Costs, savings and benefit are usually distributed unevenly among the actors involved. Often, the economic situation of individual actors will deteriorate permanently, even if the overall competitiveness of the rail system improves. From a financial point of view, it is therefore necessary to transfer shares of benefits to those actors who incur the main costs. A distinction must be made between the transfer requirement in the migration phase and that in permanent operation:

Migration phase: The transfer requirements during the migration phase concerns the rail system as a whole, which initially becomes more inefficient. For the time being even in the sum of all participants the system is disadvantageous.

Operational phase: In the operational phase, the overall economic situation of the rail system has to improve. So, a sustained transfer requirement refers just to cash flows between system participants to offset persistent cost-benefit imbalances within single actors. External funding is not required because the innovation is beneficial from an overarching perspective.

The overlay of the cost-benefit curve with the penetration-benefit curve shows that the break-even point is primarily defined by the shape of the cost curve. As a result, systems with decreasing marginal utility generally achieve break-even points at lower penetration levels than systems with progressive marginal utility.

Conclusion 3: Transfer mechanisms that, with some sort of credit, bridge the critical initialisation phase of disseminating an innovation, could greatly speed up the dissemination.

Innovation potential and ideas

In other words, system innovations can only be successful if they provide substantial benefits even at a low level of penetration and at the same time do not require high initial investments. This raises the question, which innovations may be considered today as being feasible, providing an answer to the major challenges of the rail system and having a favourable relationship between benefits and implementation costs.

The currently observable innovations in the railway sector can be grouped, for example, as follows:

New concepts of passenger transport: However, since the development and introduction of the integrated timetable in recent decades, this area currently appears to be less creative. The widely stagnating demand shows, however, that an innovation boost is urgently required.

New forms of supply and operation of freight transport: Firstly, attempts are being made to revolutionise conventional rail freight transport, whether with automatic or self-propelled vehicles. Secondly, an almost unimaginable number of intermodal transport systems has emerged, most of which unfortunately fail because of the low cost of competing directly with lorry transport.

Vehicle concepts and vehicle construction: Recent developments show the standardisation and modularisation of vehicles in the sense of standard designs, which are only specifically configured for the customer. This trend will continue to intensify with the internationalisation of the suppliers. Unfortunately, not all railways are willing to formulate their requirements so that they can be covered with standard type vehicles. The innovations in vehicle construction seem to be in the opposite direction with regard to vehicle weights: potential weight savings are offset by stricter safety standards and comfort features, among others.

Vehicle control: The full digitisation of the state-of-the-art traction control system allows novel approaches to automatic train operation (ATO), be it to relieve the train driver, to align the driving style to a predefined target or to completely shift to driverless trains. These innovations are particularly interesting in conjunction with traffic management systems (TMS).

Infrastructure planning and design: Little innovation has been seen in infrastructure planning. The separation of passenger and goods traffic through their own infrastructures is an old idea, but in reality, practically never feasible and ecologically not desirable. The station designs are not very innovative and do not follow innovative concepts that consider the latest knowledge on pedestrian flows.

Infrastructure usage planning: New methods from operations research have proven that the automated generation of timetables is feasible today, even in real time. This is one of the most groundbreaking innovations.

Infrastructure construction and maintenance: Very promising innovations go to sensors, diagnostics and state prediction. This area belongs to big data and will benefit greatly from the corresponding general developments as well as support the further mechanisation of maintenance. Silently, the track construction types and their components are constantly being developed, but without any fundamental breakthroughs being foreseeable. A maintenance-free track compared to the costs of a track on ballast does not seem to be feasible.

Safety and control technology: Digitisation opens the way to the most fundamental changes in this area. This applies first to new interlocking generations without specific national limitations, but a purely generic core. Second, the control technology is constantly being developed stepwise to full automation, first of all applied to the infrastructure, but ultimately the rail system as a whole. It thus becomes the core of the entire planning and production concept of the railway system.

Energy use: New traction and storage modes in addition to the electric traction with contact wire and the diesel engine are – despite extensive research and development – unpredictable. The large train weights and traction power requires amounts of energy that can only be obtained from the catenary or by fuel. More promising is the intelligent use of energy through automated energy-saving trajectories, but also the situation-dependent feeding of the comfort facilities of the train.

In contrast, no innovation will have any chance of implementation, when aiming at splitting the trains into individual vehicles and allowing them to run on demand. In addition to the almost unimaginable challenges in the timely control and management of these units, it is above all the long braking distances of the wheel-rail system that would radically worsen the capacity. 'Railways' will therefore always mean 'trains', but these trains will become shorter and more flexible!

Potential of railway automation

The most significant increase in performance and quality for the users at the lowest possible cost can be achieved by combining ATO and TMS into a fully automated rail system. Key factors are (1) the precision of the operating processes, (2) closed information and production control loops and (3) the automation of all critical operational processes.

"The most significant increase can be achieved by combining ATO and TMS"

The train protection systems, in particular ETCS Level 2, allow driving in the physically shortest possible time of around 100 seconds. In order to use this in daily operation, TMS must automatically generate new timetables about every one to two minutes, which considers the current operating situation and its potential further development. To ensure that these precisely calculated slots can be used by the trains, their trajectories must be defined by correspondingly precise specifications. Since this overstretches the capacities of humans, at least in the nodal areas of the network, so the automatic operation has to take over the train from the driver.

In all passenger trains, passengers can be counted automatically; empty seats can be transmitted in real time to the passengers at the following stations. This improves the load factor and the variation of the stopping times can be reduced. This, together with the high-precision guidance of the trains, will contribute to the homogenisation of slot usage and/or to the minimisation of variations of the train runs and thus maximise capacity.

Even in the future, disruption will not completely disappear. However, if its probable duration can be predicted more accurately, dispatching can get more appropriate and more economic. The accompanying information to passenger and freight customers can also be significantly improved. Mathematical methods, such as neural networks, also allow predicting the expected future component failures. Proactive measures can pre-emptively replace components at risk of failure and thus reduce the frequency of faults.

New technologies for new supply systems

The full automation of the rail system, together with the digitisation of infrastructure management, is the largest foreseeable system innovation, since it changes all subsystems profoundly, from customers to infrastructure:

Standardise and streamline passenger services with denser and strictly systematic schedules for passengers. Since the trains no longer need train drivers, the economies of scale of very large trains are less favorable than they are today. In other words, more shorter trains do not cost much more than one single very long train of the same capacity. Thus, the schedules can be radically intensified practically without additional costs, but providing substantially more revenue.

Standardisation of rolling stock and operational processes; large series of uniform vehicles with economies of scale in procurement as well as efficiency-optimised production with minimised inefficiencies reduce production costs.

Radically simplified track topology and increased availability; leads to drastic cost reductions of railway infrastructure. Train connections no longer need to be concentrated in a few dedicated main stations, because trains follow each other within short intervals anyway. The track layout, even of major stations, will thus be radically simpler, and the railway infrastructure will resemble a metro infrastructure with its minimal topology

Therefore, this innovation strategy makes significant contributions to all four identified priorities:

1. Performance: The rail network can be used to its physical limits. Without adaptation of the topology, at least 15 to 25% higher train numbers are realistic, in combination with innovative service concepts even more.
2. Economic Efficiency: The infrastructure will become much simpler and thus more cost-effective as well as more reliable. At the same time, vehicle costs are falling due to increased productivity, and passenger revenues are rising due to the more attractive offers.
3. Adaptability: Automation allows the permanent adjustment to the effective demand and thus the load variations, regardless of the shift schedules and duty stations of the train drivers.
4. Resource Consumption: Automated train control reduces traction energy requirements. At least as important is the saving of grey energy for the production and construction of the railway infrastructure.

Finally, migration is made easier by the fact that these innovative approaches can be implemented in a modular and successive way, not needing unbearable costs, but already bringing great benefits locally in an early phase.

Synthesis: The Railway 2058 – A quarter of a millennium of innovations

The economic pressure on the railway will not weaken, on the contrary; it will be superimposed by massively increased requirements on performance and quality. "More performance for the same money" will take the place of "less money for the same performance", which, given the inherent economies of scale, can be a huge opportunity for the railways. At the same time, innovation strategy must consider the specific conditions of the rail system.

If the railways want to use them, they have to pursue four strategic directions:

1. Comparative strengths: Focusing on those areas where rail has comparative strengths over other transport systems. Specifically, these are the high-speed connections over medium and long distances, the urban and suburban transport as well as long distance cargo.
2. Information and intelligence: Rail operations today are characterised by open control loops and thus hard to keep within the defined margins. Information technology now enables an interactively and finely regulated network-wide operation on a closed-loop-basis.
3. Highly efficient and available infrastructure: Reducing costs and increasing availability of infrastructure, especially in the case of track and civil engineering. This is in addition to low wear components, continuous condition monitoring and streamlined maintenance procedures.
4. Minimisation: Advances in materials technology do not seem to have arrived at the railways yet, and progress is essential, and certainly possible.

The railway will be able to remain a relevant means of transport if it succeeds in minimising infrastructure costs while maximising capacity utilisation. Otherwise, it becomes a niche product, because many years of experience show that a really cheap train is physically not possible – the train is forced to maximise load and utilisation! Mixed traffic will continue to be the norm, minimising infrastructure investment as well as land consumption and landscape degradation.

If the railway uses its innovation potential, it will be marked in 2058 by fully automated planning and operation and thus maximum system performance and tight monitoring of the system and vehicle condition. Availability maximisation through early failure detection and novel, metro-like nationwide services with the greatest benefit for passengers together with radically simplified infrastructure with lower construction and maintenance costs.

"Fully automated planning and operation and thus maximum system performance"

All required innovations are already present in their basic principles or initial applications. The railway is obviously still capable of innovation, but its innovations must not be hampered by regulations.

A major challenge for the coming decades will initially be that all actors see themselves as solitary contributors to the innovation process, regardless of their direct selfish interests. Standardisation and procurement procedures must be designed and practiced as drivers of, not as brakes on innovation. Finally, financial mechanisms have to be developed which balance asymmetric costs and returns between the actors. This should be understood as an opportunity to develop a new cooperation culture between all actors of the railway system under the new conditions, instead of mourning the patterns of cooperation of bygone days

In 2058, the railways will have been around for a quarter of a millennium, comparable to the lifetime of the Roman road network. The railway network will then be highly accurate, responsive, proactive, robust and economical. Maybe it will be less extensive, but it will meet even more the needs of the mid-21st century and continue to serve as a valuable, useful land transport alternative to the road.

About the author ...

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ETH Zurich (Swiss Federal Institute of Technology in Zurich; German: Eidgenössische Technische Hochschule Zürich) is a science, technology, engineering and mathematics university in the city of Zürich, Switzerland. It is an integral part of the ETH Domain that reports to Switzerland's Federal Department of Economic Affairs, Education and Research.

What do you think?

Do you agree with Ulrich's view of the past and the future? Do you think that the 40-year innovation constant is still appropriate, or is change more rapid than in the past? Do you think that we are committed to innovation, or are we always playing 'catch-up' as an industry? We'd love to hear what you think, email your views to **irsenews@irse.org** for inclusion in our Feedback column.