The CER Essay series

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Railway innovation in the 21st century

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CER Essays

The CER Essays initiative features a series of essays that show the rail sector as contributing not only to EU transport policy, but touching on different aspects of society at large. Topics covered by the initiative will range from modal shift, climate policy, infrastructure investment, high-speed rail, demography and more. Each essay will feature a different topic and be co-authored by a CER member CEO and a leading academic from the same country and will be used to spark debate among political stakeholders on the role of rail in the EU.

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Contents

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About the authors

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Chairman and CEO, SNCF Group

Mr Farandou began his career in the Denver, Colorado office of Amax, a US-based mining company, and joined SNCF in 1981. He worked a full range of transport jobs from signaller to train driver, train controller to Managing Director of Thalys International, an SNCF subsidiary

By 2006 he had joined SNCF's Executive Committee, and that year he created and began managing SNCF's Proximités division, which included Transilien, TER, Intercités and the Keolis-Effia Group. In 2012, Mr Farandou was named Deputy CEO of SNCF Group and began a seven-year term as Executive Board Chairman at Keolis, an urban transport specialist.

As SNCF's Chairman and CEO, since November 2019, Jean-Pierre Farandou is working with his management team to pursue the Group's strategy of expanding rail use in France. He has also positioned SNCF Group as a global leader in achieving sustainable passenger and freight mobility by 2030, and as a vital player in meeting two of society's most urgent needs—fighting climate change and promoting regional development—even as it rises to the challenge of a fully liberalized rail market.

Jean-Pierre Farandou holds a degree in engineering from École des Mines de Paris and is a Chevalier de la Legion d'Honneur.

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Alain Quinet, an Inspecteur Général des Finances, has worked in French public institutions since 1988.

In 2002, He was appointed economic advisor to the Prime Minister, and in 2005 took up the post of deputy director of his cabinet for economic affairs. In 2007, Alain Quinet became Director of Réseau Ferré de France. From 2008 to 2010, he was Chief Financial Officer of the Caisse des Dépôts Group and Chairman of CDC Infrastructure. In December 2010, Alain Quinet was appointed Chief Operating Officer of RFF. He is now Executive Director for Strategy & Corporate Affairs at SNCF Réseau and Co-Chair of PRIME, the platform of European Railways Infrastructure Managers.

He is the author of numerous articles and reports on Climate change, Long-term investing and infrastructure.

Alain Quinet,
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Executive Summary

Railway innovation in the 21st century

Railways were certainly the most visible element of the first two Industrial Revolutions, that of the steam engine and then that of electrification. In a Europe that has reached economic maturity, railways have continued to be a vector of innovation, notably through the emergence of high-speed rail and the development of mass transit in major cities.

Maintaining this momentum is essential. It will not be possible to achieve the highly ambitious, necessary objectives for rail development which the European Union and its Member States have set for themselves through the Green Deal, without rolling out major innovations that make it possible to develop rail traffic on the existing network.

Up until now, traffic has mostly developed through the creation of new lines, and there is no doubt that several interconnections – particularly high-speed ones – still need to be built. But it will be neither technically nor financially feasible to develop traffic solely by building new lines. The main challenge now is to roll out innovations, particularly in order to improve the reliability of the rail system and offer new services that are key to the attractiveness of rail transport: digitalisation of signalling, increased capacity and punctuality, predictive maintenance, station flow management, digital freight trains, digital services for passengers, real-time information, and new intermodal mobility offers.

The major rail operators (transport service providers and infrastructure managers, etc.) are not “inventors” in the strict sense of the term, but integrators of “technological building blocks”, capable of making long-term investments and ensuring the coherence of technical systems. They will be all the more capable of taking full advantage of the potential offered by the abundance of new technologies if they develop collaborative innovation, supported by a large enough ecosystem of laboratories, businesses, and start-ups.

Executive Summary

Contemporary railway innovation, taking full advantage of new technologies, is based on two prerequisites:

- The first step is to renovate the network. We have inherited a railway system that is huge –200,000 km of lines in Europe– and ageing. Renovation is the prerequisite for modernisation: it would be economically and commercially inefficient to deploy rail innovations on a network that is subject to slowdowns or breakdowns;

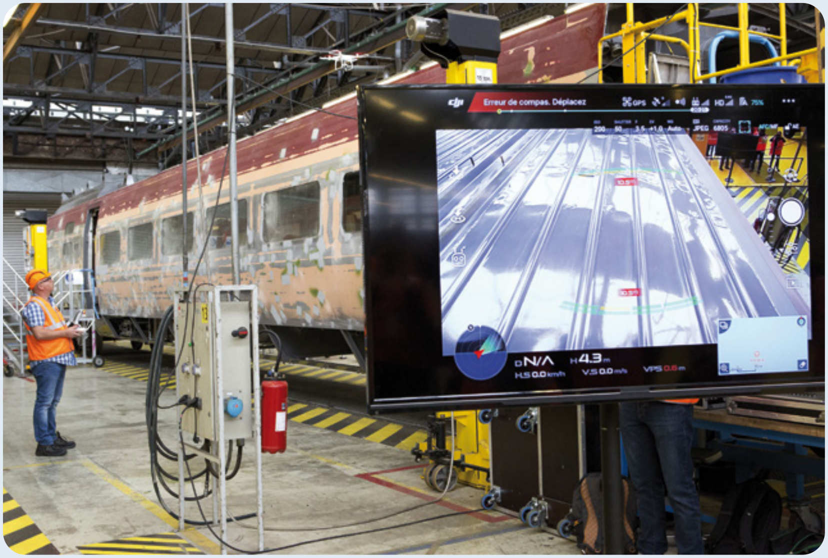
- A second requirement then, is interoperability: innovation must bring European networks closer together, not fragment them. Without this, the growth potential of cross-border traffic will struggle to materialise. The roll-out of the ERTMS in Europe is a key test in this respect.

In this context, Europe has an essential role to play in creating the conditions for interoperable innovation:

- Through its technical requirements, which must provide a stable common framework, because stability and visibility make the large-scale deployment of new technologies possible;

- Through its support for innovation. With Europe's Rail, a new cycle of European innovation and research has begun for the rail industry. Activities will run from 2023 to 2030, using an integrated systems approach to deliver a high-capacity, flexible, multimodal, and reliable European rail network.

- Through its financial incentives for the deployment and industrialisation of interoperable technologies on the existing network, in addition to incentives for new interconnections.



Alberto Mazzola

CER Executive Director

Foreword

The Green Deal is the EU's answer to the ongoing climate crisis, a once in a lifetime opportunity to modernise the EU's economy and society by reorienting them towards a just and sustainable future. However, reaching net-zero emissions will require faster innovation in technology and adaptation of business models. Companies, and railways, will also need to deploy intelligent solutions to address the current and future challenges faced by the European economy.

After nearly two centuries of existence, European railways remain a future-oriented transport solution and are strategically placed to help the EU deliver on its Economic, Social and Environmental promises. The railways have in their innovation agenda to improve the network by reliable, safe, high-speed infrastructure and at the same time get the most out of existing network by modernisation and digitalisation.

Rail has the potential to provide high-performing, quality and more sustainable alternatives to individual car rides and short-haul flights. Suitable infrastructure will be essential to connect European capitals and major urban nodes through high-speed rail services. Challenges around urban areas in terms of congestion and pollutants are to be tackled by the modernisation of railway lines for regional rail passenger traffic.

Being rail a system, system innovation and technologies can greatly improve efficiency and productivity as well as performances and quality. The European Rail Traffic Management System (ERTMS) is a key enabler to improve cross-border operations by providing a single European command, control and signalling system, ensuring transport reliability, increasing capacity, and improving safety levels. Rail infrastructure capacity will also benefit from Digital Capacity Management (DCM) to reduce bottlenecks through smart data management and put more trains on the existing infrastructure. This will be also useful for better planning maintenance works of the existing network.

For passengers, harmonisation of ticket sales and distribution based on sector-designed initiatives and Mobility as a Service are to provide tools for operators and customers. European railways are committed to the implementation of the CER Ticketing Roadmap with the objective of achieving a seamless passenger experience when buying tickets, together with journey continuation and providing, real-time information.

New technologies such as Digital Automatic Coupling (DAC) will be key to enable the needed increase in efficiency and transparency of rail freight. The rail sector is now in the migration phase and requires a European master plan for the deployment of DAC with suitable funding. ERTMS, both on trackside and onboard, needs to be deployed at a higher pace with a centralised EU level ERTMS governance and higher cooperation among the different stakeholders.

Introduction

Today's European railway system is the result of two centuries of demographic and industrial growth, and national planning policies. After strong growth in the 20th century, its size has stabilised over the last twenty years, with some 200,000 kilometres of lines in use, 5% of which are high-speed lines. It currently accounts for around 10% of passenger and freight traffic.

Railways were certainly the most visible element of the first two Industrial Revolutions. From the early 19th century onward, steam-powered trains carried goods and people faster than at any other time in the history of the world, encouraging the development of trade and the opening up of new markets. The electrification made possible by the Second Industrial Revolution made the rail network even denser and more extensive. In a Europe that has reached maturity, railways have continued to be a vector of innovation, particularly through the emergence of high-speed rail and the development of mass transit in major cities.

Achieving the highly ambitious, necessary targets for ecological transition that the European Union and its Member States have set themselves through the Green Deal will require strong growth in rail traffic over the coming decades. This will involve developing new lines, particularly where high-speed connections are lacking, which is the case for cross-border links between France, Italy, and Spain, or East-West links in the centre of Europe. But it will be neither technically nor financially feasible to develop traffic solely by building new lines. It is at least as important to seek an increase in capacity and service quality on the existing network, particularly in the major metropolitan areas.

It is in this new context of modernisation of the existing network that innovation is now taking place. The most promising technologies concern infrastructure, its use in dense areas, rolling stock and on-board systems, particularly through automatic operation, as well as passenger services, with a view to multimodality, what has been dubbed "Mobility as a service".

The challenge of innovation is an ongoing one for each of the national networks. But such innovations still need to be interoperable in order to enable traffic to develop throughout the European Union. A comparison with other major regions of the world shows that long-distance traffic in Europe is not up to its potential, due to the fragmentation of networks and a lack of interoperability. Paradoxically, the modernisation of the railways, through electrification and then signalling, has had the effect of accentuating this fragmentation, due to the development of specifically national technological solutions. This risk persists with the new ERTMS signalling system, which does not yet fully meet this objective of interoperability. If Europe wants to achieve the objectives of decarbonising mobility by relying on its rail "backbone", its railways must enter squarely into a third Industrial Revolution based on "natively" interoperable digitalisation.

I) Rail at the heart of the Industrial Revolutions

Even if the quantitative share of rail travel is currently limited to 10% of journeys, it is important to appreciate the role it plays in structuring mobility, and economic and social development. Over the years, the railway has been one of the main points of application for the generic innovations that have shaped the Industrial Revolutions and post-war Europe.

A) Rail, a major innovation

The birth of the railway during the First Industrial Revolution

The invention of the locomotive, supported by developments in the steam engine as well as in the design of rails and track, made it possible in a short span of time to switch from systems using wooden rails, then cast iron or iron, to steel, and from human or animal traction to powerful machine traction.

The steam engine was designed by James Watt in 1769, and it was perhaps the most important invention of the Industrial Revolution, without which fast trains would not have been possible. In 1801, Richard Trevithick invented the first steam-powered vehicle, and then made it operational by running it on specially-built rails. The idea of a steam train was born.

In 1812, the American engineer Oliver Evans published his vision of the development of the steam railway, with a network of long-distance lines served by fast locomotives, linking towns together and significantly reducing travel times for both passengers and goods. One year later, George Stephenson persuaded the manager of the coal mine where he worked to let him build a steam engine. He built the Blücher, the first locomotive using wheel adhesion: the Stockton-Darlington railway company opened its first line on 27th September 1825 with Stephenson driving the engine himself.

In this new boom, the United Kingdom leads the way both in terms of capitalisation and the length of its networks: the very strong stock market expansion of the 1840s in England also known as "Railway mania", gave England half of Europe's 9,500 rail kilometres by 1845. In 1845, a line linked Manchester to London in eight hours' travel time, whereas a passenger on the old stagecoaches would have covered the same distance in 80 hours.

The electrification of railways during the Second Industrial Revolution

The 1785-1848 period is almost universally considered by historians and economists to be that of the First Industrial Revolution. It was as if, between 1850 and 1875, we were witnessing both the consolidation of the technical system that had emerged from the First Industrial Revolution and the preparation of a second stage of industrialisation. In the traditional fields of textiles, steel-making, and the use of steam power, for example, technical improvements were continuous. Meanwhile, industrialists and scientists were "gathering" the achievements of past inventions, for example in the field of electricity, and developing new techniques that would become operational between 1870 and 1900 and form the basis of the future technical system.

It was the advent of electricity that marked the beginning of the Second Industrial Revolution, with its first applications in the railway sector. The first electric train was presented by Werner Von Siemens at the Berlin exhibition in 1879. The first major applications did not really get off the ground until the turn of the 20th century: in France with the 30.5-kilometre St Georges de Commiers - La Mure line in 1903, followed by the Paris - Orléans line and the Compagnie de l'Ouest (Ouest-État).

Extending the areas of influence of markets and sources of supply involved in particular the construction of railways in Continental Europe, but also in the colonies. However, the networks were designed completely differently in the two cases. Whereas in Europe and the United States the aim was to link up different regions to open them up, the railways built in Africa and India were designed simply to link production areas to the sea, to ensure the flow of raw materials and goods by sea. This partly explains why technical progress did not spread to other countries. The increase in transport safety resources (Westinghouse compressed air and vacuum brakes in 1869, automatic, and then electric, signalling from 1885, etc.) was also the result of numerous innovations. But the basic technology remained that of the steam engine, although by the end of the period, electric traction had been developed through the use of "diesel-electric".

B) The economic and social transformations made possible by the development of railways

The railway, a unifying factor

The industrial concentration that began with the First Industrial Revolution took place in two ways: either around existing towns that were already highly organised, or because of the low cost of land or energy sources, in places where there was no pre-existing social life. In this second case, a new type of habitat and lifestyle has been created around economic activity. The rhythm of life was modelled on that of the factory, with the entire local population taking part. Housing and ancillary activities were often owned and managed by the factory owner. This situation contrasted with that of workers in Paris, for example, who lived alongside a diverse population (in terms of social level and type of activity) and had a variety of infrastructures and centres of interest around them.

The extent of the economic impact of railway development on economic development remains a subject of debate among economists, in the wake of the work of Nobel Prize-winning economist Robert Fogel (1962). However, there is no doubt that the railways, by reducing travel cost and time, have had a lasting impact on territories and trade:

- Lower transport costs enabled manufacturers to take full advantage of the economies of scale brought about by the concentration of production. Factory owners could then build their factories closer to towns and were no longer restricted to sites close to waterways or coal deposits. Suburbs grew up around cities, with workers travelling by train to work in the city centres. Manufacturers no longer needed to keep large stocks of goods but could dispatch them as soon as they were ready. The savings generated by reducing the number of warehouses meant that more money and space could be devoted to manufacturing, reducing costs, and creating more jobs.

- The opening up of regions and the development of trade have encouraged the creation of truly national economies. This is why many economists saw the railway as a tool for national unification. This was particularly true of Friedrich List (1857), who saw the railway as the necessary complement to the *Zollverein* (customs union) in the construction of a unified Germany.

- Within such new national markets, the railway enabled territories to specialise according to their "comparative advantage", to use the expression of the classical economist David Ricardo, stimulating the growth of wealth through the development of trade. Fishing zones could deliver products such as fresh fish to inland regions. Similarly, seaside resorts flourished thanks to cheap weekend excursion tickets, and factory workers formed clubs to which they regularly contributed in order to save up for a company outing.

The knock-on effect on industry

As well as transporting people and goods more quickly and cheaply, the new railways led to the creation of fully-fledged industrial sectors. Steam trains needed huge quantities of coal, which created more mines and more jobs (far more

than those that were lost in other areas). The steel and iron needed for locomotives, wagons, rails, bridges, and tunnels led to a boom in those industries. Britain produced just 2.5 million tonnes of coal a year in 1700, but by 1900 that figure had risen to 224 million tonnes. The railways also enabled vast construction projects that employed tens of thousands of workers. The railways also needed engineers, drivers, station managers, ticket collectors and, in the stations, porters, toilet attendants and refreshment stand staff, because millions of first-, second-, and third-class passengers were now using rail services on a regular basis.

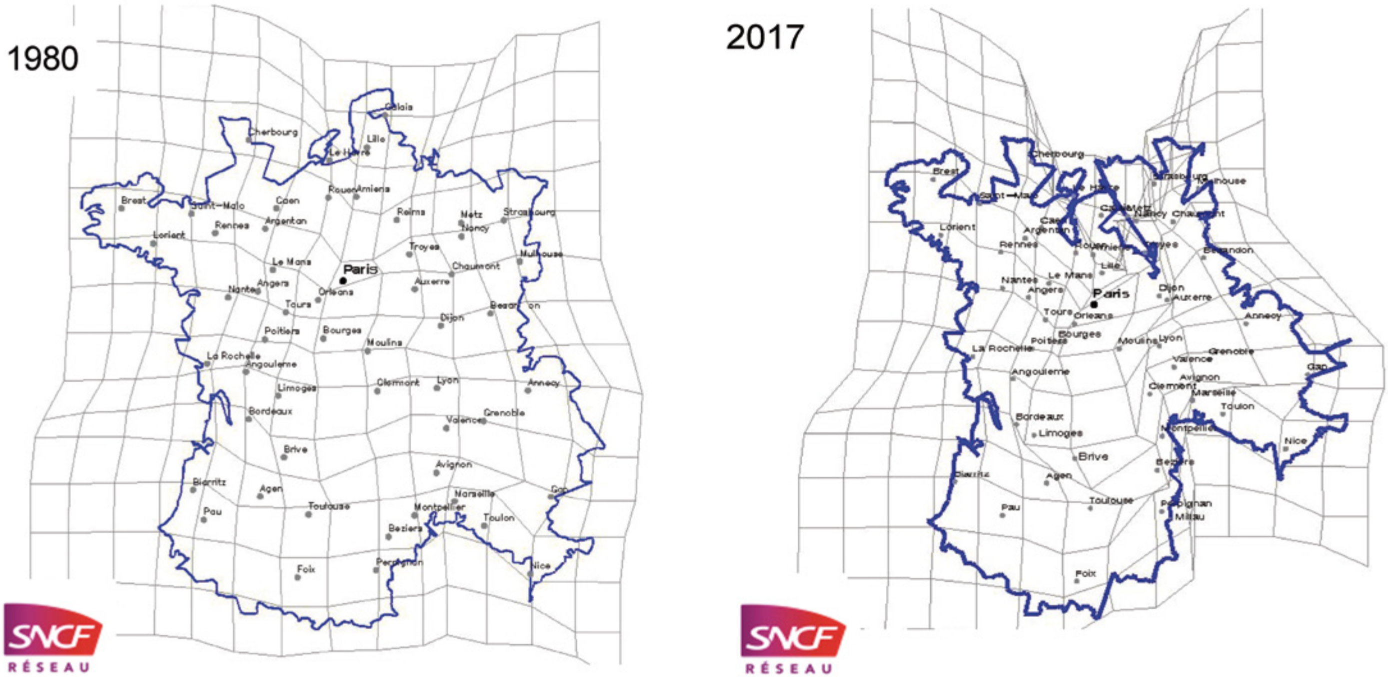
High-speed rail is based on a relatively limited number of innovations but their integration into a coherent technical system enables the implementation of a high-value service for passengers.

C) High-speed rail, the answer to intermodal competition

High speed rail is not part of a "new industrial revolution", but rather a major industrial innovation in European countries that are already mature and have even begun a long cycle of de-industrialisation. High-speed rail is based on a relatively limited number of innovations (train set articulation, on-board signalling, high-speed train set, network of new lines, etc.), but their integration into a coherent technical system enables the implementation of a high-value service for passengers.

This innovation came at a time, in the 1960s, when there was considerable competition from other modes of transport, particularly the private car, the use of which was encouraged by the development of motorway networks. This period also saw the "democratisation" of air transport. It was against this backdrop that SNCF engineers came up with the TGV (train à grande vitesse) high-speed rail system, capable of offering a competitive solution in the face of such new competition.

As the anamorphic maps of France below show, high-speed rail has the effect of reducing the distances between France's major metropolises, and making the country's economic geography denser, with significant economic gains as a result. In particular, a recent econometric study (Charnoz et al, 2018) has shown that the construction of high-speed rail lines has led to greater specialisation of companies' establishments and an increase in their profitability. Another study, based on Japanese data, shows that high-speed rail helps improve matching between companies in the subcontractor/supplier relationship (Bernard et al, 2019). By enabling the creation of a high quality of service transport offer, aimed primarily at major cities, high speed rail is a transport system that is particularly relevant and suited to contemporary European economies.



Source: SNCF Réseau

The development of high-speed rail can be seen in relation to the evolution of the contemporary production system, marked by a form of metropolisation of the economy. Research has shown that railways can make a positive contribution to growth in contemporary economies by improving the productivity of firms. Using the typology proposed by Duranton and Puga (2004), we can identify three main mechanisms by which transport infrastructure can improve business productivity:

- Improved accessibility leads to productivity and wage gains when there are economies of scale in production (Sharing);
- Better accessibility means a better match between labour supply and demand, with companies finding better qualified workers for the jobs (Matching);
- Finally, improved accessibility brings a large number of people together, and facilitates Learning in the broadest sense (study, research, exchange of practices or information).

II) Innovation in order to develop Rail Traffic

Europe needs to take full advantage of the opportunities offered by digital technology by promoting innovation that is both Brownfield and interoperable.

The development of rail traffic has traditionally involved the opening of new lines. But it must also increasingly involve the modernisation of existing lines and the promotion of new uses – either for daily journeys – mass transit – Metropolitan Regional Express Services – or for long-distance travel. To this end, Europe needs to take full advantage of the opportunities offered by digital technology by promoting innovation that is both "*Brownfield*" –focused on the performance of existing networks– and interoperable from one network to another.

A) Rail's contribution to the European Green Deal

Europe has set itself some very ambitious targets for rail development: doubling rail freight traffic and tripling high-speed rail traffic by 2050.

The ecological virtues of rail innovations

In fact, rail has three major environmental advantages that make it essential today:

- It saves energy: wheel-rail contact, steel on steel, provides low rolling resistance, unlike, for example, tyre-road contact, rubber against asphalt, thus minimising energy consumption. The study, The future of Rail (2019) published by the IEA, shows that rail transport is the least energy-intensive mode of transport.
- It saves land: with its high load capacity, it minimises the consumption of space, particularly in urban areas. Along with other public transport modes, it is the only one capable of handling *mass transit*. Cities and metropolises will continue to grow, giving greater comparative value to rail, which saves space and energy and prevents road congestion. Rail flows, which used to be predominantly intercity, are increasingly becoming mass transit for everyday journeys.
- It saves CO_2: its extensive use of electric traction (in Europe, 80% of trains run on electric traction) minimises greenhouse gas emissions thanks to the decarbonisation of the European energy mix. The European Green Deal outlines the European Union's major climate objectives up to 2050: achieving climate neutrality by 2050 (zero net emissions –"ZNE"– of greenhouse gases); reducing

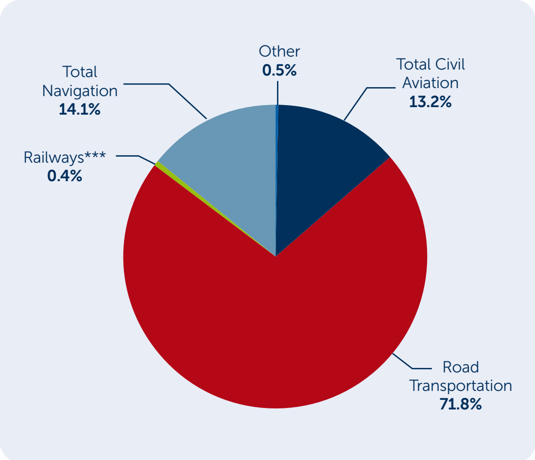
FIGURE 1: ENERGY INTENSITY OF DIFFERENT TRANSPORT MODE, 2017

Notes: toe = tonne oil equivalent. The boxes in this figure indicate the range of average energy intensity in various countries, while the horizontal lines represent the world averages.

Sources: IEA Mobility Model (IEA, 2018a), using assessments based on UIC (2018a); UITP (2018d); ITDP (2018a); National bureau of Statistics of China (2018); Eurostat (2018); Indian Railways (2018a); Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017) and Russian Federation State Statistics Service (2018).

transport emissions by 90% by 2050. As shown in the graph below, taken from the technical preparatory documents for the Green Deal (*Commission staff working document*, 2020), the railways have already reached the "ZNE" objective.

FIGURE 2: SHARE BY MODE IN TOTAL TRANSPORT GHG EMISSIONS, INCLUDING INTERNATIONAL BUNKERS, IN THE EU-27 IN 2018



Source: Commission staff working document, 2020

Brownfield innovation as a condition of the Green Deal

The quantitative objective of developing the railways must be achieved primarily by modal shift if we are to combine CO_2 savings and energy sobriety.

Modal shift is achieved by new lines, and in particular by the time saved by high-speed rail, which is the only way to compete with both road and air. The intensity of high-speed rail traffic in Western Europe perfectly illustrates the relevance of this mode for linking major European cities 300 to 800 km apart. In Europe, there is still a need for new lines to connect networks and create alternatives to air travel: connections from the Baltic networks to the European network (via the *Rail Baltica* project), high-speed connections from the Italian network (via the Lyon-Turin tunnel and its future access points) and from the Spanish network to the French network; East-West connections in Central Europe.

But modal shift must also be the result of improving the performance of the existing network, with the key need for "*Brownfield*" innovation, innovation based on improving the network and promoting new services. This is particularly true of those parts of the network that carry most of the short-distance traffic used by everyday travellers. To attract more passengers, rail must be able to offer a multimodal mobility service of equivalent quality to the private car. Rail services must therefore be able to offer a high-performance service in terms of frequency, range of hours, and continuity of service, offering users flexibility.

The performance of the network is therefore assessed in terms of its ability to carry a large number of passengers in complete safety, under satisfactory conditions of comfort, regularity, and reliability.

Does reducing congestion in metropolitan areas require the creation of genuine Metropolitan Regional Express Networks (SERM) offering a regular, scheduled, integrated, multimodal rail service for "everyday travel" regular, scheduled rail service, integrated into multimodality?

Desaturating nodes can involve heavy investment to change the configuration of the network: to "relieve" city centres by means of tangential and bypass lines, and to develop suburb-to-suburb links (as part of the Greater Paris approach). But it can also involve targeted investment or changes to standards in order to increase capacity at stations and forecourts and facilitate last mile connections. In a few years' time, the Ile-de-France (Paris) region will have an "enhanced" network of modern RER (mass transit) trains, complemented by a ring of tram-train lines and stations interconnecting with the Greater Paris metro. The deployment of more efficient signalling systems, such as the Nexteo system in the Ile-de-France region, is another response to this challenge.

In France, around ten SERM projects with traffic development potential have been identified to date. In this context, a gradual increase in the service offering will have to take shape, initially with a constant infrastructure, by modernising and digitalising the network, and then by implementing the more or less heavy investment needed to support the growth in demand for rail transport.

In densely populated areas, modal shift effects are spontaneously only second rate. This has been seen in experiments to develop urban public transport: a large proportion of the increase in ridership has come from new users, who previously did not travel, or from users who were already using public transport, albeit by a slower route or mode. Another, smaller, portion comes from former car users. But the space they freed up on the roads and streets was taken up by new motorists, who wanted to take advantage of the improved traffic conditions. In such circumstances, modal shift implies constraints on the use of private cars, which the development of new transport services can make more acceptable to the inhabitants of metropolitan areas.

Rail innovation for interoperability

The *Green Deal* is about modal shift at all levels: urban, metropolitan, regional, national, and European. It is therefore important that innovations in the rail sector should help modernise each rail system, increase its performance and accessibility, and improve interoperability.

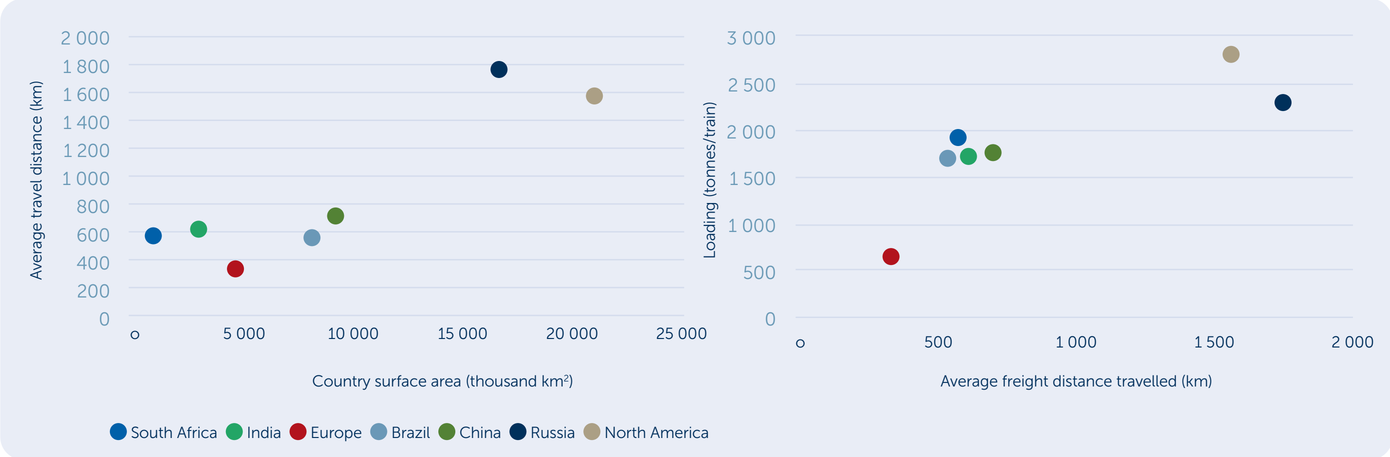
As we know, European rail systems have been built on a national basis, alongside one another and sometimes against one another. With the modernisation of the railways, the various historical techniques, initially limited essentially to track gauge, were intensified with electrification and then the emergence of modern safety and signalling systems: in the second half of the 20th century, rail networks were less interoperable than they had been before the two world wars.

The result is that today's long-distance rail traffic is not up to the level that Europe's geography allows. This is what the IEA's analyses show, for passengers, but especially for freight (graph below).

It is now essential to make innovations interoperable to enable the development of short- and long-distance cross-border traffic. To implement a common reference system, Europe has introduced the Technical Specifications for Interoperability as part of the directive on the interoperability of the rail system, which establish

The Green Deal is about modal shift at all levels: urban, metropolitan, regional, national, and European.

FIGURE 3: AVERAGE FREIGHT TRANSPORT DISTANCE VERSUS COUNTRY SURFACE AREA (LEFT) AND TRAIN LOADING VERSUS AVERAGE TRANSPORT DISTANCE (RIGHT), 2016



Source: IEA (2019)

the rules that are essential for harmonising the European railway area. The Technical Specifications for Interoperability (TSIs) are designed to enable drivers to operate in a unified manner across Europe, thanks to identical signalling systems in all countries, and to enable the number of trains to be increased. Applied to both rolling stock and infrastructure, the TSIs lay down the technical conditions needed to guarantee the safety and interoperability of the various elements of the rail system.

In the more specific area of signalling, the deployment of the new ERTMS signalling system – which manages the headway of trains on a line and enables interoperability of traffic – is being put to the test. The new TEN-T regulation put forward by the European Commission provides for accelerated deployment of ERTMS on the extended core network by 2040 and the global network by 2050.

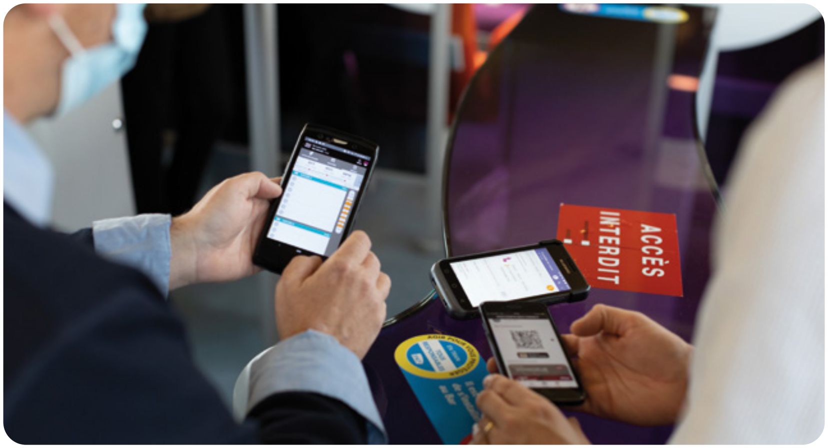
In this respect, the roll-out of the new ERTMS (European Rail Traffic Management System) signalling system is the key test for the introduction of interoperable innovations. This European standard comprises three systems:

- ETCS (European Train Control System): on-board system used to supervise train movements and, if necessary, bring the train to a halt
- RMR (Railway Mobile Radio), a system based on GSM-R or soon FRMCS, which enables communication between the train and the track
- ATO (Automatic Train Operation), which enables the train to be driven fully automatically

Once fully deployed, ERTMS will enable:

- Greater interoperability between the various European networks: rolling stock equipped with it can travel on the entire continental network using this single on-board system.
- Increased capacity and safety on the lines.
- Economies of scale, particularly for trains, where the number of on-board equipment units could be reduced, and for infrastructure, with the disappearance of side signals.

B) Towards more collaborative rail innovation



Technical progress corresponds to innovations resulting from the application of science and technology to the economic process. Where does innovation come from? Can it be a spontaneous creation? Is it the mark of a break with the past, of a sudden change? In the history of French railways which began in the early 19th century, the development of the railways was largely based on a strong political will on the part of the central government in the direction it took and the resources it deployed. However, it was private initiative that led to the creation of the first lines, and the central government belatedly came to organise this sector of activity and create the necessary rules and standards in economic and safety terms.

The Schumpeter–Arrow controversy

Behind the answers that economists have given to this set of questions, it seems that two very divergent conceptions of technical progress are emerging: Schumpeter's creative destruction, and the peaceful coexistence of old and new technologies. In the first case, it will be emphasised that the railways ousted the horse before seeing their market share shrink in the face of the road; in the second case, the sustainable coexistence of several modes of land transport and the emphasis now placed on multimodality will be highlighted.

According to Schumpeter (1939) technical progress is not continuous; it is the result of very specific actions taken by entrepreneurs. Schumpeter said: "*The carrying out of new combinations we call "enterprise"; the individuals whose function it is to carry them out we call "entrepreneurs"*. The entrepreneur themself does not have to be the initiator of the research. Their role is to apply ideas to the production process that will transform the relationship between the entrepreneur, as producer, and the markets, with all the risks that this entails. This notion of risk is essential: not every producer is capable of taking a risk. It takes a specific skill and qualification to become an innovator, in fact an "entrepreneur".

"Why doesn't evolution proceed continuously, but in fits and starts? This is exclusively because the execution of new combinations is not evenly spread over time", says Schumpeter. The expansion phase is explained by the clustering of new combinations that allow wages and interest rates to rise and unemployment to fall. Such phases are obviously linked to the simultaneous appearance of numerous entrepreneurs. The emergence of one entrepreneur will make it easier for other entrepreneurs to emerge.

Schumpeter is best known for his theory of creative destruction. He nevertheless emphasised the crucial role of large companies, with their strong market power, in the process of innovation. He sees two reasons for this:

- Concentrated markets, organised as oligopolies or monopolies, reduce the uncertainty associated with innovation activities, because it is easier to anticipate the actions and reactions of other agents. In addition, large companies with a certain degree of monopolistic power can generate profits more easily, which implies a greater capacity for self-financing R&D activities that are by their very nature risky.

- Such companies are driven to innovate in order to maintain their market power and face competition from other new entities.

Arrow (1962) provides a new perspective. He argues that increased competition in goods tends to encourage investment in R&D. In his view, this is due to the "cannibalisation effect": a monopoly has little incentive to invest in R&D because its expected gains from innovation are limited by the size of its current market. A significant proportion of the results of its innovation will simply replace its pre-existing results.

The decision to innovate is in fact a risky process, since innovators are generally not sure in advance that their inventive efforts will be rewarded commercially, or even that they will succeed technologically. In fact, according to Arrow, it is very simple to show that in the case of a process innovation consisting of lowering the marginal cost of production, the incentive for a monopoly to innovate is weaker than that of a firm in perfect competition. This result, known as the replacement effect, simply conveys the fact that by carrying out a process innovation, a monopoly secures a smaller profit differential than a company in perfect competition. In fact, by innovating, a monopoly replaces itself by simply moving from a monopoly profit before the innovation to a higher monopoly profit after the innovation, whereas a company in perfect competition obtains a higher profit differential since it moves from a zero profit before the innovation to a monopoly profit after the innovation.

The role of rail operators

Since the development of these two theories, empirical research has painted a picture of a more nuanced reality, where the two theories do not conflict but coexist. Small and large companies are complementary in their innovations, which can be explained by asymmetries in incentives and financial capacity:

- Large companies are more inclined to invest in incremental or process innovations. Indeed, by innovating, part of their new sales will come from cannibalising their old product, and their growth expectancy is limited. In this sense, small businesses have more incentive to develop disruptive innovations.

- But it is clear that large companies have greater access to finance than small ones. The latter are penalised by their lower collateral, the greater perceived risk associated with their financing, and their lower capacity to diversify into R&D activities. For young innovative companies, the lack of information, particularly about their past activities, further increases the risk associated with their financing.

Historically, the railways has relied on large private and State-owned companies, because the rail business model is highly capital-intensive: infrastructure is a natural monopoly; the number of operators capable of investing in rolling stock is limited. The same applies to the number of suppliers which, despite the European Commission's demanding competition policy, remains limited due to the scale of investment in R&D and capital. The major operators in the rail sector are thus "Schumpeterian" entrepreneurs. They are not inventors in the strict sense of the term, but integrators of "technological building blocks", capable of designing coherent technical systems and taking advantage of economies of scale.

Such companies now need to develop a more collaborative approach to innovation, along the lines of other industrial ecosystems. We are living in an era where a wide variety of generic technologies are being deployed simultaneously, whereas previous Industrial Revolutions focused on one key technology (the steam engine and then electricity). Collaborative innovation is precisely the approach by which the new opportunities offered by autonomy, robotics, the man-machine interface, geolocation, 5G, data storage, artificial intelligence, batteries, hydrogen, etc. will find their way into rail applications.

> *Companies now need to develop a more collaborative approach to innovation, along the lines of other industrial ecosystems.*

Innovating for a low-carbon, digital railway

The principle of collaborative innovation has taken on its full meaning when it comes to decarbonisation. In the field of traction energy, the solution of battery-powered trains is beginning to be deployed: the batteries on board the train will be recharged when the trains run under catenary lines, but also via dedicated infrastructure in non-electrified areas, with rapid recharging points or partial electrification. In addition to battery-powered trains, the beginnings of hydrogen trains are part of the technological transformation of the sector that will have a positive impact on industry, users, and our environment. Gradually replacing diesel-powered trains with hydrogen or battery-powered trains is one of the major trends emerging in the rail sector. Adapted solutions (light or very light rail) coupled with lighter infrastructure could meet some of the mobility challenges of sparsely populated areas, where rail services are currently struggling to find a business model.

In the digital field, the rail sector is working on the automation of trains, facilitated by the presence of rails and signalling to reinforce safety. In Germany, the *safe.trAIn* project led by Siemens is due to continue until 2024. Its aim is to use artificial intelligence technologies to optimise train movements and hence the use of infrastructure. It also aims to pave the way for autonomous trains to run on the general network, and not just on closed circuits. As for SNCF, major innovation programmes carried out in partnership with industrialists are enabling the creation of autonomous train prototypes and the validation of traffic trials in real conditions up to the GOA4 level, the highest level of autonomy. In terms of technology, the systems are relatively similar to those developed for the car industry, particularly around LIDAR, which enables proper perception of the signals deployed around the track. The SAMIRA system, funded by the European Union, uses technology to automate freight switching manoeuvres.

New digital and telecommunications technologies will make it possible to put more intelligence into networks. These new technologies make it possible to more effectively manage infrastructure assets (topographical representation of the network, remote monitoring, predictive maintenance, etc.), increase capacity where it is needed (more train paths on saturated routes thanks to new signalling technologies), optimise the routing of train paths and responsiveness to customer requests (new “SIPH” timetable production mode, new customer portal), regulate traffic flows more efficiently, monitor the network more effectively in order to improve security and further enhance safety as the network is modernised.

Digitalisation is also likely to improve the public transport experience for end customers by offering them a personalised service. This issue relates in particular to real-time information and the integration of local public transport services (the “last mile”) into railways’ digital tools. For passengers, it is all about giving them visibility on a door-to-door journey. This is a crucial issue, as public transport's competitors already offer this type of features: all motorists can easily access real-time traffic information that is updated live. For public transport, this integration is only partial, and is more complex for operators to implement, as it involves integrating data from different operators into the same platform, with issues of collaboration and data sharing between players.

For the European rail freight sector, Digital Automatic Coupling (DAC) is a powerful lever for boosting the performance, safety, and reliability of operations, because it will enable operations to be automated. The introduction of digital automatic coupling will make it possible to shorten the time taken to assemble goods trains and to digitise the braking and control processes: wagons can be handled more quickly and efficiently in marshalling yards; trains can be built longer and heavier and run faster. Up to 15% more capacity could be gained with like-for-like infrastructure. The implementation of DAC will be particularly beneficial for single wagon load trains, which are very time-consuming to manoeuvre and hook up. It will considerably improve the working conditions of railway workers and ensure their job security. DAC is also an illustration for railways of the need to scale up innovation in terms of the resources required to shift the paradigm.

To meet such challenges, the role of Member States and the role of Europe must be clearly articulated:

- The role of Member States is to remedy the traditional limitations of markets in financing innovation: the uncertainty inherent in any research and development activity, the indivisibility of the costs to be incurred, and the external effects that widen the gap between the social benefits and the private benefits that can be appropriated. All these shortcomings call for an intellectual property and funding framework to ensure a sufficient level of R&D and innovation.

- Europe's role is to deal with a second category of shortcomings: the fact that each national government, taken in isolation, does not sufficiently account for the effects of its choices on its European partners, and in particular underestimates the potential gains from interoperability and interconnections. The European level is crucial: it is the natural scope for the decarbonisation efforts set out in the Green Deal; it is the level that gives the rail sector sufficient critical mass to reap the benefits of economies of scale; it is the level that sets the long-term framework for interoperability and enables the convergence of investment efforts; one that enables collaborative innovation within the rail sector and its industrialisation, following the example of the steps taken within the framework of Europe's Rail, the European Union's joint undertaking for rail technologies.
In this context, Europe has established itself as a prescriber of interoperable standards. Beyond that, Europe needs to step up its contribution to rail innovation in two ways: stabilising requirements to stimulate the deployment of new technologies; targeting R&D funding on collaborative innovation in the European rail sector and European transport policy funding on the roll-out of interoperable technologies and physical interconnections.

Conclusion

Until now, innovations have mostly been implemented through the creation of new lines, particularly those enabling higher train speeds and denser traffic. The main challenge now is to roll out innovations where existing networks are saturated or ageing.

Modern rail innovation, taking full advantage of new digital and energy technologies, calls for mobilisation on three levels:

- For Europe, the need to establish a long-term framework to strengthen innovation for greater interoperability. Innovation should bring European networks closer together, not fragment them. This means stable technical requirements, calibrated to just what is needed to limit compliance costs, and financial support for the industrialisation and roll-out of such innovations;

- For each Member State, a requirement to renovate the network. From the past, we have inherited a considerable, ageing railway heritage. Renovation is the prerequisite for modernisation: it would be economically and commercially inefficient to deploy rail innovations on an ageing network that is subject to slowdowns and breakdowns;

- For rail operators, the need to open up to collaborative innovation, to encourage the development of rail uses for generic technologies born outside the rail system. Here again, Europe has a role to play in catalysing and supporting such collaborative innovation, notably through its *Europe's Rail* programme and its successor programme.

Railways were at the heart of the first Industrial Revolutions. Louis Armand, CEO of SNCF in the 1950s, said that "*the train will be the mode of transport of the 21st century, if it survives the 20th century*". We are there: rail is responding to strong social and environmental expectations. It must draw on the tremendous potential of new technologies in order to meet such expectations.

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Key facts

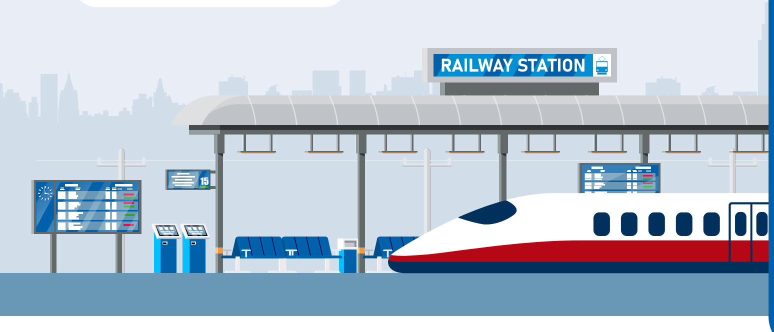
1801 – First steam-powered vehicle

1879 – First electric train

1981 – First run of TGV in France

1996 – Creation of ERTMS

Towards brownfield innovation on the existing network and the application of new technologies born outside railways



Towards ever closer collaborative research

2001: creation of the European Rail Research Advisory Council (ERRAC)

2014: launch of Shift2Rail

2021: launch of Europe's Rail (follow-up programme to Shift2Rail)

Key facts

How the EU can help

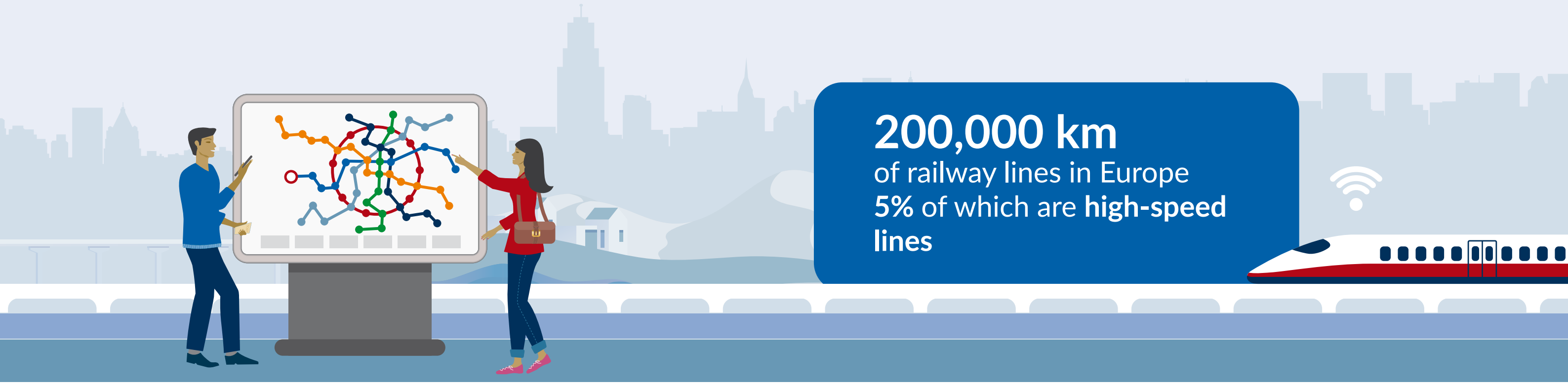
- Harmonisation and stabilisation of technical requirements and interoperability
- Support for innovation
- Financial incentives for the deployment and industrialisation of interoperable technologies on the existing network, in addition to incentives for new interconnections.

Key ongoing innovations for railways

Decarbonisation: Phasing out diesel engines by developing hybrid and battery-powered trains, hydrogen trains, use of biofuels

Mobility for all everywhere : New lighter rail solutions for sparsely populated areas; New mobility systems door-to-door for metropolises

Digitalisation for more robust and customer-friendly operations: train automation, predictive maintenance, train location, asset management, capacity management, real-time information, traffic management system and digital automatic coupling



200,000 km
of railway lines in Europe
5% of which are **high-speed lines**

SNCF GROUP

SNCF group is a world leader in passenger and freight transport services. Its corporate purpose is "working for a dynamic, caring, sustainable society". The group has 270,000 employees in 120 countries and a turnover of 41.4 billion euros in 2022, of which a third abroad. The SNCF group is organised around a single parent company and includes SNCF Réseau (management and operation of the French rail network), SNCF Gares & Connexions (management and development of stations), Rail Logistics Europe (rail freight transport and logistics), SNCF Voyageurs (regional and intercity public transport, high-speed rail in France and Europe), Geodis (logistics in France and 120 countries) and Keolis (public transport in Europe and worldwide).

CER

The Community of European Railway and Infrastructure Companies (CER) brings together railway undertakings, their national associations as well as infrastructure managers and vehicle leasing companies. The membership is made up of long-established bodies, new entrants and both private and public enterprises, representing 71% of the rail network length, 76% of the rail freight business and about 92% of rail passenger operations in EU, EFTA and EU accession countries. CER represents the interests of its members towards EU policy makers and transport stakeholders, advocating rail as the backbone of a competitive and sustainable transport system in Europe.

CER
The Voice of European Railways

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