HIGH-SPEED WORLDWIDE

Historical, geographical and technological developments

INTERNATIONAL UNION OF RAILWAYS

CONTENTS

HIGH-SPEED RAIL: INNOVATION AND DEVELOPMENT FOR A BETTER LIFE

Since the dawn of time, humans have been on the move. Whether driven by necessity or curiosity, mobility has always been essential in satisfying their needs, evolving over time from just a means of transport to an end in itself.

From the earliest days of humanity, when gatherers and hunters moved according to the seasons, animal migrations, and nature’s ever-changing conditions, mobility was essential for survival. Although the advent of agriculture and livestock farming encouraged a more sedentary lifestyle, the desire to explore never disappeared.

Humans have always benefited from exchanges, whether of goods or ideas, and have continually dreamed of discovering new territories. No environment has escaped their ambition to tread the unknown. While nature equipped them with the ability to walk, they also sought to move through water like fish and through the air like birds. Today, space itself has become a new frontier for exploration and even conquest.

Mobility is an intrinsic part of life, especially in humans. Therefore, **the pursuit of a better life only makes sense if this fundamental need for movement continues to be fulfilled and even expanded as a source of satisfaction – without causing harm**.

The modes of transport used by humans have constantly evolved and improved. Initially, people relied solely on their own muscles, through walking or running. Later, they formed partnerships with animals, particularly horses, to travel farther and faster. Eventually, machines replaced animals, with successive generations of technology mirroring the evolutionary process seen in living species. Innovation led to refinements being made, and the new modes of transport surpassed earlier ones in both speed and efficiency. In this "mechanical ecosystem," natural selection occurs: the fastest and most productive options prevail.

The rule governing this evolution is simple. Any system approaching perfection is destined to become obsolete. Once improvements become prohibitively expensive, progress shifts toward entirely new technologies. This was the case with steam power, which was surpassed by diesel and electric traction.

Rail transport was born 200 years ago, and in July 2025, the **International Union of Railways (UIC)** will celebrate this bicentennial during the **World Congress on High-Speed Rail** in Beijing, an acknowledgment of China's significant role in developing high-speed rail worldwide. Reflecting on the past serves two purposes: recognising this two-century-old legacy as an asset and demonstrating that rail is far from reaching its limits, that it still holds immense potential for innovation and adaptation.

Rail transport benefits from its long history. Over time, it has established itself in urban environments of all sizes. Thanks to existing networks and interoperability, high-speed rail can increase accessibility without severely disrupting densely populated urban areas. In fact, this historical advantage allows **high-speed trains to serve as powerful tools for regional development and connectivity**.

Although cars and aeroplanes emerged after rail and could have rendered it a relic of the past, rail – and especially high-speed rail – has demonstrated a remarkable resilience against the constant competition from alternative modes of transport. Neither maglev technology nor vacuum-based systems (such as the Hyperloop) have made traditional rail obsolete, despite decades of research and experimentation. In parallel, the commercial speed of trains has continuously increased, from 210 km/h in Japan in 1964 to currently over 400 km/h in China, reflecting a steady progress of approximately 3 km/h per year over the past 60 years. In contrast, other modes of transport have stagnated or even slowed: cars have reduced average speeds for safety reasons, and aeroplanes have maintained a cruising speed below 1,000 km/h.

High-speed rail's resilience is evident, but its greatest strength lies in its **adaptability**. It thrives under diverse geographic, demographic, and economic conditions. Whether in densely populated, infrastructure-rich regions like Europe, or sparsely populated areas with limited transport options like Saudi Arabia, high-speed rail continues to expand. Where it is already established, demand fuels further growth, with success breeding more success.

This brochure aims to explore the remarkable history and future of high-speed rail, with a particular emphasis on China, given its prominent success in this field.

FOREWORD

It is no coincidence that the 12th World Congress on High-Speed Rail, organised by UIC and China State Railway Group Co., Ltd. (CR), and hosted by China Academy of Railway Sciences Corporation Limited (CARS), is taking place in Beijing, fifteen years after the 7th edition, and is also being held at the same venue. As of the end of 2024, the operational length of HSRs in China reached forty-eight thousand kilometers, the equivalent of going once around the Earth!

This is an excellent opportunity to take stock of this transport system and to understand that, while no country has done as much as China, many have made progress by starting up in this field or by expanding their infrastructure. The club of countries using high-speed rail is constantly recruiting new members, of which there are now around 22.

High-speed rail, which was initially an isolated phenomenon in a few countries, and which for a long time remained almost "classified", has now taken off in an incomparable way. Transporting around 3 billion passengers a year (or 1,000 billion passenger-kilometres), high-speed rail is definitively affordable for everyone and not a service accessible only to the richest. With the standardisation of infrastructure construction, productivity linked to speed, and competition – particularly within the railways following the liberalisation of the sector – high speed is now within everyone's reach. ***From exclusive to inclusive***, the global network now spans 60,000 km and has therefore reached a size which makes the investment in its construction entirely justifiable, thanks to the numerous virtuous externalities of rail transport.

The first part of this brochure includes some of the information provided in UIC's *"Atlas of High-Speed Rail"*. It provides a general overview of this network, which is highly developed in Asia and Europe, and is now being extended to Africa and America, with further planning underway elsewhere. The second part in particular describes and illustrates what China has achieved in this field. High-speed rail's resounding success here is partly due to its technical evolution. To ensure this success endures, especially in the face of various challenges, continuous innovation will be essential:

- Decarbonisation of infrastructure and rolling stock, including the development of renewable energy production on the huge rights of way used to install the networks
- Automation of daily track patrol inspection operations
- Precise train location and connectivity through telecoms 5G / FRMCS (Future Rail Mobile Communication System), allowing new services, digitalised operations, supporting ETCS up to level 3
- Resilience to and prediction of the effects of climate change
- Extensive use of artificial intelligence
- Multimodal services for a decarbonised end-to-end travel (like with ticketing supported by standards as OSDM, accessibility of stations, …)

In light of this, the slogan adopted for the 12th World Congress on High-Speed Rail, ***"High-speed rail: innovation and development for a better life"*** seems more relevant than ever.

Enjoy your reading!

François Davenne
UIC Director General

PART 1

High-speed rail around the world

DEFINITION OF RAILWAY

Railways are guided, low-grip overland transport systems.

A ground transport system	A transport system guided by two rails and tapered wheels	A low-grip transport system
Advantages: 1. Offers intermediate stops 2. On the same train, brings together flows of people not making the same journey in order to achieve a critical size of demand 3. Serve the regions in a more precise manner	**Advantages:** 1. Precise control the direction of movement 2. Ensures safe movement 3. Contributes to passenger comfort on board thanks to the tilt	**Avantages:** 1. Reduces the effort required to pull a heavy load 2. Carries large convoys with a low amount of energy 3. Operates at high speeds while maintaining low energy consumption

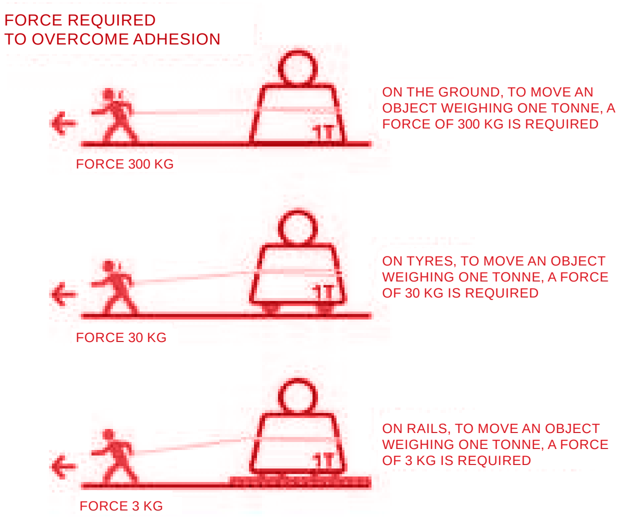
Thanks to these qualities, rail has become the **fastest and safest** form of land-based transport. Additionally, the extension of its network over the last two centuries has provided **unparalleled accessibility in both urban and rural areas**.

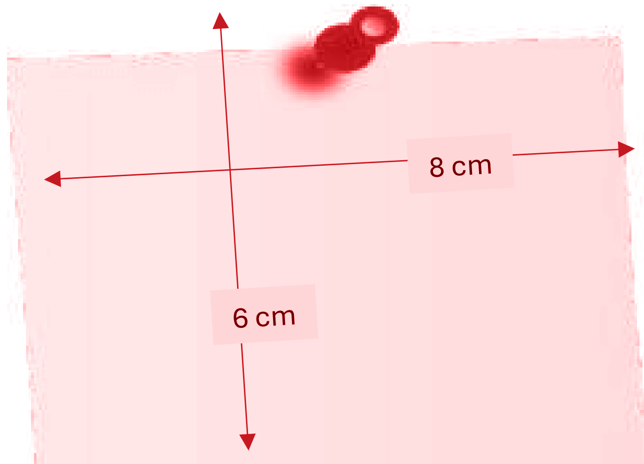
French railway network at the beginning of the 20th century

American railway network in 1898

American railway network in 1870

Rail networks continued to expand until the first half of the 20th century, as railways were the only real tool for territorial development. In the second half of this century, automobiles became more accessible and widespread. They also played a major role in territorial planning by making rural areas, previously isolated from transportation, more accessible. Today, roads and railways share this role of fine distribution, with trains having ceded the localised service of sparsely populated or even abandoned areas to roads, as mass rural exodus toward cities reduced transport demand for collective systems. However, the decline of rail networks has slowed. It is now offset by the development of new infrastructures, largely built for high-speed rail, which represent a kind of revival for trains due to the qualitative leap in speed and the environmental benefits of this transport mode.





This post-it note represents the total surface area of contact with the rails of a 200-metre-long high-speed train.

A ground transport system

Disadvantages:
Rail requires linear infrastructure, which means:
1. Expropriating the owners of the land concerned and depriving it of any use other than transport
2. Having a negative impact on the environment of railway rights-of-way during construction
3. Requiring substantial investment

A transport system guided by two rails and tapered wheels

Disadvantages:
1. Inability for one train to overtake another on the same track
2. Reduced infrastructure throughput when used by trains of varying speeds
3. Necessity of scheduling operations to prevent trains from overtaking and colliding

A low-grip transport system

Disadvantages:
1. Difficulty in braking
2. Need to maintain separation between convoys, leading to flow restrictions

Given the high cost of infrastructure and the need to space trains far apart, the only way to make investment profitable is to mass produce trains. By design, rail is a form of **mass transport**


© FS

AN ANCIENT HISTORY OF GUIDANCE AND GRIP

Around 700 BC, goods were transported by land across the Isthmus of Corinth on chariots pulled by slaves, using the “diolkos”, a track made of stone slabs with wooden rails inserted between them.

This ***“traction track”*** was a predecessor to the railway, functioning as an overland track which used the principle of guiding and reduced friction by greasing the wooden rails.

This principle of the traction railway was again used in the coal mines of Great Britain. However, here the stone slabs were replaced by wood reinforced with iron at the bottom.

A similar wooden ***“carriageway”*** for horse-drawn carriages also appeared in Alsace, France, as early as the 16th century.

THE BIRTH OF RAIL

At the end of the 18th century, the Englishman William Jessop invented cast-iron grooved rails for flanged wheels. In 1802, Jessop opened the *Surrey Iron Railway*, using L-shaped rails and horse-drawn traction over a distance of 29 miles (47 km).

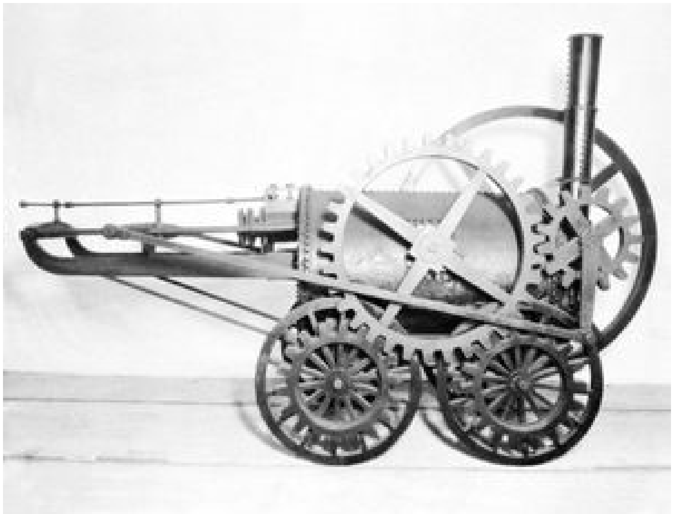
Building on early developments in steam technology, Richard Trevithick, a British mechanical engineer and inventor, successfully harnessed high-pressure steam and, in 1803, constructed the world's first steam-powered railway locomotive. A second, similar engine followed in 1805 at Gateshead, and in 1808 Trevithick demonstrated a third locomotive, the Catch-me-who-can, on a circular track laid near Euston Road in London.

Capitalising on the advancements to the steam engine made by James Watt and Thomas Newcomen, in 1825 George Stephenson built a locomotive, the "locomotion", capable of transporting 400 passengers at a record speed of 24 km/h. He went on to win a contest for a locomotive to operate between Manchester and Liverpool. His "Rocket" reached speeds of 54 km/h, making it the fastest engine on earth at the time. This demonstrated the extraordinary potential of torque, combining guidance and low grip.

Thus, 1825 can be considered as the birth year of the railway.

The 12th World Congress on High-Speed Rail, jointly hosted by UIC and CR and organised by CARS in Beijing in July 2025, will coincide with the 200th anniversary of this milestone.

Surrey Iron railways horse-drawn



New Castle

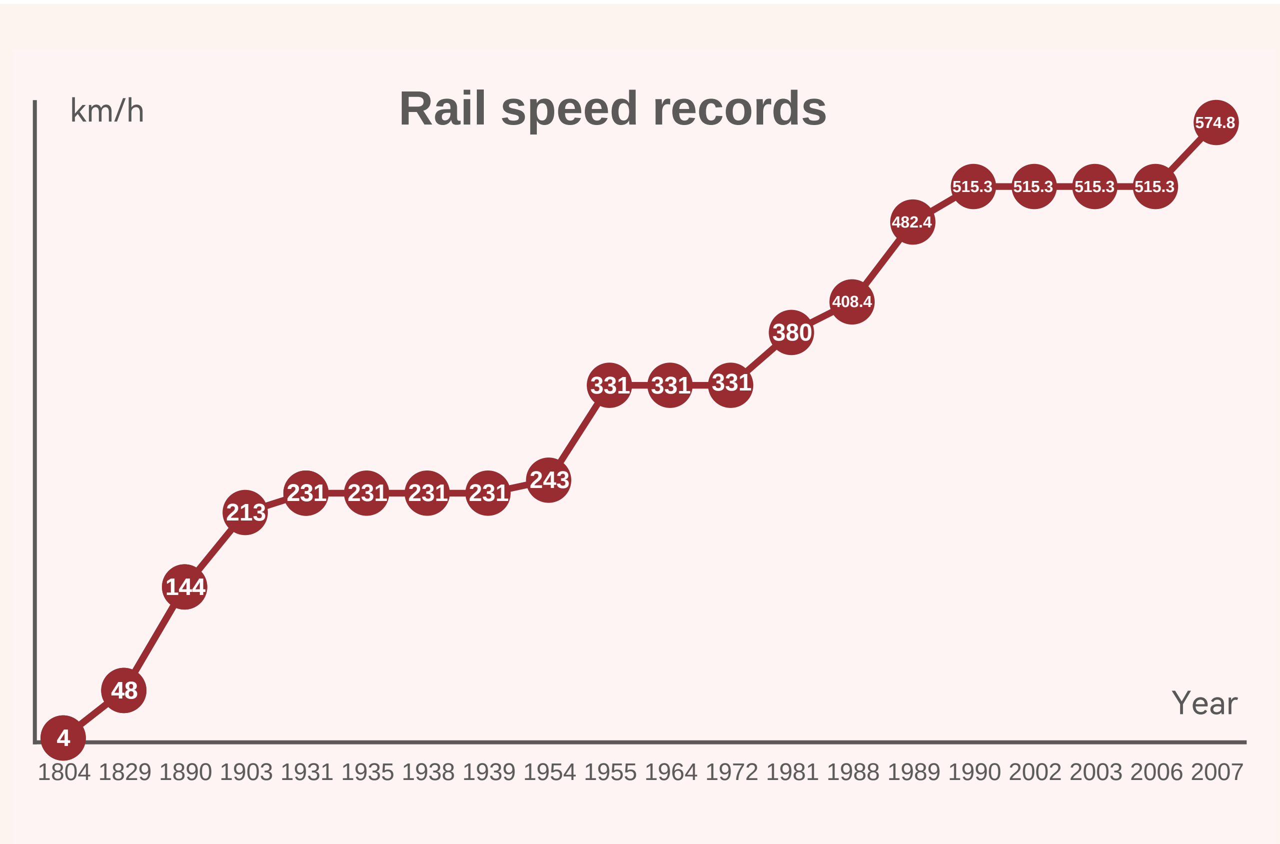
The locomotion

THE TECHNOLOGICAL RELEVANCE OF RAIL

The technological relevance of rail has been demonstrated in two key ways.

Firstly, technically, through an incredible succession of speed records.

© SNCF Médiathèque, Christophe Recoura



Secondly, it is also due to railways being adopted as a universal mode of transport, with the global rail network now spanning over 1,100,000 km and being deployed in nearly every country with significant land area.

THE CHANGING PARADIGM OF RAIL OPERATIONS

The various ways in which the infrastructure can be used to transport both passengers and freight constitute a paradigm, that of mixed operation.

1. Rail was initially created to transport freight, specifically mining products.

2. Passengers were subsequently added to the freight wagons.

3. Mixed trains carrying freight wagons and passenger coaches were then introduced.

4. As the areas to be served differed for freight and passenger transport, trains became specialised, but with the same track being used for most of their journey.

5. As steam and then electric and diesel traction progressed, accelerating passenger trains became more important than doing the same for freight trains simply destined for marshalling yards. This increased the speed differential between passenger and freight trains.

6. This widening speed gap quickly led to throughput problems. To prevent passenger trains from catching up with freight trains, several solutions were implemented. These included improving train braking, the performance of train spacing systems (signalling), and finally doubling the tracks. However, this latter solution was very costly and was only implemented on a few extremely busy routes. On all others, it was preferable to separate trains of different types by not running them at the same time (i.e. by creating time slots reserved for passenger or freight trains). This temporal separation of trains has often, even now, led to freight train operations being concentrated at night. Over time, the incompatibility between passengers and freight has become more acute, especially as rail has found itself in competition with road and air transport, necessitating faster services to better compete in this market.

7. High-speed rail was partly born of the desire to speed up passenger trains to the point where it became difficult to operate them alongside freight trains on the same infrastructure when freight applications were about running heavier trains with good grip conditions.

Freight trains only

Freight trains with passengers in or on the wagons

Mixed trains comprising freight wagons and passenger coaches

Freight and passenger trains operating in parallel on the same infrastructure

Freight and passenger trains operating on the same infrastructure but not in parallel

High-speed rail

- **Freight and passenger trains with separate infrastructure, except at certain junctions**
- **Freight and passenger trains running at high speed on dedicated infrastructure**
- **Fully exclusive right-of-way high-speed trains**

DEFINITION OF HIGH-SPEED RAIL

High-Speed Rail (HSR) is a grounded, guided transport system and could also be categorised as a railway subsystem. The most important difference, however, is the speed. As travel times had to be reduced for commercial purposes, speed emerged as a decisive factor with HSR providing the necessary improvement, which is why UIC considers a commercial speed of 250 km/h is the principal criterion for defining a line as high-speed.

Nevertheless, average distance is a second criterion when a line does not have to compete with air travel, where it may not be as important to run at 250 km/h. A lower speed of above 200 km/h (any lower is within the capability of a conventional train) and more commonly 220 or 230 km/h is enough to capture the highest possible market share for a collective mode of transport. This also applies to very long tunnels whose construction cost depends on the diameter linked to the square of the speed.

For speeds above 200 km/h, the infrastructure can be categorised as "high-speed" if the system in operation complies with the necessary standards regarding track equipment, rolling stock (generalisation of trainsets), signaling systems (eliminating trackside signals), operations (long-range control centers), and the geographical or temporal separation of freight and passenger traffic.

The High-Speed Railway network can also include infrastructure sections that link high-speed lines without them needing to have all of these characteristics. Therefore, not all lines included in statistics can reach very high speeds, as shown by the graph below which breaks down the global network by cut-off speed.

High-speed rail is also characterised by **certain technical aspects**:

- Reversible trains
- On-board signalling: signalling information is received in the driver's cab and there are no lateral signals along the track
- Long-range traffic control centers to manage traffic and power supply
- Strict temporal separation between passenger and freight traffic, in cases where the infrastructure is not entirely dedicated to passenger services
- A track capable of supporting trains travelling at least 250 km/h

DEFINITION OF THE HIGH-SPEED RAIL NETWORK

This definition of high-speed rail is shaped by two considerations:

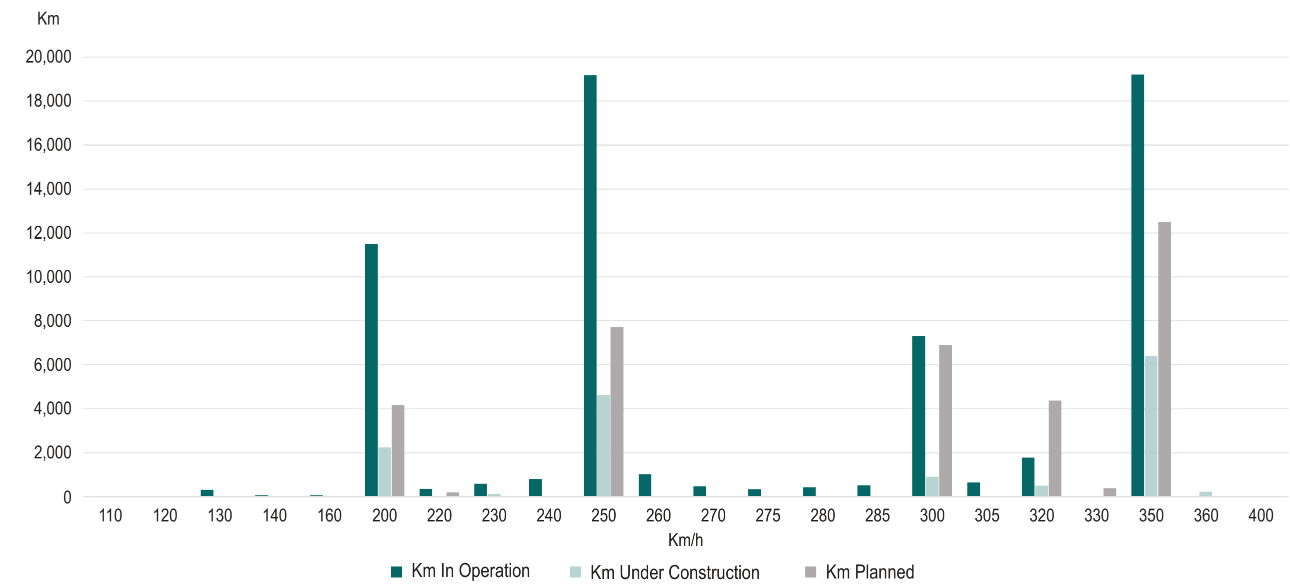
- High-speed lines are intended to form networks
- The aim of high-speed rail is not merely technical performance, but to enhance the attractiveness of rail at a reasonable cost

The first consideration supports the inclusion of infrastructure segments that enable high-speed lines to be interconnected, even without possessing all of the characteristics of high-speed lines. The second is that if the market share can be effectively captured with speeds below 250 km/h, then this threshold can be modified.

Newly-built or modernised old lines that allow trains to travel at speeds exceeding 200 km/h, but not reaching 250 km/h, may be included in high-speed rail network statistics, provided that they contribute to forming a network with other high-speed lines or that their performance is sufficient to capture a significant share of the medium-distance market at a reasonable cost.

The concept of a high-speed network is based on several criteria, including technical performance, the interconnection of lines to create a coherent end-to-end service, and intermodal competition in the medium and long-distance transport market. Statistics related to this network take these criteria into account, with their weighting varying from one country to another.

Length (km) of the high-speed network according to maximum speed and status of implementation (2023)



Source: compiled by authors based on International Union of Railways

THE COMMERCIAL SPEED OF HIGH-SPEED TRAINS

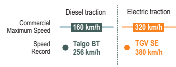
The concept of speed needs to be clarified, distinguishing between:

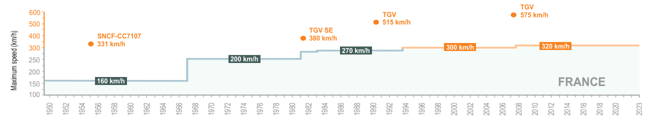
- The speed permitted by the infrastructure's characteristics, particularly in curves, depending on the radius of curvature and the lack of superelevation
- The average commercial speed calculated from the published timetable between two stations
- The maximum commercial speed achieved by trains at any point along their route

Compared with the average commercial speed of conventional trains on standard infrastructure, the difference to high-speed rail is considerable. In many instances, the average speed is almost doubled for high-speed rail.

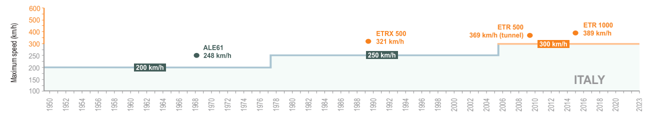
The maximum commercial speed has constantly increasing, whereas on the road, with a few exceptions, the maximum authorised speed is around 110-130 km/h, essentially for safety reasons. For aviation, speeds also remain at around 800-900 km/h, essentially due to technological and economic aspects.

Evolution of maximum speed in commercial services in France

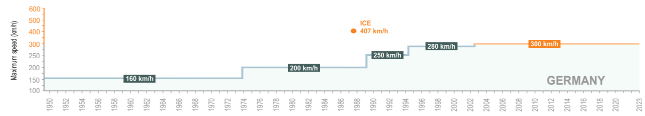




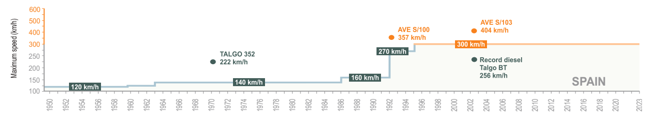
Evolution of maximum speed in commercial services in Italy



Evolution of maximum speed in commercial services in Germany

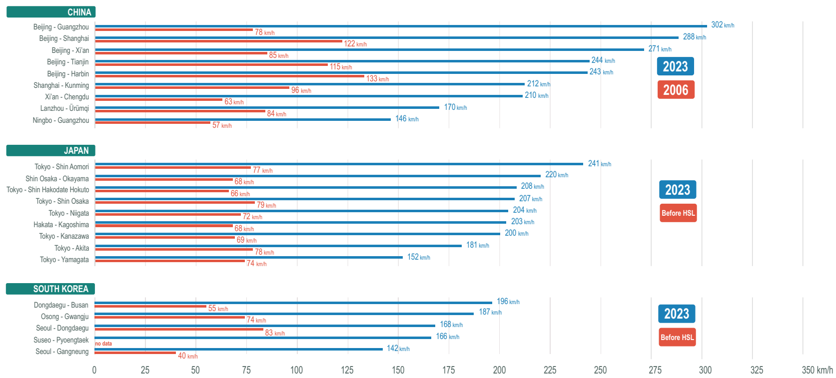


Evolution of maximum speed in commercial services in Spain



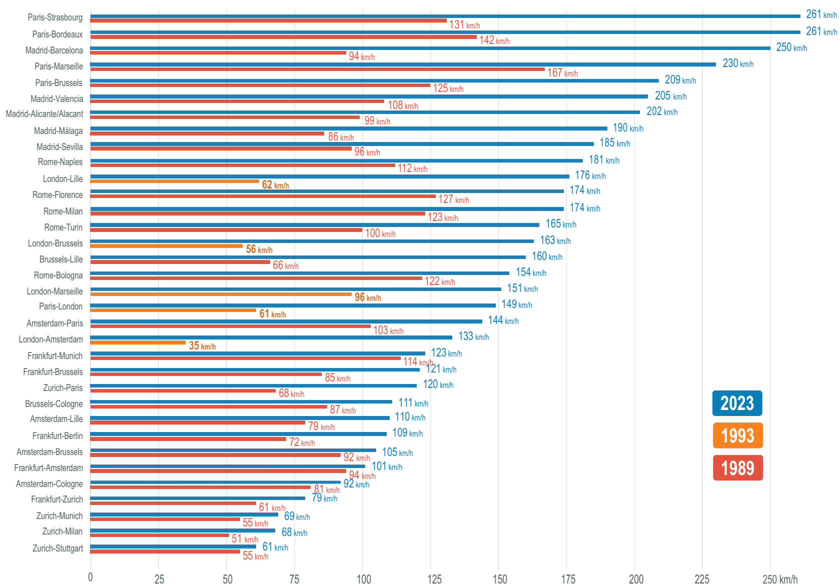
Source: miscellaneous data sources
Note: speed records, signaled by dots in the graphics, were set in non-commercial operations. Representation of available data (non-exhaustive)

Evolution of average speed on Asia-Pacific high-speed lines



Source: International Union of Railways

Evolution of average speed on European high-speed lines



Source: compiled by authors based on "European Timetable" Thomas Cook Travel Guides 1989, Railway Operators websites, British Rail Timetable 1993 and Indicateur Horaires Ville à Ville SNCF 1993
Note: before 1994, travel between London and France was carried out by Ferry or Hoverspeed with their corresponding journey times

THE BIRTH AND WORLDWIDE EXPANSION OF HIGH-SPEED RAIL

High-speed rail was born in Japan in 1964

The first Japanese railway opened on 12 September 1872 between Shimbashi and Yokohama, and was designed by British engineers with a track gauge of 1.067 mm or 3 feet 6 inches. The reason for choosing this gauge remains uncertain, although historians have two theories: it was either more cost-effective to build than a standard gauge of 1.435 mm (or 4 feet 8 inches), or the builders opted to use their previous experience with the narrower South African track.

Subsequently, the Japanese rail network continued to develop using this narrow-gauge standard, which considerably limited train speeds.

In the first part of the 20th century, plans emerged to construct a second line between Tokyo and Osaka, the busiest section of the rail network. However, this project was only seriously launched after World War II, with the intention of adopting the standard gauge and widening the tracks to allow freight wagons to be loaded with containers positioned transversely to the train's longitudinal axis. Concurrent progress in rolling stock during the line's construction also enabled passenger trains to operate at much higher speeds.

Even before the new line was completed, it became evident that the high density of passenger traffic attracted by faster trains would be incompatible with freight traffic, which would need to be divided between the old and new infrastructure. Consequently, the decision was made to dedicate the entire new line to passenger traffic.

In 1964, the standard gauge passenger line was inaugurated, with trains achieving a record commercial speed of 210 km/h.

Thus, high-speed rail was born. It benefited from new infrastructure, specialised in passenger traffic, while also offering a wider gauge than the standard gauge, as the tracks initially been intended to accommodate wide goods trains. This explains why Japanese high-speed trains have rows of five seats abreast, compared to four abreast elsewhere.

Identical track gauge, but varying train widths

As a result, high-speed rail became almost systematically associated with the specialisation of infrastructure for passenger traffic, despite this feature not being part of the initial plan. Nevertheless, the advantages of this specialisation were quickly recognised.

... then developed in Europe and spread around the world

The Direttissima Rome-Florence line can be considered to be the first project in Europe which was built with the aim of increasing train speeds while also offering more capacity. However unlike in Japan, it initially was used for mixed operations which prevented very high speeds from being reached. After being adapted, it was then classified as a high-speed line in 1988.

© Sandro Baldi, Bologna, Italia, ETR 450 verson Monzuno, Appennino Bolognese, Wikipedia

In 1981, the newly opened Paris-Lyon line was, from the outset, dedicated to passenger traffic, adopting geometric characteristics that were incompatible with freight transport needs, such as having ramps and gradients of 35‰. As only highly motorised trains would be able to use the line, the idea was to reduce the distance by avoiding the valleys traditionally that the conventional rail network traditionally used, and to limit the number and scale of engineering structures to be built.

© SNCF Médiathèque, droits réservés

The Paris-Lyon line, France

Fully opened in 1983, the 425 km line does not have any new tunnels, with engineering structures (bridges and viaducts) accounting for only 2% of its length, as the gradients allow the line to follow the natural terrain. The initial commercial speed was 260 km/h, which was quickly increased to 270 km/h in 1985, and then to 300 km/h around ten years later.

The majority of high-speed lines in Europe have similarly adopted the principal of specialised infrastructure dedicated to passenger transport at high speeds. However, in Germany, the first new lines were built for both passenger and freight trains, although they have never really run at the same time, being restricted to separate time slots. An examination of the gradients adopted on new infrastructure in Europe clearly shows that most of them are not adapted for use by heavy freight trains.

Maximum slope (‰)

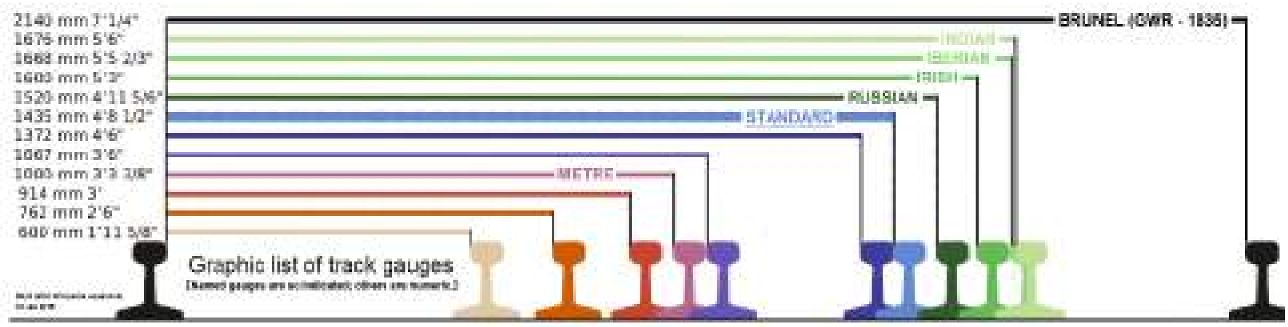
Source: compiled by authors based on International Union of Railways

© Cécile Gendrot

INTEROPERABILITY AND STANDARDISATION

A transport network is only efficient if it is interoperable, requiring that various segments be built or adapted to meet standardised criteria. However, the global rail network, developed over an extended period and across regions often divided by significant natural obstacles, falls short of this requirement.

For example, no fewer than 12 rail gauges have been in use across various regions worldwide.



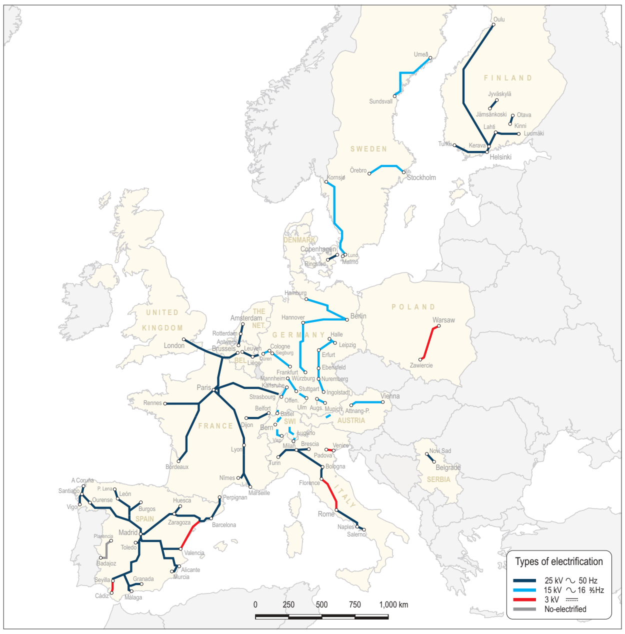
Train spacing systems are just as numerous, as are electrical power supply and distribution systems (including catenary or third rail systems and with different electrical voltages).

On the other hand, the infrastructure for high-speed rail is relatively recent, meaning that there is less variation in the standards adopted:

- The rail gauge is the standard 1435mm.
- On recent lines, the spacing of trains is insured by telecommunication-based systems without track-side signals providing information into the driver's cab.
- Most electrification uses 25 kV single-phase 50 Hz, although some lines operate with 15 kV 16 2/3 Hz or even 3000 V direct current.

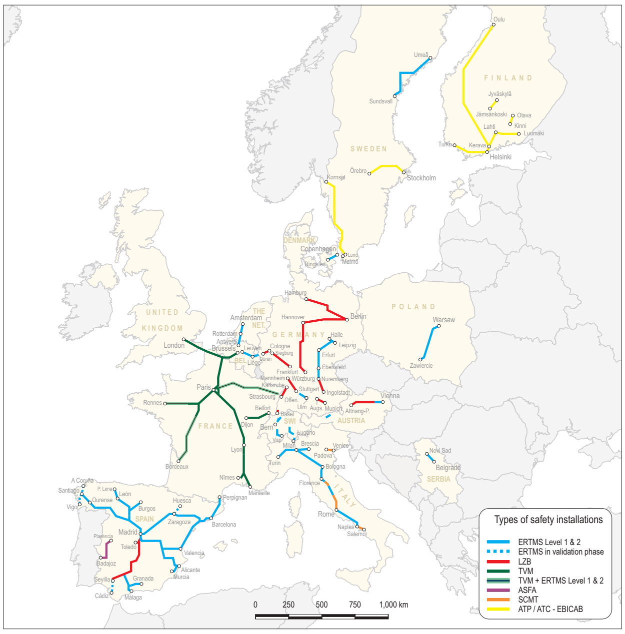
© ADIF

Electrification



Source: compiled by authors based on International Union of Railways

Signalling



Source: compiled by authors based on International Union of Railways

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To this end, UIC contributes by publishing International Railway Solutions (IRS) based on comparative experiences and the search for best practices.

However, it is important to recognise that railways, which have existed for two centuries, largely reflect a legacy that is challenging to transform or adapt due to the significant investment required for such conversions.

Consequently, solutions often need to be found through rolling stock or alternative methods such as tracks equipped with three rails to accommodate two different gauges.

HIGH-SPEED ROLLING STOCK

All high-speed train architectures share two common features: their length and ability to be coupled.

Typically, each trainset is 200 meters long. As two trainsets can be coupled, a 400m-long train is formed, which corresponds to the platforms length at most stations.

Therefore, it is the infrastructure, particularly the stations, which imposes a length constraint on the trainsets, in addition to other related to the wheel or wheelset gauge, for example. Given the lack of homogeneity in infrastructure across different countries, or even within the same country, rolling stock is the principal method for ensuring interoperability. For example, until all new lines are equipped with the same version of ETCS signalling, rolling stock operating on heterogeneous lines must be equipped to “read” all of the systems encountered. The same applies to electrical power supply, distribution systems, wheelset gauges, and so on.

In terms of technical and economic performance, the following factors play an important role:

- The total weight of the trainset
- The simplicity of its architecture
- Its seating capacity
- Its aerodynamics

These parameters significantly impact three key ratios:

- The purchase cost per seat
- The maintenance cost per seat-kilometre
- The energy consumption per seat-kilometre

The possibility of having two levels, or 5 seats abreast, is particularly advantageous as it lowers these ratios by increasing their denominator.

© Korail

Energy consumption depends on speed, inertia, and friction. Inertia is related to train's mass, while friction occurs at two levels: between the wheels and the rail, and between the train and the air (drag). To minimise air resistance, it is essential to reduce the master torque (the surface area penetrated by the air), with an aerodynamic design of the front of the train.

Additionally, air friction along the undercarriage can be mitigated by reducing gaps between train bodies and making the side surfaces as flat and smooth as possible. Friction between the air and underbody (especially the wheels) and upper body (especially the pantographs), can also be reduced by fairings, which have the added benefit of reducing dynamic noise.

It is important to note that aerodynamic effects become more significant as speed increases. One advantage of a train is that it operates as convoy, with the leading vehicle being the only one with a master torque (frontal surface) for air penetration. On the other hand, cars or lorries have as many master torques as there are vehicles. This provides an energy advantage further enhanced by the fact that rail guidance perfectly aligns and shelters the train bodies behind the locomotive, making the air penetration effort almost solely the responsibility of the leading vehicle.

With increasing speeds, factors such as current collection from the catenary, ballast projection, noise, and crosswinds must also be taken into account.

TRAIN TYPES AND FLEETS AROUND THE WORLD

Articulated or non-articulated

In an articulated train, most of the bogies are located between the carbodies, whereas in a non-articulated train, each carbody has two bogies.

Bogies or independent wheels

Certain articulated trains do not have bogies but instead have independent wheels (which therefore do not travel at the same speed in curves).

Concentrated or distributed traction

Trains which have a locomotive at each end are considered to have concentrated traction as opposed to trains where motorised bogies are distributed along the train. The advantage of distributed traction is that seating can be provided in the end carriages. Concentrated traction is mandatory for double-decker trains where it would be difficult to insert motorised bogies under the carriage.

Tilting or non-tilting

A tilting train is fitted with a mechanism which allows the vehicle body to incline into a curve in order to balance out the discomfort of excess canting. This mechanism may be passive (activated by inertia) or active (executed and controlled by a computer). A tilting train goes faster into a curve without disturbing passengers.

Fixed or variable gauges

To ensure that networks working with different gauges are interoperable, a train may have a system to change the wheelset gauge.

One or two levels

Double-decker trains offer around 50% more seating capacity than single-decker trains.

Single or multi-current

To ensure that networks working with different electric power supplies are interoperable, some trains can take multiple different voltages. This is above all the case in Europe where there are multiple different supply voltages in use.

Single or multiple signage

To ensure that networks working with signalling systems are interoperable, some trains can be fitted with multiple signalling systems. This is above all the case in Europe where there are multiple different incompatible signalling systems in use.

Dual drive

In order to be able to run on non-electrified tracks, some trains may have dual traction: diesel and electric. With current technology, hydrogen high-speed trains are feasible, within certain power limits.

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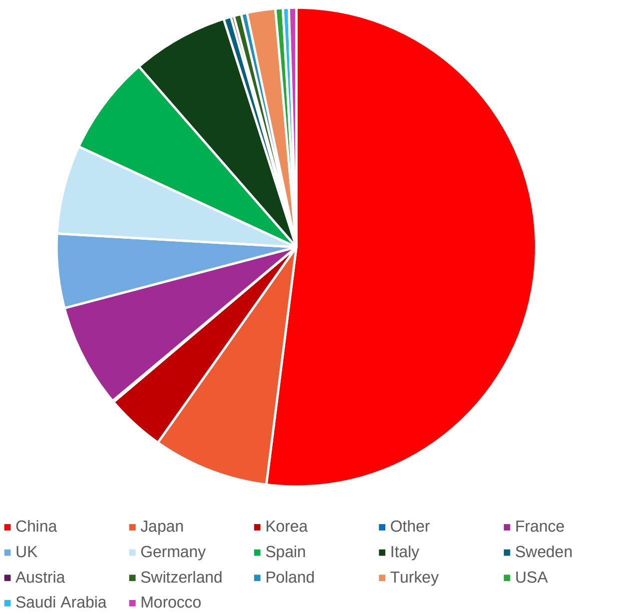
© SNCF Médiathèque, Maxime Huriez

Common features of high-speed trains

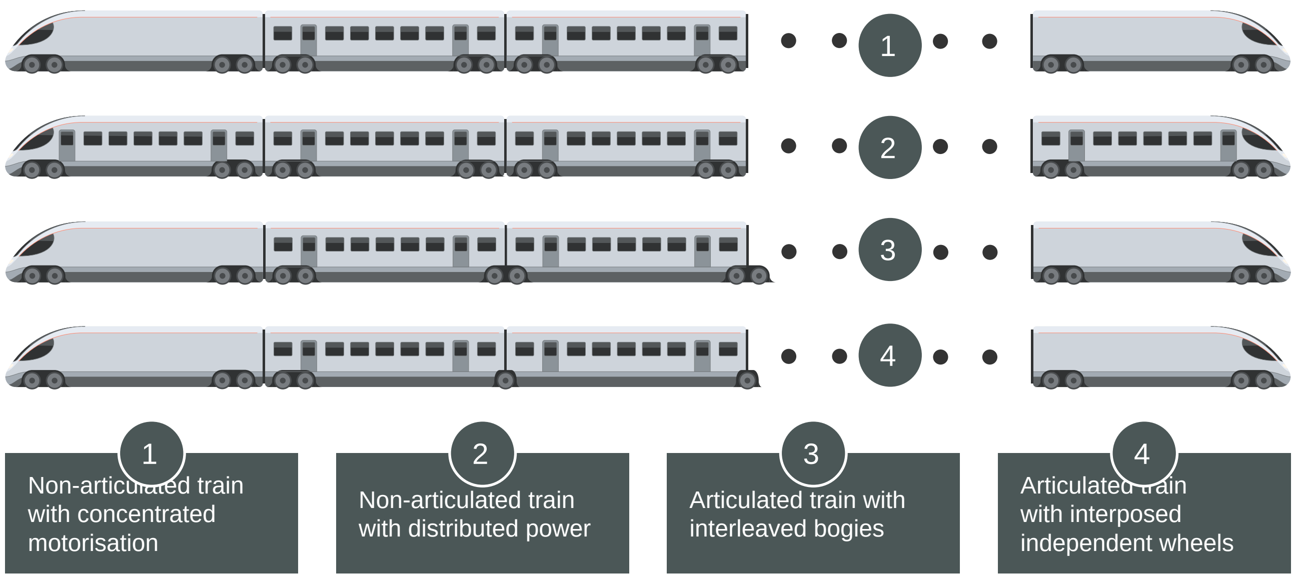
- Self-propulsion
- Fixed composition and bidirectional operation
- High level of technology
- Limited axle load (up to 17 tonnes for 300 km/h in Europe)
- High power-to-weight ratio
- Control circuits, a computer network, and an automatic diagnostic system
- Optimised aerodynamic shape
- In-cab signalling systems
- Additional braking systems
- Improved commercial performance
- High level of RAMS (reliability, availability, maintainability and safety)
- Good airtightness
- High technical and safety requirements (in compliance with standards)
- Infrastructure compatibility (track gauge, loading gauge, platforms, catenary, etc.)

The world's rolling stock fleets

There are more than 6,500 high-speed trains in the world, over half of which are in China.



Global rolling stock fleet by country (2022)

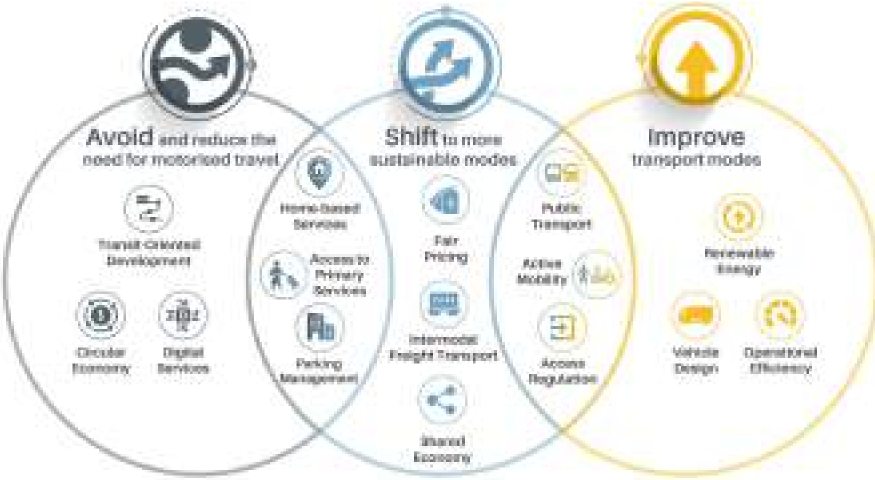


HIGH-SPEED RAIL AND SUSTAINABLE MOBILITY

Strategies for reducing the ecological footprint

Widely known as "Avoid-Shift-Improve", this approach aims to significantly reduce greenhouse gas emissions through a holistic and integrated approach to mobility systems.

Three strategies are being implemented in this context:



© SLOCAT Transport and Climate Change Global Status Report, 2nd edition
Source: SLOCAT https://slocat.net/asi/

Avoid unnecessary motorised trips based on proximity, accessibility, and new ways of working.

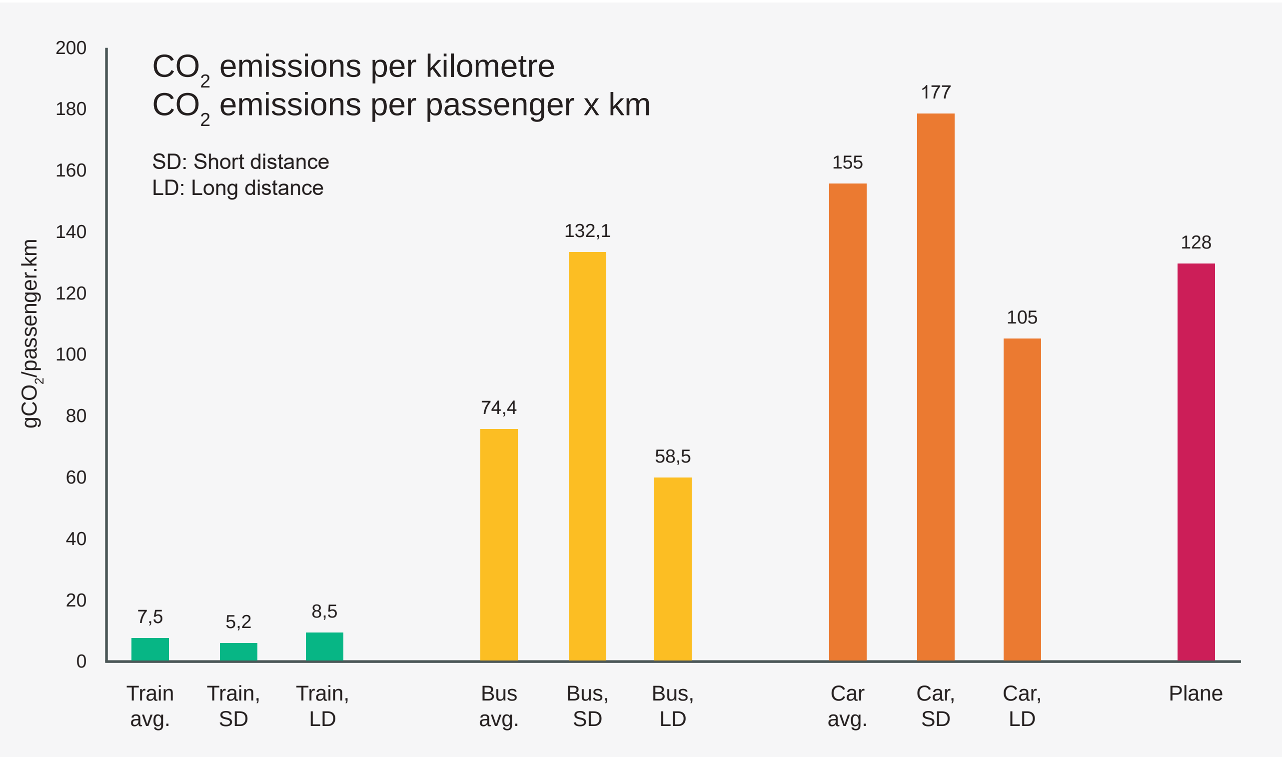
Shifting to less carbon-intensive modes of transport, for example, from private vehicles to public transport, shared mobility, walking and cycling, sea and river freight, electrified road-rail freight, and d bikes for last-mile deliveries, to name just a few.

Improving vehicle design, energy efficiency and access to clean energy sources for different types of transport vehicles.

Rail accounts for 8% of global passenger transport and around 9% of freight activity, but only 3% of transport energy consumption. Over the last two decades (before the COVID-19 pandemic), the share of rail passengers remained constant at around 10% and, unless significant investment is made in high-speed trains, this share of passenger transport will likely still be at the same level in 2050.

High-speed trains can provide an attractive alternative to short-haul flights, with only a fraction of the emissions. For instance, a Eurostar journey from London to Paris emits 90% less greenhouse gases than the equivalent flight.

	Train			Bus			Car			Plane
	Avg.	CD	LD	Avg.	CD	LD	Avg.	CD	LD	Avg.
CO_2/ passenger.km	7,5	5,2	8,5	74,4	132,1	58,5	155,5	177	105	128
$kgCO_2$/m	0,56	0,18	1,1	3,2	1,8	5,2	6,7	6,5	7,9	90
$kgCO_2$/trip	0,19	0,005	1,5	1,2	0,5	18,4	2,4	2,0	30,6	311



Life cycle emissions from high-speed rail

High-speed projects are generally assessed in terms of their economic and environmental footprint.

For the environmental perspective, it is important to consider the entire life cycle, from the design stage, construction, operation, and maintenance through to decommissioning.

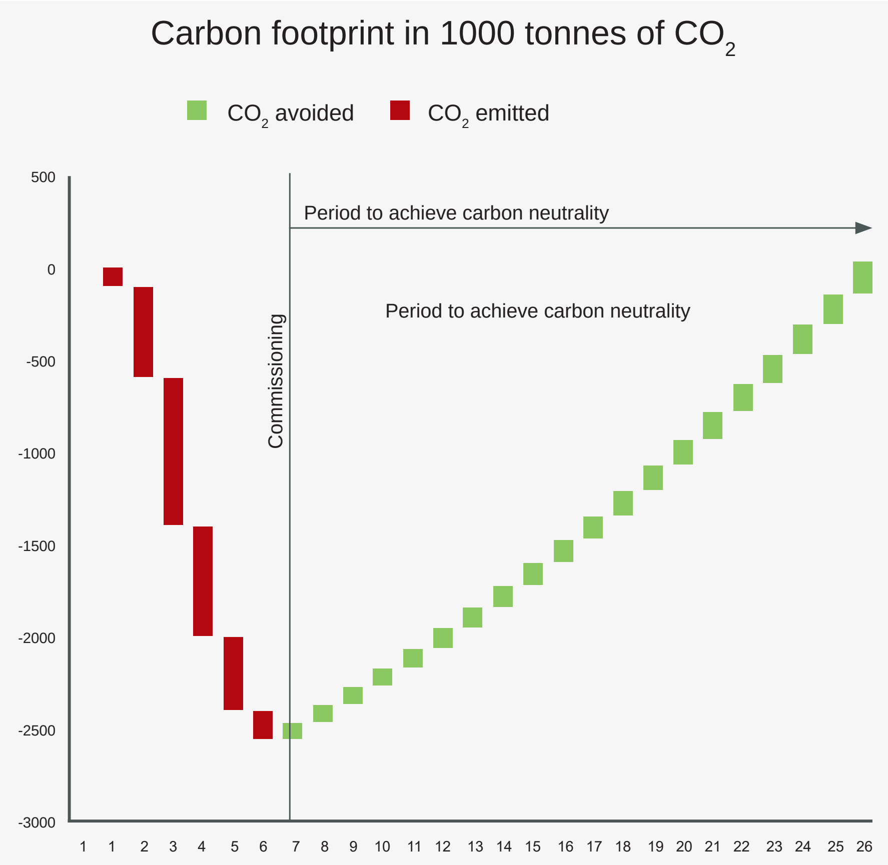
This means that the footprint includes carbon emissions when :

- Designing the line, as engineers and draughtsmen will need buildings and equipment to house them and provide comfort and heating or air conditioning, fuel for getting to the site or to meetings, etc.

- Constructing the line, stations and rolling stock, including emissions for extracting and shaping materials (e.g. steel or cement), as well as their transport (e.g. moving soil or transporting rails)
- Operating trains and stations
- Maintaining infrastructure and rolling stock
- Distributing tickets
- Recycling infrastructure and rolling stock components

Carbon balances have been drawn up for certain new lines around the world. They are presented as an algebraic sum of two negative factors and one positive:

- The first negative factor relates to the CO_2 emissions from building the infrastructure and rolling stock. It is substantial and comes into play before operations begin.
- The second negative factor relates to the rail system's operations and becomes an issue after the infrastructure is put into service, while also lasting for the duration of operation and varying according to the volume of traffic.



- The positive factor relates to traffic volumes switching from other modes of transport to high-speed trains, as this reduces CO_2 emissions.

These footprints show that any emissions caused by constructing the system are offset by its operation, as the emissions avoided by shifting from one mode to another far exceed the emissions of operating high-speed trains. However, this compensation only occurs after a certain number of years of operation. How long it takes for a line to reach a carbon balance after it is commissioned (before it becomes positive) depends largely on three factors:

- The amount of greenhouse gases emitted during construction, as the more concrete and earthworks that are used on the line, the greater the quantity will be
- How much transport shifts onto the line, the more this happens the more emissions are reduced
- The amount of CO_2 released when creating the electric current needed to run high-speed trains

Analysis of the carbon footprint of high-speed infrastructure shows that all CO_2 emission-reducing innovations during the construction phase have a big impact. The two main sources of CO_2 during construction are :

- Emissions linked to the site machinery used for earthworks and move soil
- Emissions linked to the production of cement, which is used to build the line's structures

Nevertheless, major progress is being made in these two areas, particularly in the production of low-carbon concrete.

HIGH-SPEED STATIONS

Railway stations have evolved into strategic multimodal hubs, designed to ensure seamless integration between various transport modes — including heavy rail, urban transit systems, micromobility solutions, car-sharing services, taxis, demand-responsive transport, bicycles, and e-scooters — while optimising passenger flow management and enhancing overall connectivity and accessibility.

Strategic station governance

Stations are the point of intersection for four groups of stakeholders:

- Local governments, for whom the station is a symbol of the city, interfacing with the surrounding neighbourhoods, and local authorities who may be in charge of urban and regional public transport
- The infrastructure manager, whose main concern is to optimise network capacity
- The railway undertakings (train operators), who ensure that passengers have easy access to their trains
- Customers and the general public, who want to find out all the required information and find an easy way through the station, regardless of their reason for being there

The station and its services

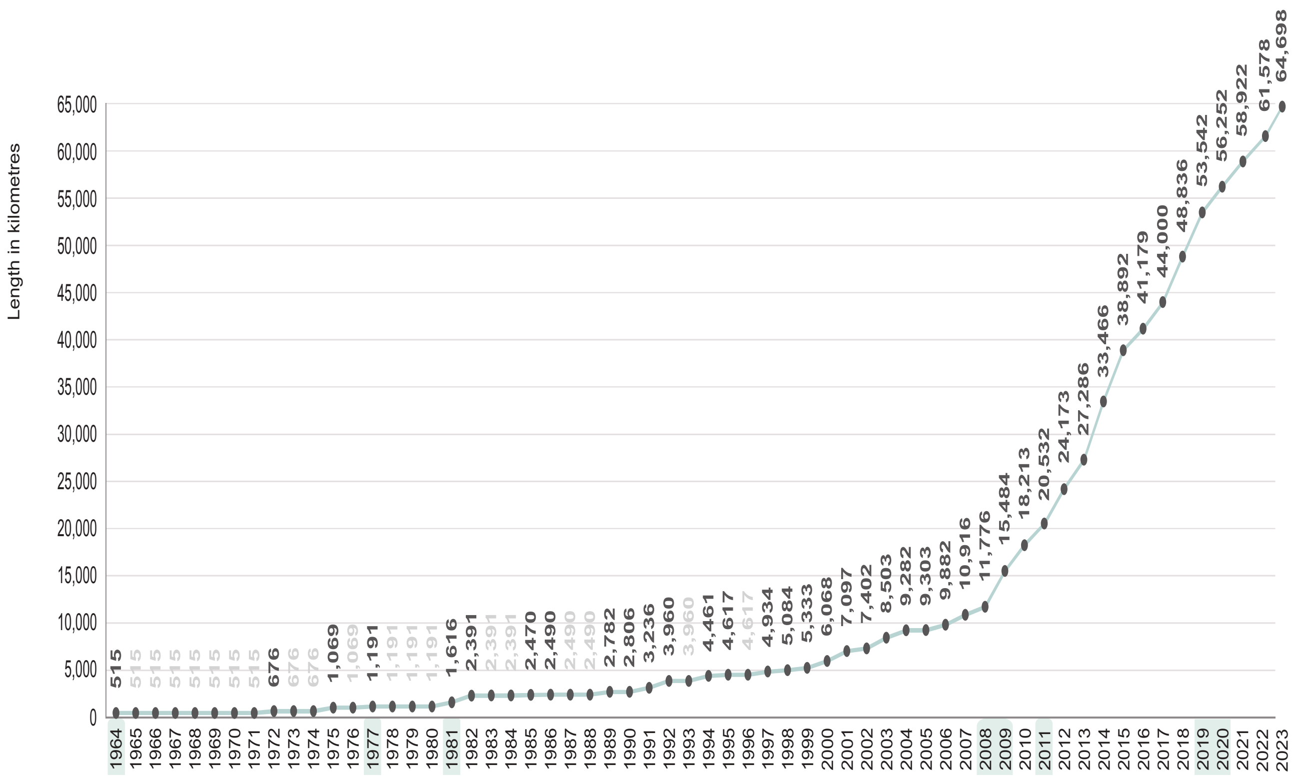
Stations are not only for passengers. They are also used by other people who may go there to buy something, meet someone, or use one of the many services available. In other words, they are public spaces that require excellent signage, so that everyone can easily reach their destination. As people are increasingly using GPS on their smartphones to find their way around streets and public buildings, stations naturally need to provide WiFi to help people access guidance apps, information, and the internet.

Station connectivity is also becoming increasingly useful for people with additional needs, providing access to all the necessary assistance apps. Similarly, trains and stations must provide sockets for customers to recharge their devices, with the entire railway system aiming to offer customers autonomy, as you are never better served than by yourself.

THE GLOBAL HIGH-SPEED NETWORK IN FIGURES

There has been steady development in high-speed railway around the world from its beginnings, however, in 2008, it saw a rapid expansion due to the construction and operation of lines in China.

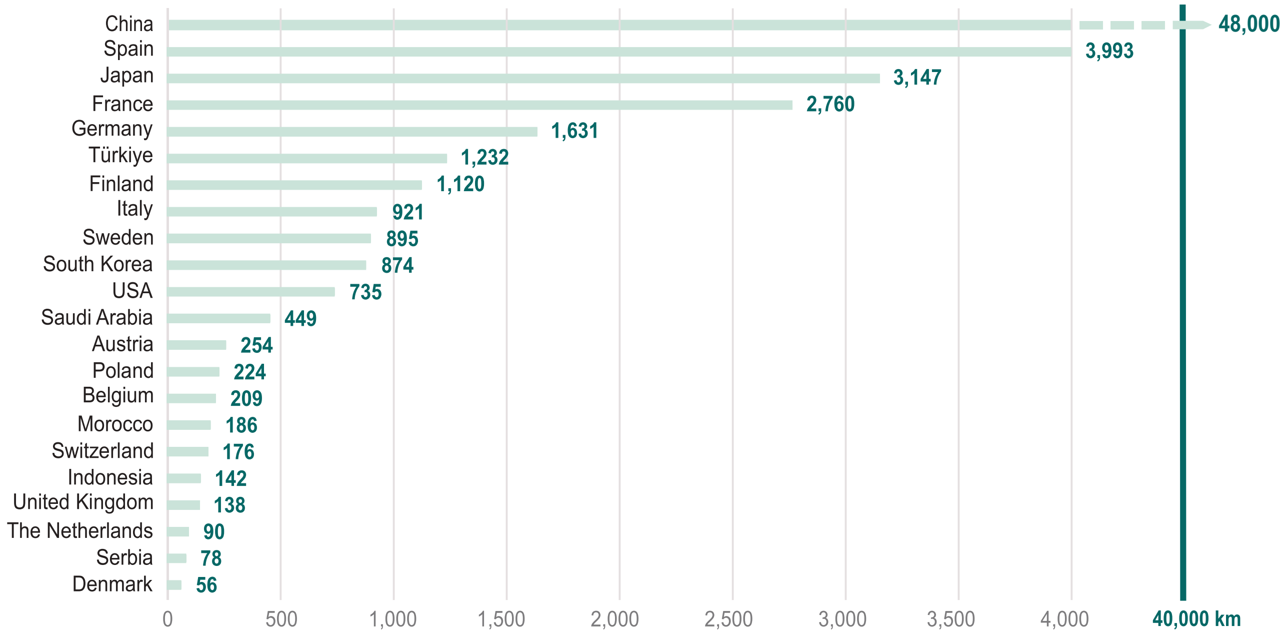
Length of the high-speed network in commercial operation worldwide (1964-2023)



© JR East

China has rapidly taken the lead in high-speed rail worldwide, with 2/3 of the world's lines now built there.

Length of the high-speed network in commercial operation by country



Source: compiled by authors based on International Union of Railways

The kilometers of line currently under construction account for 30% of the existing network's length. Given that infrastructure projects typically take five to six years to complete, the annual growth rate of the global network will be around 5% per year over the next five to six years. This is a steady growth rate, indicating the importance of this transport system's continuous expansion.

Length of the high-speed network in commercial operation by UIC Regions

Source: compiled by authors based on International Union of Railways

Length of the high-speed network under construction by UIC Regions

Source: compiled by authors based on International Union of Railways

THE GLOBAL HIGH-SPEED NETWORK IN MAPS

Africa

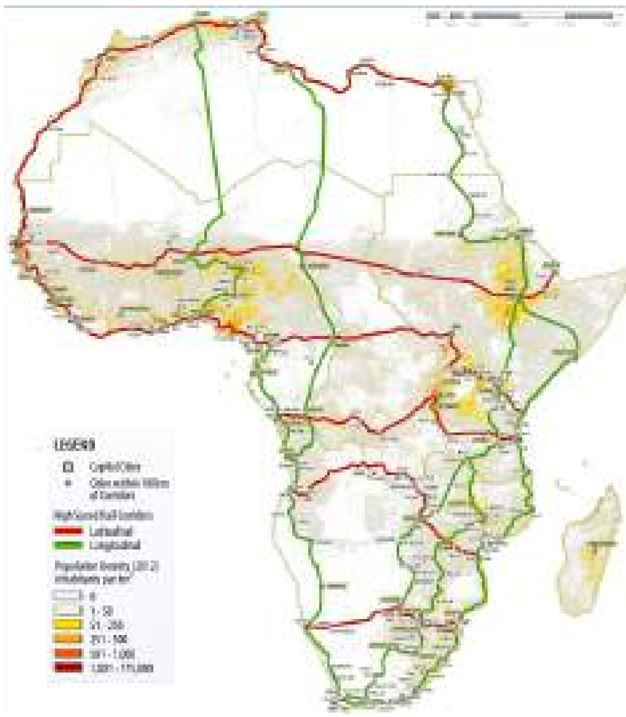
Africa's high-speed rail map is, for the moment, relatively sparse, although Morocco has played a pioneering role on this continent, with a first stretch of line opening between Tangiers and Kenitra in 2018.

The country has also already committed to extending this section, with the ultimate aim of creating a series of lines serving the entire country.

Egypt is the second country to venture into high-speed rail, with a project connecting the Red Sea to the Mediterranean—a 660 km "Suez Canal on rails" from Mersa Matruh to Ain Sokhna. This ambitious endeavour is just the first phase of a nationwide network extending south to Abu Simbel and east to Safaga.

Once the commercial success of this initial infrastructure has been demonstrated, (as is already the case in Morocco), this will encourage other countries to adopt high-speed rail.

The Agenda 2063 envisions a new, modern rail infrastructure that spans Africa from East to West and North to South. With no shortage of powerful urban centers, and a growing population, this presents a crucial potential market. Moreover, in many cases, the distances between major cities make rail transport more practical than road or air transport.



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America

As in Africa, there are currently very few high-speed corridors in America.

In the United States, the vast distances have fostered a tradition of air travel, despite the extensive rail networks connecting the East and West. While the rail network has retained its relevance for freight and dedicated most of its capacity to it, it has not been sufficiently modernised for passenger services. The exception to this is regional services around major urban centers.

Nevertheless, as is the case in all densely populated areas around the world, railways are essential for mass transport. This is evident on the northeast coast of the United States, where efforts are underway to enhance and modernise the existing network, including the use of tilting trains.

Even more ambitious is the California's high-speed project, currently under construction, with the first service scheduled for 2025.

Canada has just signed an infrastructure project aimed at developing the corridor linking Toronto to Quebec. Brazil, also has high-speed line projects. While these initiatives take considerable time to materialise, the successful completion of the first project often accelerates the development of subsequent ones, fostering the concept of a comprehensive network.

© Statewide system map, Wikipedia
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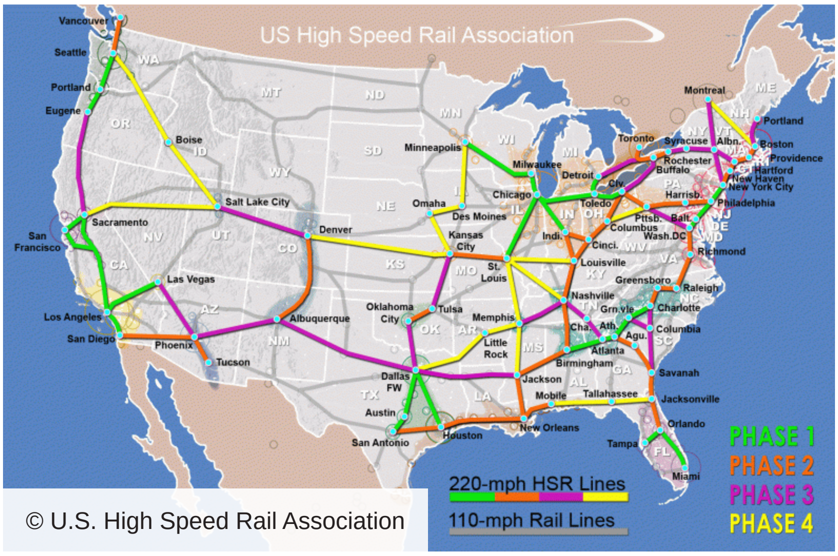
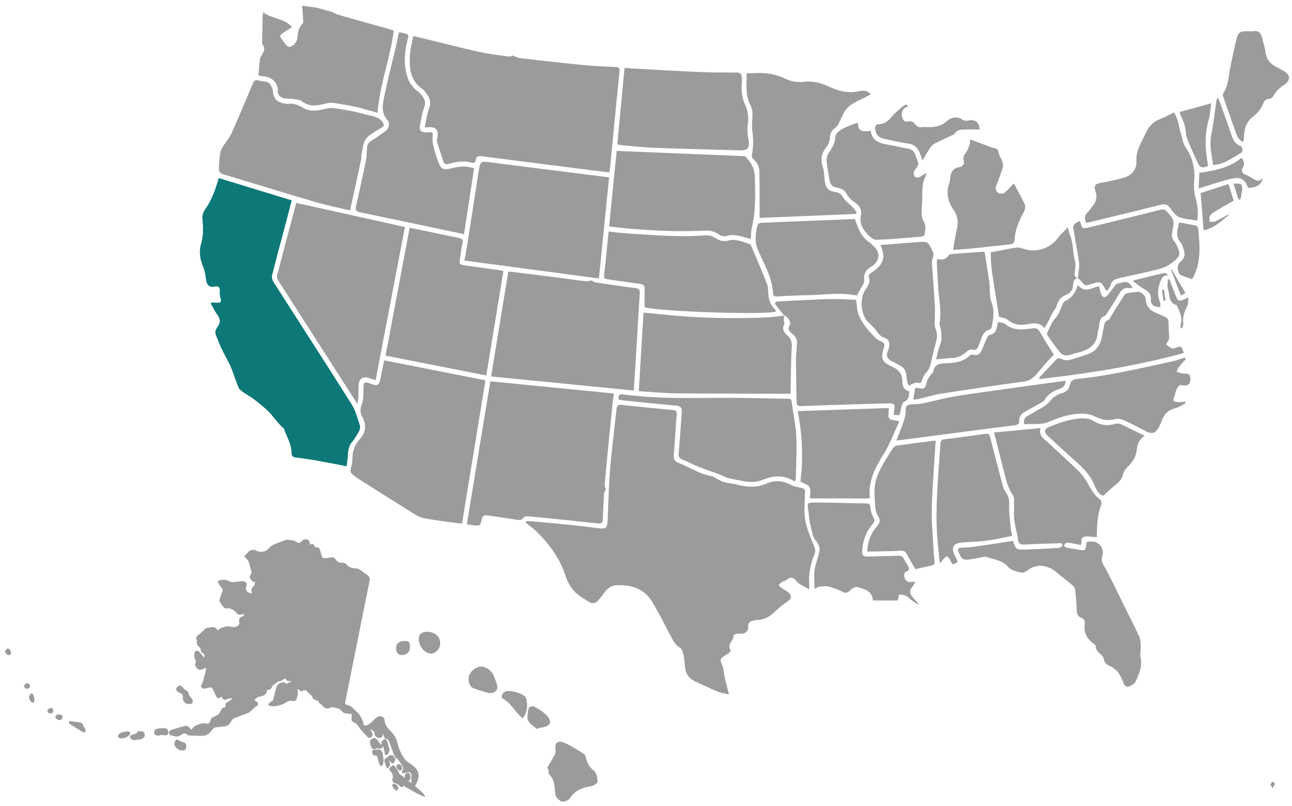
For example, in the United States, such a network is being advocated for by the US High-Speed Rail Association, with a planned construction in four phases. Even before the full implementation of this plan, Phase 1 is already underway, with the new Los Angeles-San Francisco line connecting to the future Los Angeles-Las Vegas Brightline, forming the initial framework of a network.

Similarly, projects in the northern United States have the potential to naturally extend across the border into Canada.



© U.S. High Speed Rail Association



Asia-Pacific

As previously mentioned, Asia is the birthplace of high-speed rail. Since its introduction in Japan in 1964, the concept has been widely adopted, particularly within Japan itself, connecting various regions and islands. Today, the country's high-speed network spans almost its entire length, from south to north, complementing the traditional narrow-gauge network.

South Korea, the second country venture into high-speed, has followed Japan's example by gradually developing a network that serves the majority of the country's inhabitants and economic centers. Having been inspired by French technology, the local industry now manufactures its own rolling stock.

Chronologically, China was the third country to adopt high-speed rail, but it quickly distinguished itself for three main reasons:

- From the outset, it committed to building a nationwide network with a comprehensive vision
- It has achieved technological mastery of the entire high-speed rail system, becoming the only country to offer a commercial speed standard of 350 km/h
- It is actively contributing to the development of high-speed rail throughout the world

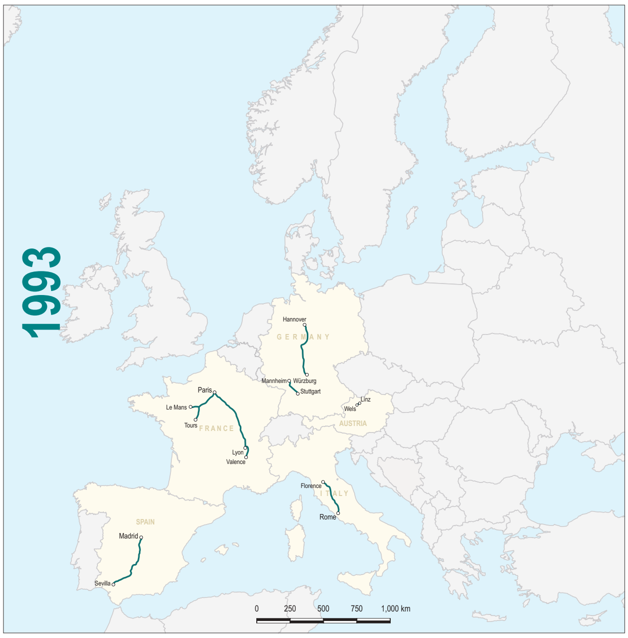
Indonesia has benefited from this support, opening a nearly 150 km long high-speed line between Jakarta and Bandung.

Other countries, such as Vietnam, Malaysia, Thailand, India and Australia, in particular, are planning to follow suit, as this region has many densely populated corridors that are perfectly suited to high-speed rail.

Europe

The European network is continuing to expand and become more interconnected. A comparison of maps from 1993, 2006, 2010, and 2023 clearly illustrates this progressive development.

Thirteen countries are now equipped with high-speed rail lines.



In Europe, harmonisation of the rail sector is underway, notably through the implementation of the railway packages, which aim to create a more integrated and interoperable system across Member States (see Standardisation, p. 18).

The Trans-European Transport Network (TEN-T) consists of approximately ten East-West and North-South corridors that cross the European Union. Projects initiated by member countries align with this overarching framework and receive financial support from the European Union, particularly for cross-border initiatives and those involving natural obstacles like mountain ranges. Ultimately, this network aims to connect all of the Member States' capitals.

Switzerland is contributing to this effort by constructing wide-gauge tunnels capable of supporting speeds of up to 250 km/h.

Notably, this network connects to the British network via the Channel Tunnel. Therefore, the Paris-London-Brussels triangle can be considered the beginning of the European high-speed network, as with its construction it demonstrated the possibility of overcoming numerous geographical and historical challenges, such as:

- The underground crossing of the English Channel
- Lines with entirely different gauges, as well as electrification and signalling systems
- Different cultures and languages

The Middle East

As in other regions around the world, the Middle East is also embracing high-speed, with projects that were initially national in scope now being connected on a larger scale to form transcontinental routes.

Currently, Türkiye has the furthest along in this endeavour, serving as a crucial link between the European and Asian continents. Its network extends in a star-like pattern around the Ankara-Istanbul axis.

In Saudi Arabia, a dedicated project has developed to link major places of worship. Concurrently, Iran is planning a star-shaped network with Tehran as its hub.

The United Arab Emirates have announced the development of a rail link between Abu Dhabi and Dubai.

FROM EXCLUSIVE TO INCLUSIVE

Exclusivity

High-speed rail first captured public attention with its significant technological and performance progress, transitioning from current speeds of 140-160 km/h to 250-350 km/h, setting successive world speed records. High-speed rail was initially seen as an exclusive product, both in terms of performance and geography, as it was limited to a single corridor within one country.

Paradoxically, the rapid improvement in rail transport created a form of regional inequity, with areas of the same country falling into two categories based on their access to high-speed rail, leading to perceptions of privilege or disadvantage.

Inclusivity

It was partly to offset these regional inequities that several countries have expanded their high-speed network, with the aim of reducing exclusion and increasing accessibility to the mode of transport.

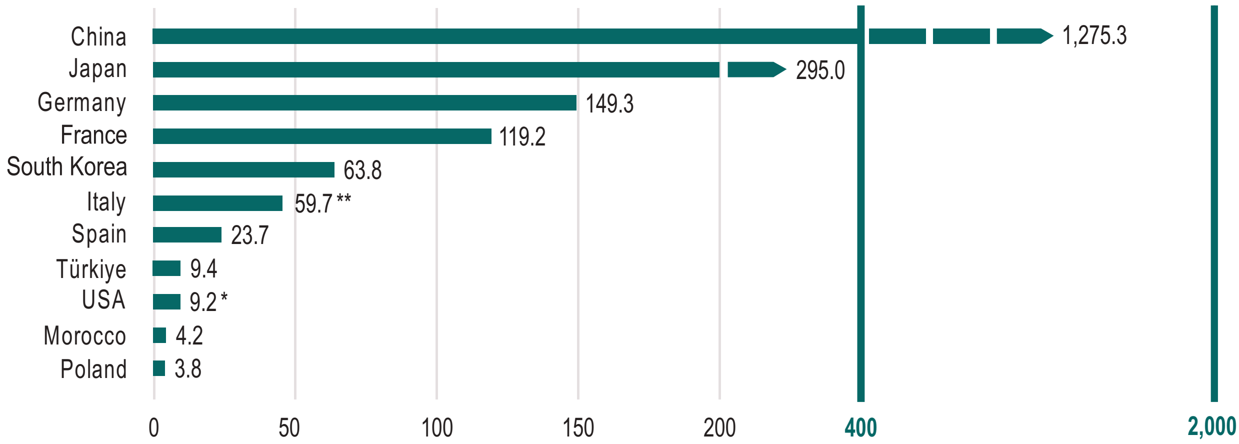
Moreover, the increased speed has proven productive in a number of ways, such as improving rolling stock rotation and leading to higher train occupancy following increased demand.

This productivity has enabled a reduction in the production cost per passenger-kilometre, thereby lowering train ticket prices. Travelling by high-speed train, once considered a luxury, has become accessible to a broader population, completing the transition from exception to inclusion.This analysis explains why there is no direct correlation between the geography of the wealthiest countries and those operating high-speed trains. It also clarifies why no country has built its first high-speed line and then ceased expansion as each has sought to extend the initial stretch to other areas.

The figures below illustrate that high-speed rail serves entire populations, not just a privileged few.

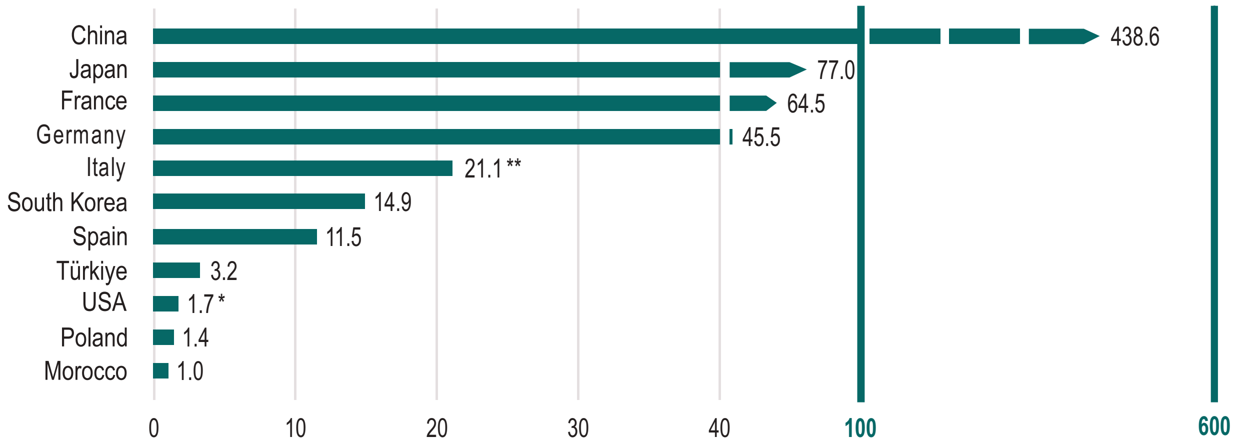
The first figure shows that the number of passengers using high-speed trains will exceed 3 billion by 2023. This is significant when compared to the world's population, as currently only around 20 out of 200 countries (with 197 of these being UN-recognised) will have high-speed infrastructure by this point.

Number of passenger (millions) by countries (2022)



Source: compiled by authors based on International Union of Railways

Number of passenger.kilometre (billions) by countries (2022)



Notes:
(*) Figures referred to fiscal year Oct 2021-Sep 2022
(**) Figures referred to 2019
Source: compiled by authors based on International Union of Railways

This volume of traffic translates to 1,000 billion passenger-kilometres, meaning that the average distance travelled by high-speed train passengers is approximately 300-350 km, a range where high-speed services are the most relevant and efficient.

The second figure shows that high-speed rail tickets have become a mainstream and widely accessible product. Very low fares are available either because the railways are state-controlled, aiming to attract as many passengers as possible to the new infrastructure once the investment has been made, or because competition is authorised, as seen with the liberalisation of transport in Europe. This has led to the introduction of low-cost trains, significantly reducing ticket prices, as is the case in France and Spain. In Spain, for example, fares for a medium-distance journey start at just €9.

A STATION OF THE FUTURE

A station of the future must adapt to changes in society, and in particular:

- Be energy-positive by using all possible sources of renewable energy to not only power itself, but also the batteries of vehicles of all kinds that visit it
- The modern station is characterised by its multimodal accessibility, offering efficient connections with soft modes of transport (walking, cycling, scooters, etc.), public transportation (metro, tramway, regional trains, etc.), and cars, including parking facilities equipped with photovoltaic installations for battery recharging
- Host a variety of public services, such as health care for example, as its location and accessibility will maximise the use of these services
- Have coworking spaces, due to its role as a hub for all types of transport

ATTRACTIVENESS OF HIGH-SPEED RAIL

The market shares in transport are undoubtedly primary criterion to take into account.

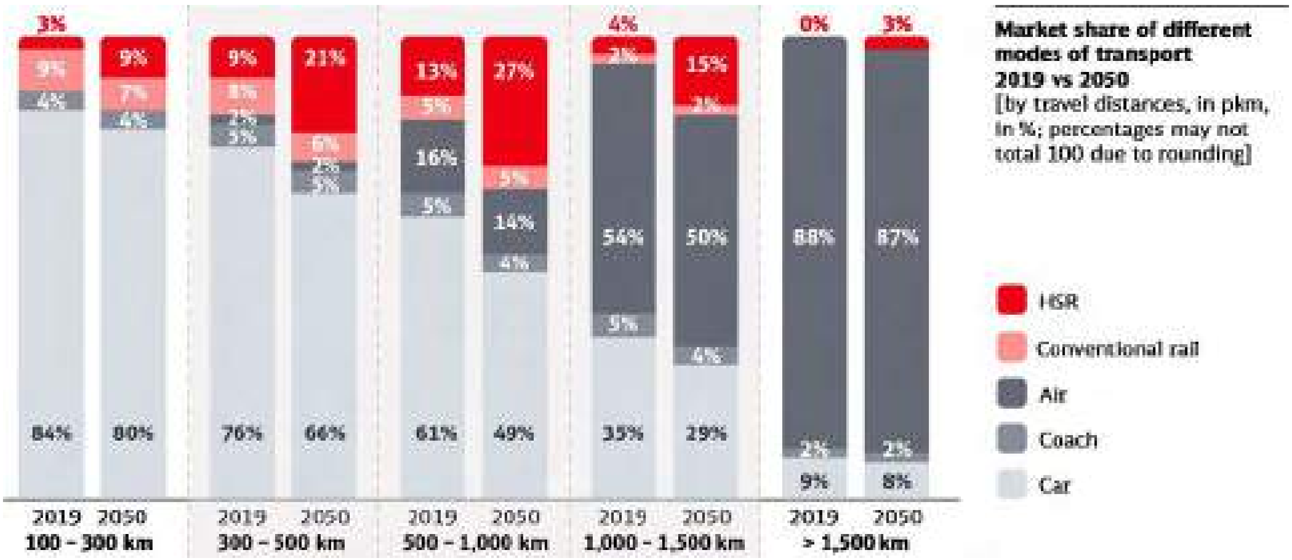
Globally, when we account for all passenger origins and destinations, trip purposes, and group sizes, road transport leads the way.

However, if we narrow the market to origins and destinations where high-speed rail and air travel compete with cars and coaches, significant market shares are captured by high-speed trains (for journeys between 150 and 700 km) and aeroplanes (for distances over 700 km). The market share of conventional rail and high-speed rail depends on two key factors:

- Distance
- The availability of a service

A study by KPMG shows the market shares obtained in 2019 by competing modes of transport, and predicts how they will evolve with the development of the European high-speed network by 2050. In 2019, rail captured 18% (13% for high-speed and 5% for conventional rail) of the market over distances of between 500 and 1,000 km, compared with 16% for air travel. By 2050, this market share is expected to rise to 32% (27% for high-speed and 5% for conventional rail) over the same distance segment, compared with 14% for air travel.

This demonstrates that high-speed rail, even over relatively long distances, can dominate in terms of collective modes of transport and account for 1/3 of the market on its own, despite not serving all destinations. It also highlights that the market for high-speed rail is not saturated, and that there is still room for even more growth in Europe.

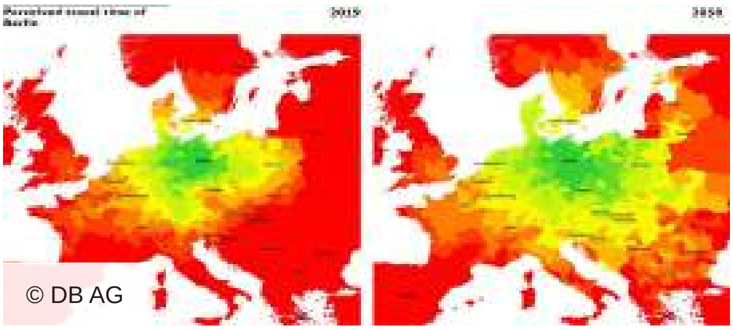


© DB AG

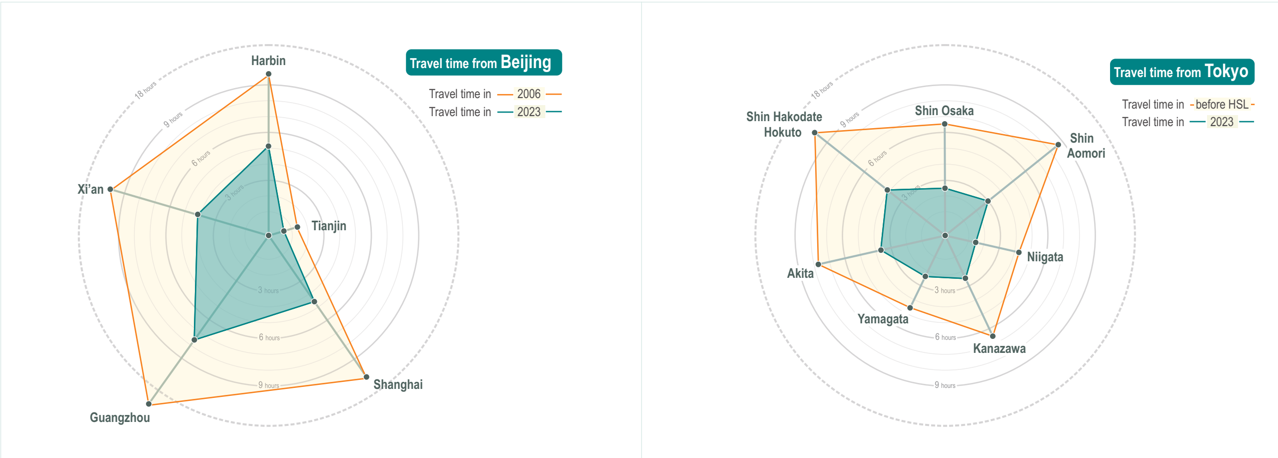
Another way of demonstrating the attractiveness of high speed is to show the change in geographical accessibility that it brings. The following map illustrates this change for the inhabitants of a city like Prague. It provides an idea of how the rail catchment area will expand when high-speed infrastructure is deployed in northern Europe, making faster trains possible.

This is a direct result of increased average commercial speeds, which in high-speed corridors rises by 50 to 100%.

This acceleration signifies a substantial reduction in journey times on high-volume origin-destination routes.

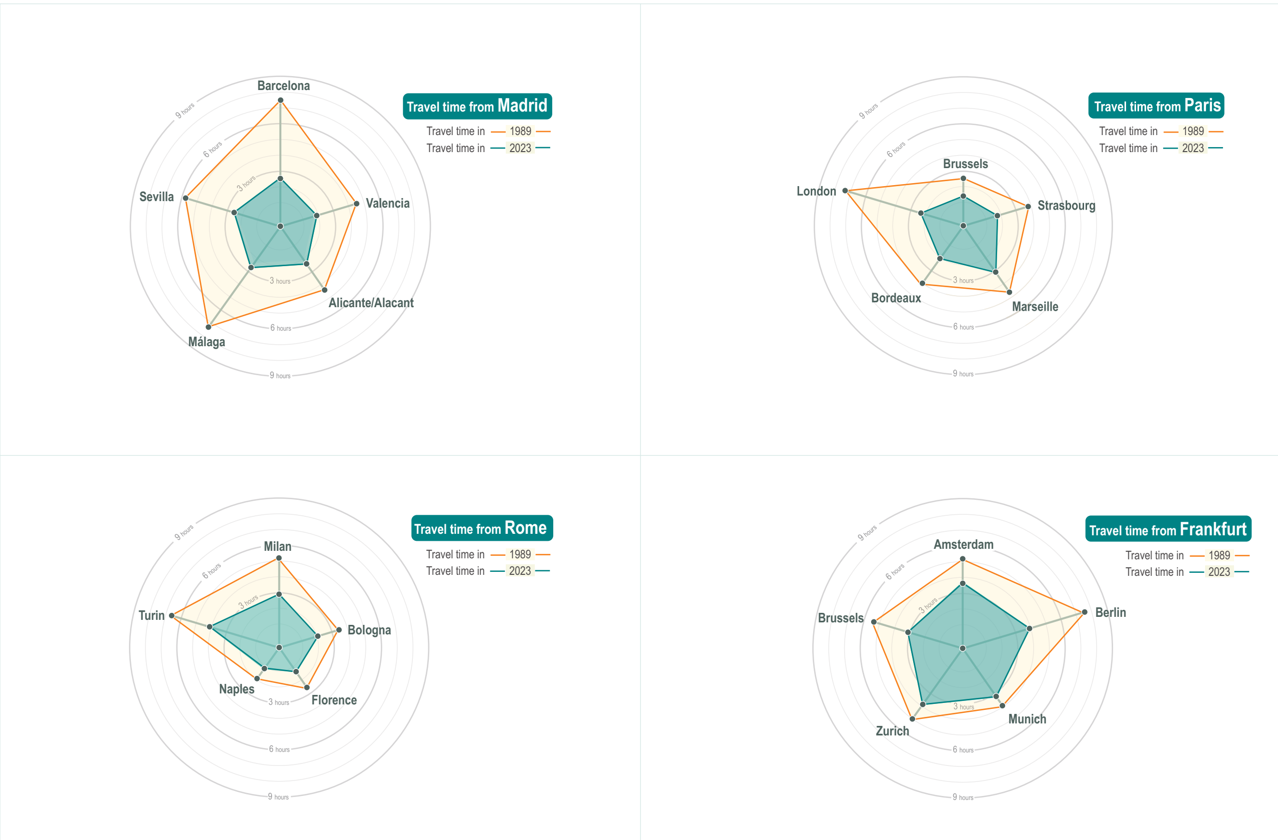


Evolution of travel time from the main chinese and japanese cities



Source: International Union of Railways

Evolution of travel time from the main European cities



Source: compiled by authors based on "European Timetable" Thomas Cook Travel Guides 1989 and Railway Operators websites

CHALLENGES TO OVERCOME

Unlocking the Full Potential of High-Speed Rail

While the future holds uncertainties, several key challenges must be addressed to enable high-speed rail (HSR) to fully deliver on its promise as a cornerstone of sustainable mobility. These barriers are not merely technical—they are also financial, political, and institutional, and overcoming them requires a shift in how we value, fund, and govern transport infrastructure.

Rethinking Investment Priorities

Despite the significant climate benefits that high-speed rail can offer over its lifetime—especially when compared to aviation and road transport—most public and private investment still flows toward these higher-emission modes. A key barrier is the lack of financing mechanisms that reflect the full climate and societal benefits of HSR. Unlocking climate-aligned finance—including through carbon markets, climate funds, and results-based finance—is essential. Emerging mechanisms such as Article 6.4 of the Paris Agreement offer an opportunity to reward projects that deliver verified emission reductions and co-benefits, including modal shift from aviation in low and lower-middle income countries.

> **Did you know?**
> High-speed rail emits up to 90% less CO_2 than planes.

Enabling Modal Shift

High-speed rail can only deliver on its decarbonisation potential if supported by policies that enable and encourage modal shift. Yet today, regulatory, fiscal, and planning frameworks often favour short-haul flights and private car use. The development of HSR must go hand-in-hand with measures that ensure integration with regional rail and public transport networks, more equitable taxation across modes, and the prioritisation of rail alternatives for journeys under four hours. Coherent public policies are essential to shift demand and unlock the environmental and socioeconomic value of HSR.

Customer experience is also essential, which needs to design an end-to-end multimodal travel through ticketing (as OSDM supporting easy sales and distribution) and accessibility of stations, trains and connection hubs with other means of transport.

Driving Digitalisation & Automation

Digital technologies and automation are indispensable tools to improve HSR system performance, enhance safety, and optimise the use of infrastructure and rolling stock. The transition to the next generation of telecoms (5G / FRMCS) supporting signalling systems, including ERTMS/ETCS Level 3, will be crucial for increasing network capacity and interoperability. Meanwhile, artificial intelligence can play a growing role in optimising train traffic, predictive maintenance, and workforce planning. Automated systems for track reconnaissance and light logistics could further enhance operational efficiency and safety, while responding to evolving passenger and freight needs.

Adapting to Climate Risks

As climate impacts intensify, high-speed rail systems must adapt to increasingly frequent and severe disruptions, from floods and heatwaves to high winds and sandstorms. Designing infrastructure that is resilient to these risks is now a fundamental requirement. This calls for the integration of climate risk assessments in planning and investment processes, the reinforcement of critical assets, and the deployment of predictive monitoring tools. Strengthening resilience is not just about protecting physical infrastructure—it is about safeguarding the reliability and continuity of the HSR system as a whole.

Decarbonising Infrastructure

A complete decarbonisation of high-speed rail includes both operations and the infrastructure itself. New approaches to construction—such as the use of low-carbon concrete and materials—can significantly reduce the carbon footprint of network expansion. Stations and trackside infrastructure also offer untapped potential for the production of renewable energy, reducing dependency on external sources. On the operational side, advances in hybrid, battery-electric, and hydrogen-powered rolling stock will be particularly important to decarbonise feeder and regional services that connect to the high-speed rail network.

Unlocking the potential of high-speed rail requires a fundamental shift in the way transport is financed, regulated, and integrated across systems. HSR must be recognised not only as a transport option, but as a strategic climate solution with long-term societal value. This means embedding its development within national climate plans, aligning investment criteria with sustainability outcomes, and ensuring that the positive externalities of rail are reflected in both policy and finance. With the right governance frameworks and financial tools in place, high-speed rail can become a driving force for decarbonisation, economic recovery, and inclusive territorial development.

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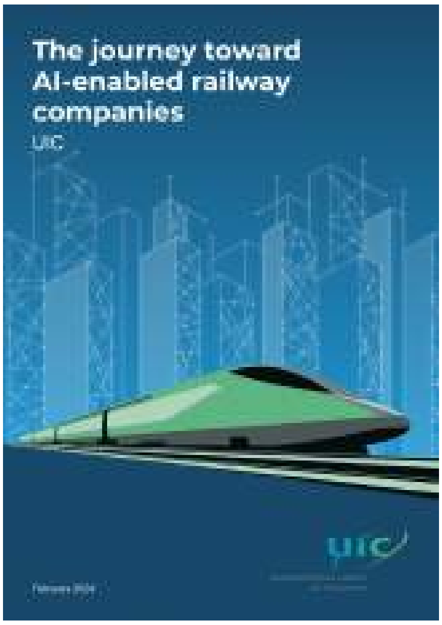
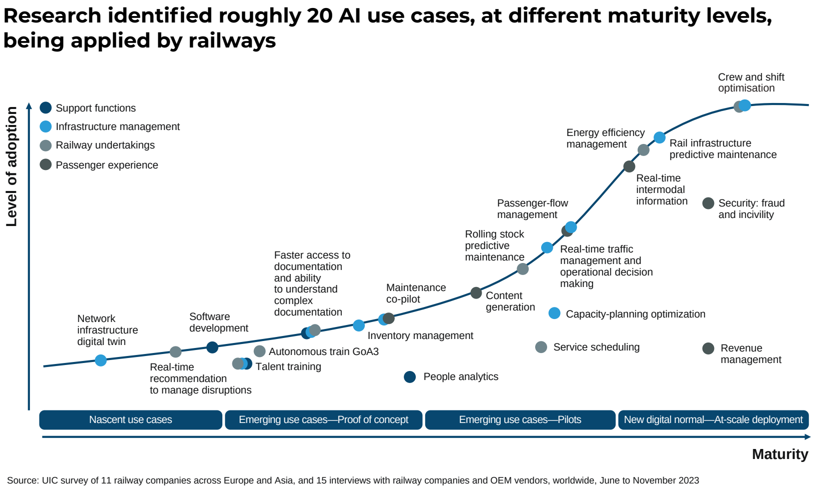


© UIC, *The journey toward AI-enabled railway companies*



Source: UIC survey of 11 railway companies across Europe and Asia, and 15 interviews with railway companies and OEM vendors, worldwide, June to November 2023

A promising innovation

A new generation of slab track has recently been developed, with an entirely prefabricated low-carbon reinforced concrete structure. This innovative design requires no platform renovation and is suitable for all types of lines, including high-speed, freight, and metro. Additionally, it incorporates a geometry adjustment system to compensate for platform settling.

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Ultra-low-carbon segments for tunnels

In the foreground, two ultra-low-carbon segments

Concrete for a circular economy

A promising solution to decarbonising concrete production lies in the use of slag, a by-product of iron and steel works. Slag, once considered waste, is now recognised for its ability to replace cement, the production of which generates significant carbon emissions. By integrating slag into a circular economy cycle, it can be recycled and used to compose up to 60% of voussoirs.

This new generation of products is classed as being "ultra-low carbon" thanks to the incorporation of an alkali-activated binder based on soda ash.

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In-plant segment production

The greenhouse gas emissions generated by these new materials are around 70% lower than those of traditional concrete, and 50% lower than those of current low-carbon concrete solutions.

HIGH-SPEED RAIL AT UIC

Every 2–3 years, UIC, in collaboration with one of its members, organises a world congress dedicated to high speed (formerly known as 'Eurailspeed'). The 2025 edition, marking the 12th Congress, will take place in Beijing, China.

The slogan for this event is:

"High-speed rail: Innovation and development for a better life"

List of UIC High-Speed Rail Congresses

1. **Lille, France (1992)**
2. **Brussels, Belgium (1995)**
3. **Berlin, Germany (1998)**
4. **Madrid, Spain (2002)**
5. **Milan, Italy (2005)**
6. **Amsterdam, Netherlands (2008)**
7. **Beijing, China (2010)**
8. **Philadelphia, United States (2012)**
9. **Tokyo, Japan (2015)**
10. **Ankara, Türkiye (2018)**
11. **Marrakech, Morocco (2023)**
12. **Beijing, China (2025)**

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PART 2

High-speed rail in China

FOREWORD

On high-speed railways traversing towering mountains, snow-covered plateaus, great rivers and serene water towns, Fuxing EMU trains criss-cross the vast expanse of China. The high-speed railway (HSR) constitutes an important symbol of the country's modernisation. Thanks to years-long innovation, China Railway (CR) has effectively promoted research on core technologies in key areas and their industrial applications, and then built and operated the largest and most modernised HSR network in the world. HSR has become a shining name card of China.

HISTORY OF HSR DEVELOPMENT IN CHINA

Legend:

A1 Beijing-Tianjin Intercity Railway
A2 Zhengzhou-Xi'an HSR
A3 Beijing-Shanghai HSR
A4 Harbin-Dalian HSR
A5 Beijing-Guangzhou HSR
A6 Lanzhou-Urumqi HSR
A7 Hainan Loop HSR
A8 Shanghai-Kunming HSR
A9 Xi'an-Chengdu HSR
A10 Guangzhou-Shenzhen-Hong-Kong HSR
A11 Beijing-Harbin HSR
A12 Zhengzhou-Chongqing HSR
A13 Guiyang-Nanning HSR
A14 Fuzhou-Xiamen HSR
A15 Beijing-Zhangjiakou HSR
A16 Beijing-Xiongan Intercity-Railway

Representative HSR lines in China

At the beginning of the 1990s, China began to explore and study the ways of developing HSR, preparing itself for its subsequent rapid HSR development. From 1997 to 2007, China undertook six large-scale projects to speed up conventional railway lines, bringing the maximum operating speed in the relevant sections of busy trunk lines up to 200 km/h.

In January 2004, the Chinese Government issued the *Medium- and Long-Term Railway Network Plan*, proposing the construction of “four north-south and four east-west corridors”, including over 12,000 km of lines dedicated to passenger transport. In October 2008, it issued a revised version of the *Plan*, proposing the construction of 16,000 km of lines dedicated to passenger transport. In July 2016, a further updated *Medium- and Long-Term Railway Network Plan* was issued, presenting the blueprint of an HSR network with an expanded framework of eight north-south and eight east-west corridors.

Under the guidance of national top-level planning, CR has vigorously advanced HSR development. It has mastered the full range of technologies required for HSR construction under various complex geological and climatic conditions. It has developed a complete system of HSR technologies and equipment with Chinese characteristics. It has built a huge number of HSR projects under challenging and complex conditions and fully mastered all the technologies necessary for the long-distance operation and management of HSR under complex network conditions. It has established an effective and comprehensive industrial chain covering research and development, planning and design, engineering construction, equipment manufacturing, and operation and management, delivering high-quality high-speed operation and services in China.

A1 Beijing-Tianjin Intercity Railway: In August 2008, the 120-km-long Beijing-Tianjin Intercity Railway was put into operation, making it an HSR reaching a design speed of 350 km/h for the first time in China.

A2 Zhengzhou-Xi'an HSR: With a total length of 523 km and a design speed of 350 km/h, the Zhengzhou-Xi'an HSR was put into operation in February 2010. It was the world's first HSR built in a large collapsible loess area.

A3 Beijing-Shanghai HSR: In June 2011, the 1,318-km-long Beijing-Shanghai HSR, with a design speed of 350 km/h, was put into operation. It is the busiest HSR line in China.

A4 Harbin-Dalian HSR: With a total length of 921 km and a design speed of 350 km/h, the Harbin-Dalian HSR opened to traffic in December 2012. It was the world's first operating HSR running in a very cold area with seasonally frozen soil.

A5 Beijing-Guangzhou HSR: With a total length of 2,281 km and a design speed of 350 km/h, the Beijing-Guangzhou HSR was put into operation in December 2012. It is the world's longest HSR, running through temperate and subtropical zones, different terrains, geological areas and multiple river systems.

A6 Lanzhou-Urumqi HSR: In December 2014, the Lanzhou-Urumqi HSR, with a total length of 1,776 km and a design speed of 250 km/h, was put into operation. It was the world's longest HSR built in a single project phase and passes through the Gobi desert and strong wind areas.

A7 Hainan Loop HSR: With a total length of 653 km and a design speed of 200 to 250 km/h, the Hainan Loop HSR was put into operation in December 2015. It was the world's first island loop HSR built in a tropical coastal area.

A8 Shanghai-Kunming HSR: With a total length of 2,252 km and a design speed of 300 km/h to 350 km/h, the Shanghai-Kunming HSR was put into operation in December 2016. It is the HSR that passes through the largest number of provinces in China.

A9 Xi'an-Chengdu HSR: With a total length of 658 km and a design speed of 250 km/h, it marks that China's HSR passed through the Qinling Mountains—the geographical and climatic dividing line that separates China's south and north—for the first time. It opened to traffic in December 2017, representing a historic breakthrough in improving the transport to and from Sichuan Province, which is famous for its challenging terrain.

A10 Guangzhou-Shenzhen-Hong Kong HSR: In September 2018, the 141-km-long Guangzhou-Shenzhen-Hong Kong HSR, with a design speed of 200 km/h to 350 km/h, was put into operation. It connects Hong Kong with Guangzhou, Dongguan and Shenzhen, marking Hong Kong's inclusion in the national HSR network.

A11 Beijing-Harbin HSR: In January 2021, the Beijing-Harbin HSR, with a design speed of 350 km/h, was put into operation. It is the fastest railway linking Northeast China and other regions.

A12 Zhengzhou-Chongqing HSR: In June 2022, the Zhengzhou-Chongqing HSR, with a total length of 1,063 km and a design speed of 250 to 350 km/h, opened to traffic. It is an HSR built with bridges and tunnels accounting for over 90% of the entire line for the first time through complex and steep mountainous areas in China.

A13 Guiyang-Nanning HSR: With a total length of 482 km and a design speed of 350 km/h, the Guiyang-Nanning HSR opened to traffic in August 2023. 80% of the railway traverses karst areas, connecting more than 30 ethnic minority areas.

A14 Fuzhou-Xiamen HSR: In September 2023, the 277-km-long Fuzhou-Xiamen HSR, China's first cross-sea HSR with a design speed of 350 km/h, was put into operation.

In recent years, China's high-speed railways have become more intelligent, safer and more comfortable with higher standards. Advanced technologies, including cloud computing, IoT, BeiDou navigation and AI, have been adopted to support the rapid development of intelligent railways.

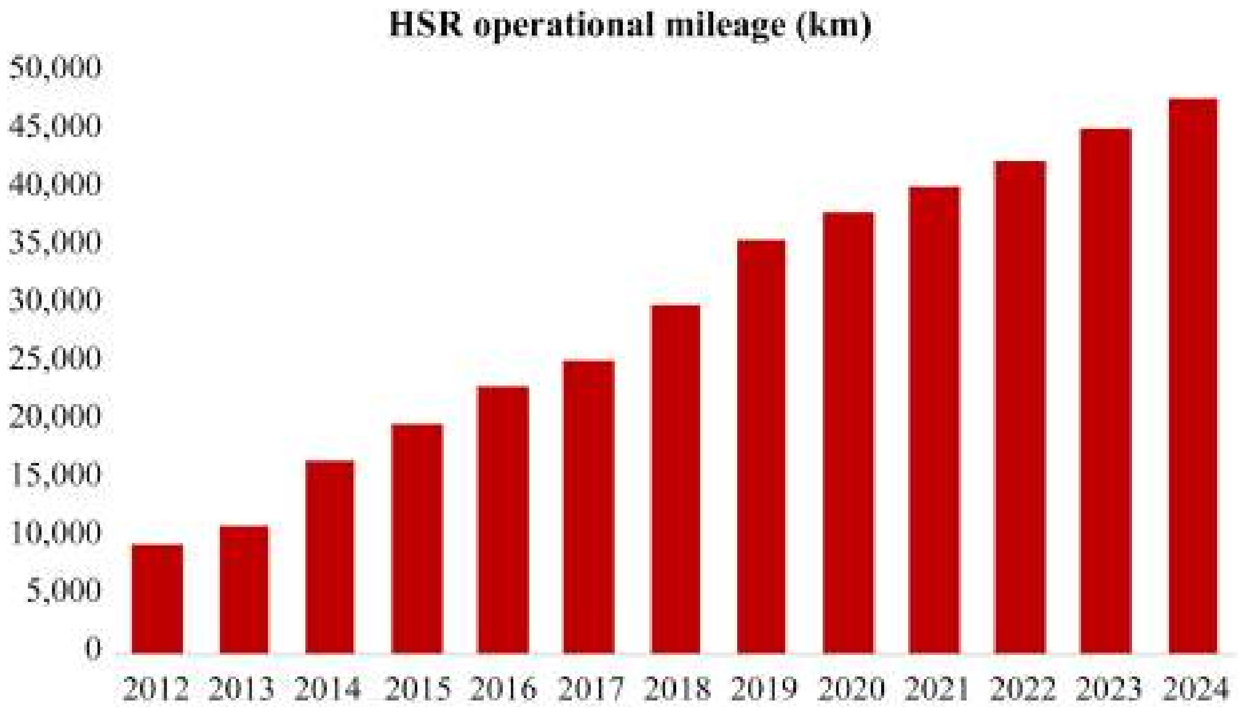
A15 Beijing-Zhangjiakou HSR: With a total length of 174 km and a design speed of 350 km/h, the Beijing-Zhangjiakou Intelligent HSR was put into operation in December 2019, serving as a crucial transport link for the 2022 Beijing Winter Olympics. On 6 January 2022, the Beijing Winter Olympics trains, which were developed on the basis of the new Fuxing intelligent EMU train, tailored to the demands of the Beijing Winter Olympics and the Winter Paralympic Games, and equipped with 5G ultra-high-definition studios, were officially put into operation on the Beijing-Zhangjiakou HSR.

A16 Beijing-Xiongan Intercity Railway: With a total length of 91 km and a maximum design speed of 350 km/h, the Beijing-Xiongan Intercity Railway, another intelligent HSR in China, was put into operation in December 2020, linking Beijing and Xiongan New Area.

DEVELOPMENT OF HSR IN CHINA

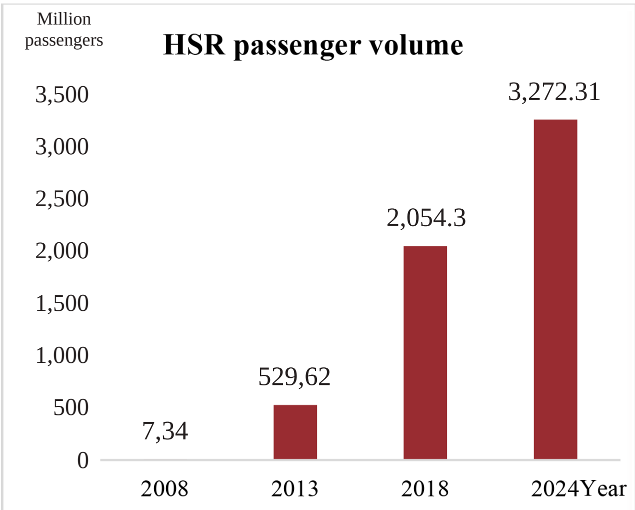
By the end of 2024, China had put into operation forty-eight thousand kilometers of HSR lines, accounting for more than 70% of the world's total HSR line length.

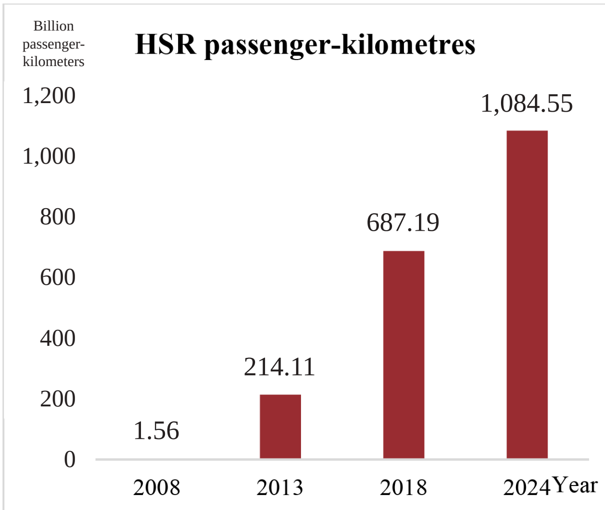
Medium and Long TermHigh-Speed Rail Network Plan



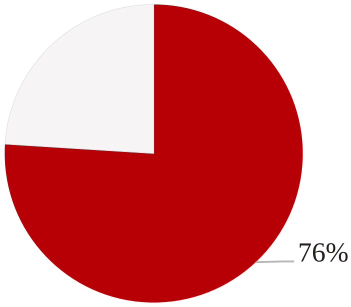
HSR operational mileage in China[1]

By the end of 2024, the total number of passengers carried by high-speed trains had reached 22.9 billion[2]. Today, China's HSR handles about 76%[3] of passenger trips and 69%[4] of passenger traffic turnover on China's railways, which equates to about 19%[5] of passenger trips and about 31%[6] of passenger traffic turnover in the overall Chinese transport market. It has become the leading player in transporting passengers for medium- and long-distance journeys, virtually solving the severe capacity shortage issue during peak traffic hours.

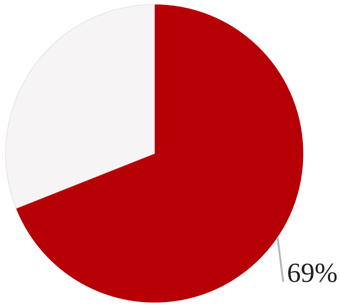




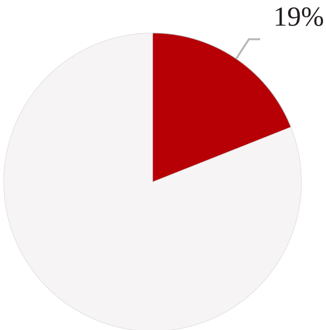
[1] The data on HSR operational mileage from 2012 to 2022 is sourced from the China Statistical Yearbook; the data for 2023 and 2024 is sourced from the official information released by CHINA RAILWAY.
[2] EMU trains nationwide.
[3] EMU trains nationwide.
[4] EMU trains nationwide.
[5] Estimated based on the proportions observed in the first three quarters of 2024.
[6] Estimated based on the proportions observed in the first three quarters of 2024.



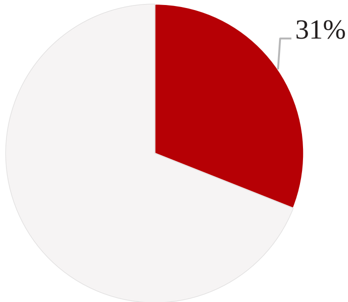
Share of HSR passengers in railway transport market (2024)



Share of HSR pkm in railway transport market (2024)



Share of HSR passengers in total transport market (2024)



Share of HSR pkm in total transport market (2024)

Waiting hall of Shanghai Hongqiao Railway Station

HSR bridges

Legend:

B1 Shanghai-Suzhou-Nantong Yangtze River Bridge
B2 Wufengshan Yangtze River Bridge
B3 Beipanjiang Bridge
B4 Pingtan Strait Road-rail Bridge
B5 Xihoumen Road-rail Bridge
B6 New Badaling Tunnel (Badaling Great Wall Station)
B7 Qilianshan Tunnel
B8 Chongming-Taicang Yangtze River Tunnel
B9 Qindong Tunnel

Typical HSR bridge and tunnel projects in China

China boasts exceptionally comprehensive bridge design and construction technologies to meet special and complex engineering conditions, such as deep water, straits, high piers and long spans. The country has built world-class bridges with super-long spans and continually promotes technological innovation in the design and construction of railway bridges. To date, the total length of HSR bridges exceeds 24,000 km.

B1 Shanghai-Suzhou-Nantong Yangtze River Bridge: The main bridge features a cable-stayed structure supported by two towers, five spans and three cable planes. The main span measures 1,092 m and the towers stand 330 m high. The bridge accommodates a four-track railway and a six-lane motorway. The main structure of the steel truss girder is constructed using Q500qE high-strength bridge steel and 2,000 MPa parallel-wire stay cables. Additionally, an integral erection process of two-segment steel girders was employed and a 1,800-ton girder erection crane developed.

B2 Wufengshan Yangtze River Bridge: This is the first HSR suspension bridge in the world, with a main span of 1,092 m. It is designed to support heavy loads, accommodating both a four-track railway and an eight-lane expressway. The bridge has the world's largest land open caisson: 100.7 m in length, 72.1 m in width and 56 m in height. Additionally, for the first time, a prefabricated parallel galvanised aluminium high-strength steel cable with the world's largest diameter (1.3 m) was utilised for the main cables. It employs a flexible suspension bridge structure and has a design speed of 250 km/h. All these adopted techniques have elevated the design and construction technologies of railway suspension bridges to a new level.

B3 Beipanjiang Bridge: This supports a double-track railway with a design speed of 350 km/h. The main structure is a deck-type concrete arch bridge that spans 445 m and sits 300 m above the water surface. The bridge is a concrete arch bridge, featuring the longest span in the world. During its construction, five significant technical breakthroughs were achieved: the maximum span for a reinforced concrete arch bridge, the maximum span for an HSR bridge, ballastless track laying on a long-span bridge, construction methods for a long-span concrete arch bridge, and rigidity control for a long-span bridge.

B4 Pingtan Strait Road-rail Bridge: This is a cross-sea cable-stayed bridge featuring two towers and dual cable planes. The bridge is located in a sea area that frequently experiences extreme weather, with winds above force 6 on the Beaufort Scale for more than 300 days per year and above force 7 for over 200. The highest recorded waves in this region have reached approximately 9.69 m. This bridge is China's first truly cross-sea rail-road bridge and serves as a successful example of bridge construction in an extremely challenging environment.

B5 Xihoumen Road-rail Bridge: Extending 3.1 km in length, this bridge features a main span of 1,488 m and employs a combined cable-stayed and suspension structure. Construction commenced in October 2022. It will be a rail-road bridge with the longest span of its kind in the world.

HSR tunnels

China's HSR tunnels are designed to adapt to a variety of environmental conditions, including plateaus, extremely cold areas, rivers, lakes, seas and shallow buried sections in urban areas. China has effectively addressed the technical challenges posed by special and complex tunnel construction, such as collapsible loess, high crustal stress and large deformation of soft rock. Over 4,500 HSR tunnels have been constructed, featuring remarkable engineering feats such as a plateau tunnel at the highest altitude of 3,607 m, a river-crossing tunnel built with a large-diameter tunnel boring machine (TBM) of 15.4 m, an underground railway station tunnel with a maximum span of 32.7 m and a loess tunnel with a maximum excavation section of 164 m^2. The total length of these tunnels exceeds 7,700 km.

B6 New Badaling Tunnel (Badaling Great Wall Station): With a total length of 12.01 km, a maximum burial depth of 102 m and a maximum span of 32.7 m, this is the bored railway tunnel with the largest single arch span in China. It passes under the Badaling Great Wall twice and is located just 4 m away from the above-ground Qinglongqiao Station of the former Beijing-Zhangjiakou Railway, making the ancient majestic Great Wall blend in with the modern intelligent HSR.

B7 Qilianshan Tunnel: This tunnel extends 16,336 m and its rail surface is 3,607.4 m above sea level. Its portals are located in extremely cold and oxygen-deficient areas (with only 60% of normal oxygen content) where the minimum temperature is -32.6°C. It is a plateau HSR tunnel with the largest excavation section, as well as the highest altitude, design standard and design speed in the world today, making it one of the most challenging projects in China's tunnel construction history.

B8 Chongming-Taicang Yangtze River Tunnel:Z With a total length of 14.25 km, this tunnel has a TBM-constructed section measuring 13.201 km long, with 1.8755 km on land and 11.3255 km underwater. It is a world-class HSR river-crossing project, featuring the longest single-end tunnelling distance in the world, the largest TBM diameter for railway tunnels, the highest river crossing speed of 350 km/h, and a maximum depth of 89 m beneath the Yangtze River.

B9 Qindong Tunnel: This is a double-track collapsible loess tunnel with a total length of 7.68 km and a maximum excavation section of 164 m^2. This tunnel is built under the unique plateau geological conditions of China.

HSR tracks

China has developed key track devices, such as high-speed rails, big-size turnouts, rail fastenings and rail expansion joints. The length of main lines featuring ballastless track is nearly 52,700 km.

CRTS III slab ballastless track

Big-size turnout

Rail fastening

HSR passenger stations

China's HSR passenger stations are designed to meet the demands of transporting large numbers of passengers and operating at high density with easy transfers. China has developed technologies for designing and building large railway passenger stations, including deep and large foundation pits, super-large deep-buried mining, long spans and station-bridge integration. Numerous green, smart, convenient and station-city integrated modern comprehensive passenger transport hubs have been built, becoming new landmarks for the railways and new growth engines for local cities. The number of HSR passenger stations in China has surpassed 1,300.

Chongqingxi Railway Station: With a total floor area of 280,000 m^2, this station represents the largest comprehensive transport hub in China's western region. A design featuring cast-in-situ pure fair-faced concrete canopies was adopted for the first time in a large-scale railway station in China. The main façade of the station building showcases a steel structure with large-span buckling moment support arches. The station also functions as a significant TOD hub, integrating railways, metro lines, long-distance coaches and buses.

Xiongan Railway Station: With a total floor area of 475,200 m^2, this railway station was designed under the concept of "station-bridge integration" and the passenger waiting area features a three-dimensional, two-storey layout. It is the first railway station in China to figure the extensive application of fair-faced concrete columns.

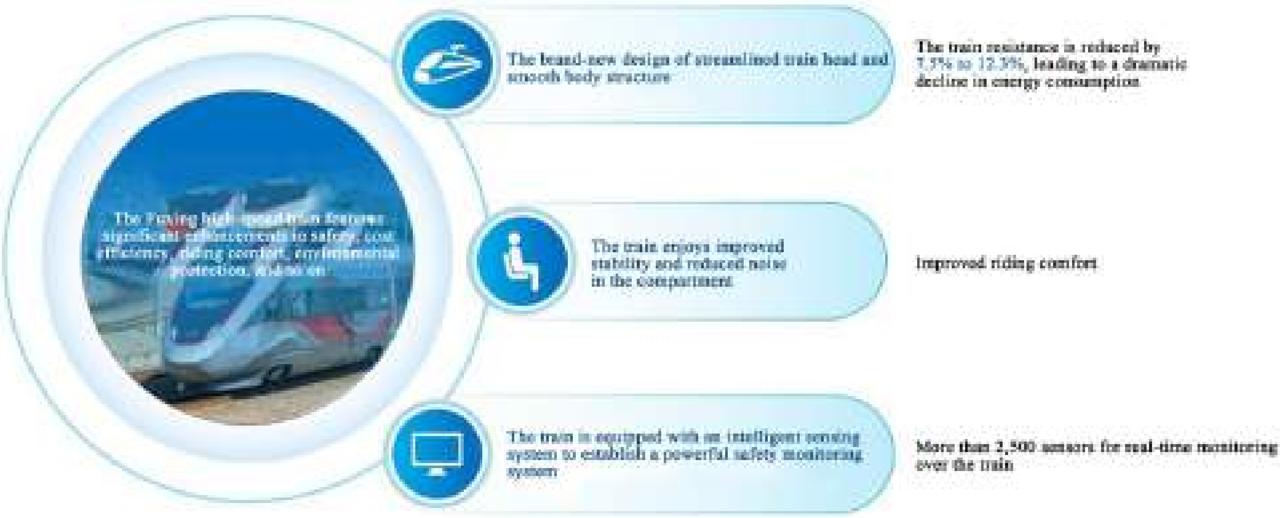
Hangzhouxi Railway Station: With a total floor area of about 510,000 m^2, this station was designed with the concepts of "station-city mergence" and "station-city integration" in mind. It is a milestone project, adding a new artery to the "Yangtze River Delta on Rails" and an important traffic support project for the 19th Asian Games in Hangzhou.

Shanghainan Railway Station: This station features a station yard of 6 platforms and 13 tracks, designed in an elevated overpass plus above-ground style. The total floor area of the station building is approximately 56,000 m^2. Using the pioneering structural system of “assembled sliding rail type movable canopies”, the station has accomplished the replacement of over 60,000 m^2 of roof polycarbonate hollow sheets and the renovation of 43,000 m^2 of perforated aluminium sheets. This innovation solved the problem of how to replace and reconstruct the largest area of roof polycarbonate hollow sheets on a station building in China.

High-speed EMU trains

To meet the demands of operating continuously at high speed, in various and complex scenarios, over long distances and in the long term, China has independently developed a Chinese Standard high-speed train suited to China’s national conditions and its railways. On 25 June 2017, this train was dubbed “Fuxing”. That same year, it was put into commercial operation at a world record speed of 350 km/h on several HSR lines, including the Beijing-Shanghai and Beijing-Guangzhou HSRs.

Compared to its predecessors, the Fuxing EMU train exhibits substantially improved safety, cost-effectiveness, comfort, energy conservation and environment-friendliness. The new streamlined head and smoothened body of the train can reduce air resistance by 7.5% to 12.3%, leading to a dramatic decrease in energy consumption. The train boasts improved stability and reduced noise in the compartment, leading to remarkably improved riding comfort. Equipped with an intelligent sensing system and a powerful safety monitoring system, the Fuxing EMU train can perform real-time auto-monitoring using over 2,500 sensors.



China has developed a series of Fuxing EMU products, with speeds ranging from 250 km/h (CR300) to 350 km/h (CR400), in standard, intelligent and Olympic models, and with formation of 8 cars (200 m), 16 cars (415 m) and 17 cars (439.8 m) to meet various transport demands. Two 8-car EMU trains can operate in a combined configuration. The traction power of Fuxing trains includes distributed power, centralised power and dual-energy power. These trains have regular, cold-resistant, and intelligent configurations, and can operate in very cold and humid operational environments, among others.

As of the end of 2024, a total of 1,932[7] standard Fuxing EMU trains have been put into operation, carrying 3.3 billion[8] passengers and safely operating over 3.25 billion[9] km across 31 provinces (autonomous regions and municipalities) and the Hong Kong Special Administrative Region.

[7] In 2023, 414 power-centralised standard high-speed trains were put into operation, and in 2024, this figure rose to 533.
[8] Power-centralised high-speed trains carried 170 million passengers in 2023 and 230 million passengers in 2024.
[9] Power-centralised high-speed trains operated over 120 million km in 2023 and 190 million km in 2024.

As of the end of 2024

- A total of 1,932 standard Fuxing high-speed trains have been put into operation
- Carrying 3.3 billion passengers
- Safely operating over 3.25 billion km
- Covering 30 provinces (autonomous regions and municipalities) and the Hong Kong Special Administrative Region

350 km/h Fuxing EMU train with 17-car formation

350 km/h Fuxing EMU train with 16-car formation

250 km/h Fuxing EMU train

Train operation control

China has developed CTCS-2 which is adapted for 200 km/h - 250 km/h lines and CTCS-3, for 250 km/h - 350 km/h lines, which have both been put into service.

Traction power supply

In response to the technical requirements of long-distance, high-speed, high-density and heavy-load HSR operations, China has built a high-tension OCS that allows double pantographs on high-speed trains to collect current, and a safe and reliable traction power supply system that enables high-speed trains in coupled or extra-long formations to run under 3-minute headway at a speed of 350 km/h. Additionally, China has established the world's largest Supervisory Control and Data Acquisition (SCADA) system for railway traction power supply.

Traffic control

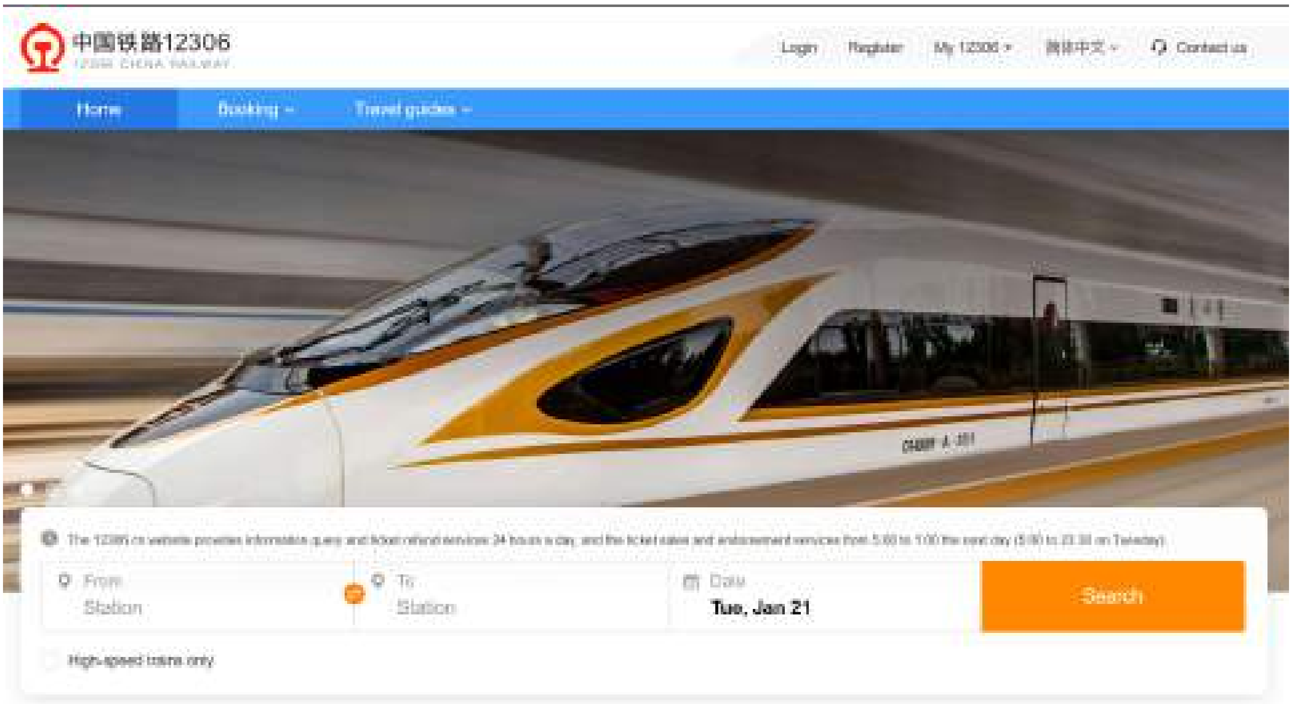
China has developed an intelligent centralised traffic control (CTC) system for HSR, achieving assisted adjustment of train working plan, and collaborative operation between railway specialties and departments. It has also improved such technical measures as efficient, safe and collaborative operation on the expansive and complex railway network, the operation of trains with different speeds on the same lines, and the operation of long-distance and crossline trains, thus enabling a minimum design headway of 3 to 5 minutes in train operation, and meeting the demands of networked HSR operations in China.

The traffic control system commands more than 10,000 passenger trains nationwide every day.

Operation services

China has developed the 12306 railway ticketing system, offering a variety of booking channels, including online, via mobile app, at ticket windows and using telephone services. This ticketing system boasts the highest page views and biggest transaction volume globally, with 720 million registered users and annual sales of 5.55 billion tickets. The percentage of tickets purchased online has reached 90%.

On 22 September 2023, 26.952 million tickets were sold, setting a new record for single-day ticket sales.



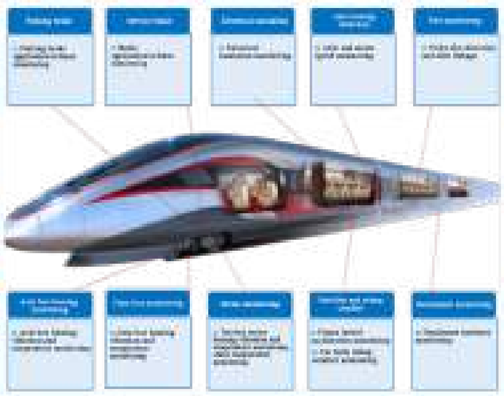
Following the popularity of the 12306 online platform, a range of new services has been introduced, including online meal ordering and delivery, a lost and found service, online seat selection, and a special service aimed at the older population, giving passengers a growing sense of fulfilment, happiness and security.

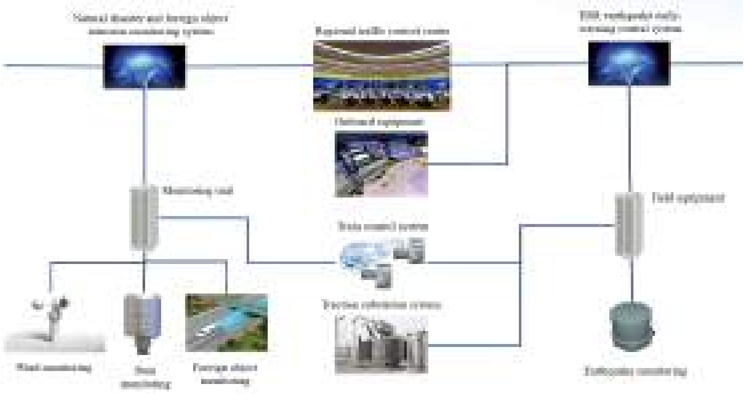
Station check-in via scanning QR code

Online meal ordering and delivery

Risk prevention and control

With a focus on railway transport safety, a safety protection system has been established for the real-time monitoring of moving railway vehicles, the periodic inspection and online real-time monitoring of fixed facilities, and the real-time perception of external environment safety.





This is a key piece of technical equipment used for periodic and constant-speed inspections of high-speed rail (HSR) infrastructure. It integrates multiple technical specialties and offers comprehensive inspection capabilities across various systems, including track, overhead contact systems (OCS), communications, and signalling. Its functions include multi-parameter inspections tailored to different technical domains, synchronized inspection across multiple systems, and dynamic inspections at constant speeds of up to 400 km/h to assess the condition of HSR infrastructure.

The comprehensive patrol inspection car is designed to inspect the external condition of key track maintenance, communication, signalling, and power supply equipment, as well as to perform dynamic measurements of geometric parameters. Its capabilities include monitoring track conditions, visually inspecting trackside signalling devices and communication leaky cables, capturing high-definition images of the catenary system, and conducting detailed inspections of track geometry and rail profiles. Additional functions include OCS geometry measurement, geomagnetic flux detection, clearance assessment, video recording of the catenary and surrounding line environment, positioning synchronisation, and comprehensive inspection data management.

Efforts are being made to develop an integrated operation and maintenance platform on the basis of information acquired from space, air, vehicles and ground. This platform aims to facilitate the comprehensive monitoring of equipment status, the automatic processing and analysis of the data collected, the automatic diagnosis and alarm for equipment faults and automatic deterioration trend analysis, and the health management of equipment.

Test platforms

As China prioritises scientific and engineering study, technical innovation and the commercialisation of R&D deliverables, the country has put in place over 30 innovation platforms, including national key laboratories, national engineering research centers and national technology innovation centers. These facilities focus on rolling stock, infrastructure, energy and traction, traffic control, transport services, and safety and security, as well as many other domains.

China has built a total-factor HSR testing and verification system based primarily at the National Railway Test Center (NRTC), with pre-inauguration and widow-time railways serving as supplementary resources. The system is supported by professional laboratories as well as operation and maintenance specialists from local operators to ensure compliance with the "all-field, all-scenario, full-chain and full-cycle" testing and inspection requirements of HSR.

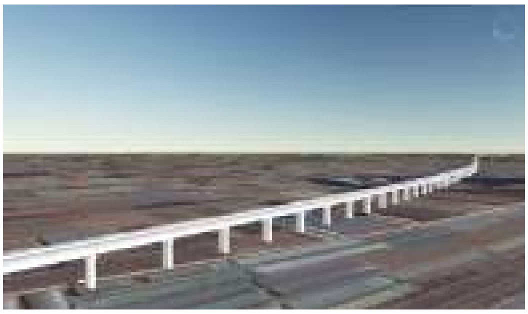
National Railway Test Center

Operation Center, NRTC

Intelligent HSR

Based on major projects such as the Beijing-Zhangjiakou HSR and the Beijing-Xiongan Intercity Railway, China has achieved breakthroughs in core technical domains, such as intelligent building, intelligent equipment and intelligent operation. It has proposed an intelligent HSR system architecture that integrates technologies, standards and data, providing China's solutions to the world's development of artificial intelligence. The research results have been applied in heavy haul railway, intercity railway and pipe network transport.

Intelligent building: China has implemented all-round and all-weather safety, quality and progress control, as well as efficient and intelligent construction management of HSR projects. Powered by BIM+GIS, the technology fully accounts for the manpower, machines, materials, methods and scenarios involved in railway projects as it integrates automatic perception, intelligent diagnosis, collaborative interaction, active learning and intelligent decision-making, among other things. The progress made has laid a solid foundation for full lifecycle management that covers design, construction, operation and maintenance.



3D visualised intelligent roaming of large project scene based on BIM+GIS technology

BIM + GIS engineering management platform

"One map" project management of Beijing-Xiongan HSR and Beijing-Zhangjiakou HSR

Intelligent subgrade filling

Intelligent equipment: China uses an array of technologies, including all-round information and situation awareness, automatic train operation (ATO), operation control, fault diagnosis, fault prediction and health management (PHM), for the automatic detection, diagnosis, decision-making, adaptation and maintenance of rolling stock and infrastructure. Building on the CTCS-3 system, an ATO system for HSR has been developed. This technology enables ATO trains to reach 350 km/h, leading to the establishment of the next generation of intelligent traction power supply and communication systems.

Intelligent EMUs

ATO system

ATO system for accurate benchmarking operation

ATO system for high-speed trains

Xinbaoan traction substation for the Beijing-Zhangjiakou HSR

Intelligent wide-area monitoring and control protection system for traction substation

Intelligent traction substation

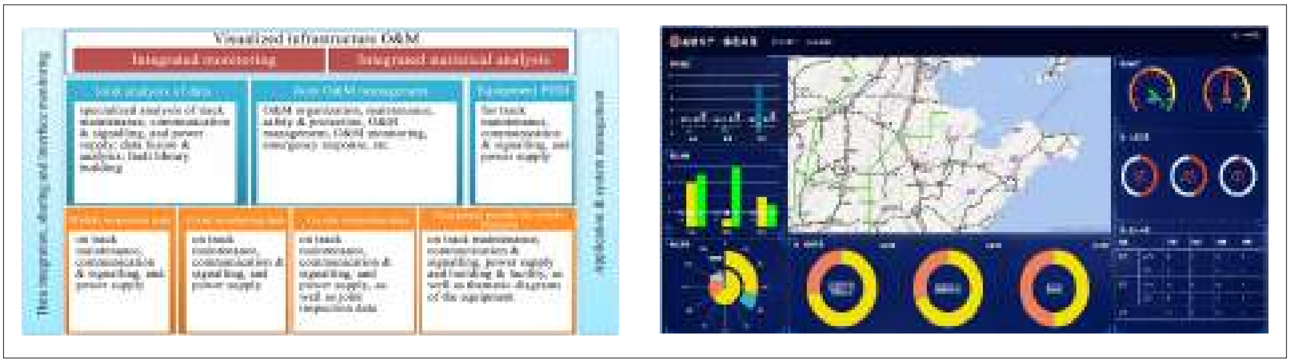
Intelligent operation: The comprehensive application of cloud computing, IoT, big data, AI, next-generation communication and BeiDou navigation, as well as other new-generation information technologies, facilitates the real-time status acquisition of all operation elements, from manpower and environment to equipment and information. Consequently, intelligent traffic control, integrated and intelligent O&M, and intelligent passenger transport services for self-service, targeted, customised and accessible services are available to passengers from both China and aboard throughout their journey.

Intelligent passenger station with an overall architecture based on "one brain, four service modules, and numerous applications," the intelligent passenger station integrates a wide range of advanced information solutions. These include a passenger service and operations management platform, in-station navigation, intelligent service robots, environmental comfort monitoring systems, equipment status monitoring and intelligent control systems, and an integrated station/train emergency response system. Together, these technologies provide passengers with convenient, user-friendly self-service options, while enabling efficient, eco-friendly operations and real-time safety monitoring.

Intelligent disaster monitoring

Pilot application of BeiDou

R&D and application of 5G technology



Integrated PHM system for track maintenance, communication, signalling and power supply

ROLE OF CHINA HSR IN PROMOTING SOCIAL AND ECONOMIC DEVELOPMENT

Convenient travel

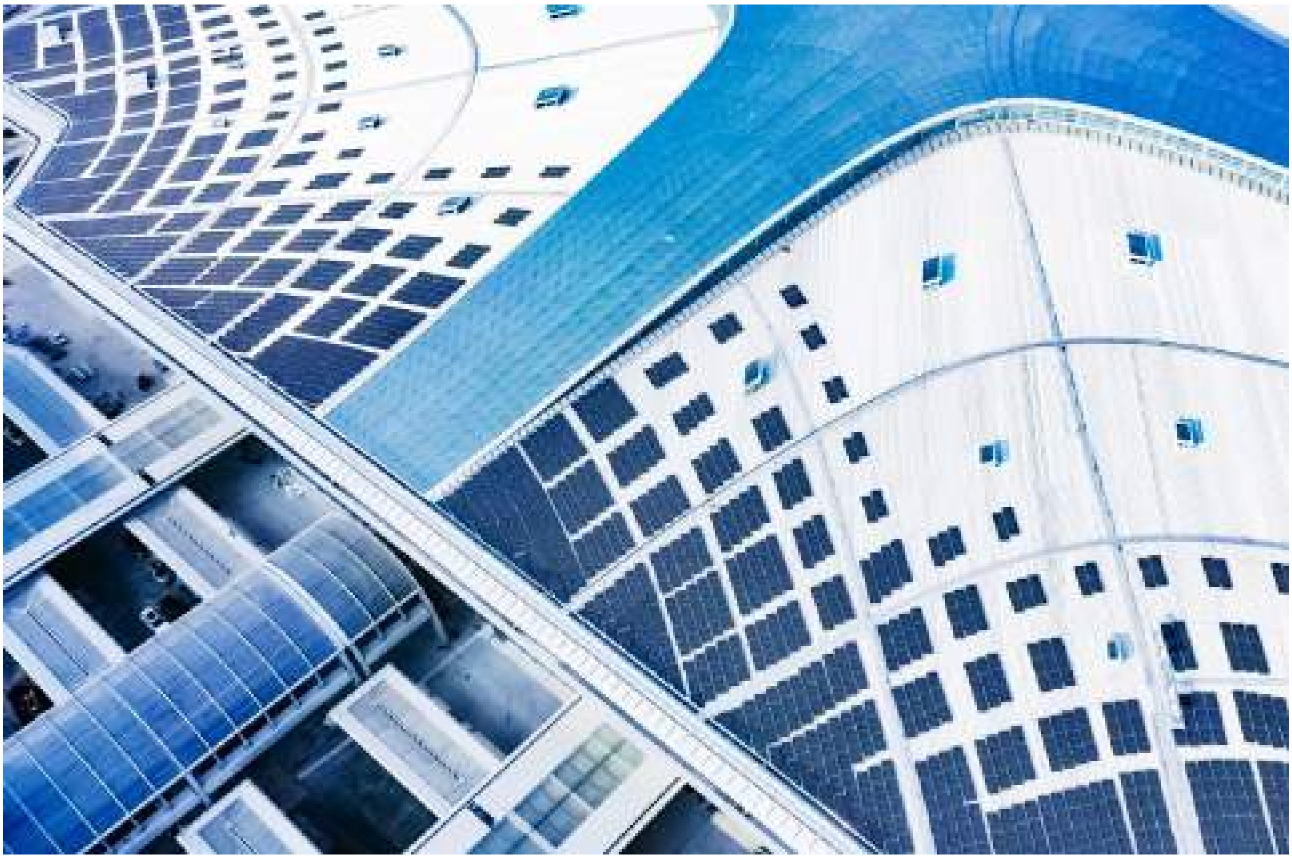
HSR has significantly alleviated the pressure of passenger transport, making travel more convenient and efficient. Following the construction of China's HSR network, travel within city clusters of a 500 km radius has been cut down to just 1-2 hours, with HSR trains running on a regular and scheduled basis. Journeys between big cities 1,000 km apart are completed in around 4 hours, which translates into a one-day return; while journeys between cities 2,000 km apart, take around 8 hours. In the latter case, passengers who opt for an early departure enjoy a "sunset arrival" on the very same day. "Travel in China by high-speed train" has become the epitome of easy travel for all our passengers, making mobility satisfactory and enjoyable.

Environmentally friendly

The considered selection of HSR routes helps to protect the ecological environment, while the use of bridges helps to save land resources. In comparison to a four-lane expressway, an HSR line – taking only 50% of the land area – requires merely 10% of the land area to achieve the same unit traffic volume. High-speed railways utilise electric traction, which eliminates combustion emissions and the impact on the atmospheric environment. Compared to aviation and road transport, they demonstrate far superior energy efficiency and environmental sustainability. HSR stations apply energy-saving technologies, with newly-developed energy-efficient materials used as station walls and ceilings, and natural light is fully incorporated for station illumination. Energy-saving, high-efficiency lighting and the corresponding intelligent control technologies are also employed to further enhance energy efficiency. All high-speed trains are equipped with closed sewage collection systems for the convenience of passengers and for the protection of the environment. China's railway sector continues to push forward both theoretical research and technological innovation in the areas of drag reduction, energy efficiency, and noise mitigation for high-speed trains. The Fuxing EMU is equipped with a low-drag, low-noise streamlined nose, a smooth carbody with optimized car-end integration, and pantographs featuring a recessed platform design. It also includes a fully enclosed exterior vestibule diaphragm to enhance aerodynamic smoothness. These design improvements contribute to a reduction in train resistance by 7.5% to 12.3%. Moreover, when operating at 350 km/h on the Beijing–Shanghai High-Speed Railway, the trains achieve a reduction of external noise levels by 1 to 3 decibels.

Since the launch of the project, the Hangzhou-Huangshan Railway prioritises the protection of its surroundings. With lush mountains and lucid waters well-preserved along the entire the line, it has met the target of building an eco-harmonious railway.

Enclosed noise barrier for Beijing-Xiongan Intercity Railway as a train passes through a village.



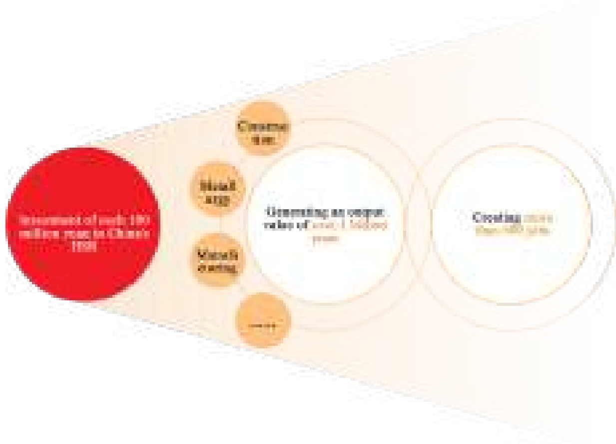
Rooftop PV power generation project on the main building of Hangzhouxi Railway Station.

Coordinated development across regions

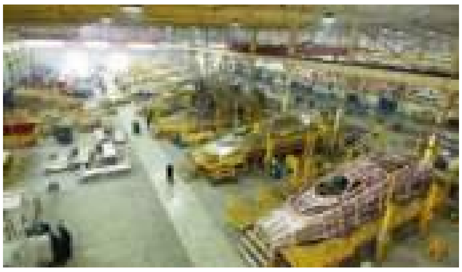
HSR has intensified people-to-people interaction, expedited the exchange of information and promoted the flow of capital. This progress helps to integrate resources along the entire line and leverage the strengths of relevant areas, bringing about an "urban cohesion effect". In other words, the development of city clusters is picking up pace, giving birth to many economic corridors connected by HSR lines.

HSR has promoted exchanges between the eastern, central, western and north-eastern regions of China, facilitating coordinated socio-economic development.

Industrial drivers



The construction and operation of HSRs have boosted the rapid growth of several industries, including metallurgy, machinery, construction, rubber, power supply, information and precision instruments, playing an important role as the industrial structure is upgraded. It is estimated that every 100 million yuan invested in HSRs in China generates over 1 billion yuan in related downstream domains – construction, metallurgy and manufacturing alike – and creates over 600 jobs[10]. The Fuxing EMU train represents a very good example. As an embodiment of high-end technologies, the model makes use of over 100,000 parts and components, over 260 independent technical systems, more than 100 core component providers, over 500 of their subsidiaries, and more than 20 provinces and cities within its reach.



EMU factory

EMU bogie workshop

100-m-long rail workshop

Cultivating new tourism

"HSR+Tour" has become a new form of tourism and also a new way of life.

HSR has extended the reach of tourists, and with less time spent on travel, tourists can spend more time on sightseeing instead. There has been a surge in visitor numbers to many places, such as Enshi in Hubei, Jixi in Anhui, Sanjiang in Guangxi, Changbai Mountain in Jilin, Xishuangbanna in Yunnan and Shennongjia in Hubei.

HSR lines have linked up the tourist attractions along them and thus boosted the formation of HSR tourism economic belts. For example, the Hangzhou-Huangshan HSR line connects many popular scenic spots, such as West Lake, Qiandao Lake and Mount Huang, forming a world-class "Golden Tourism Line".

HSR has also ignited a boom in "agritainment" farms and specialty farm product sales along its routes, driving robust growth in rural tourism-agriculture-culture integrated industries. It has become a potent engine for poverty alleviation and rural vitalisation, delivering tangible results in former revolutionary base areas, ethnic minority regions, border areas, and newly poverty-eradicated zones.

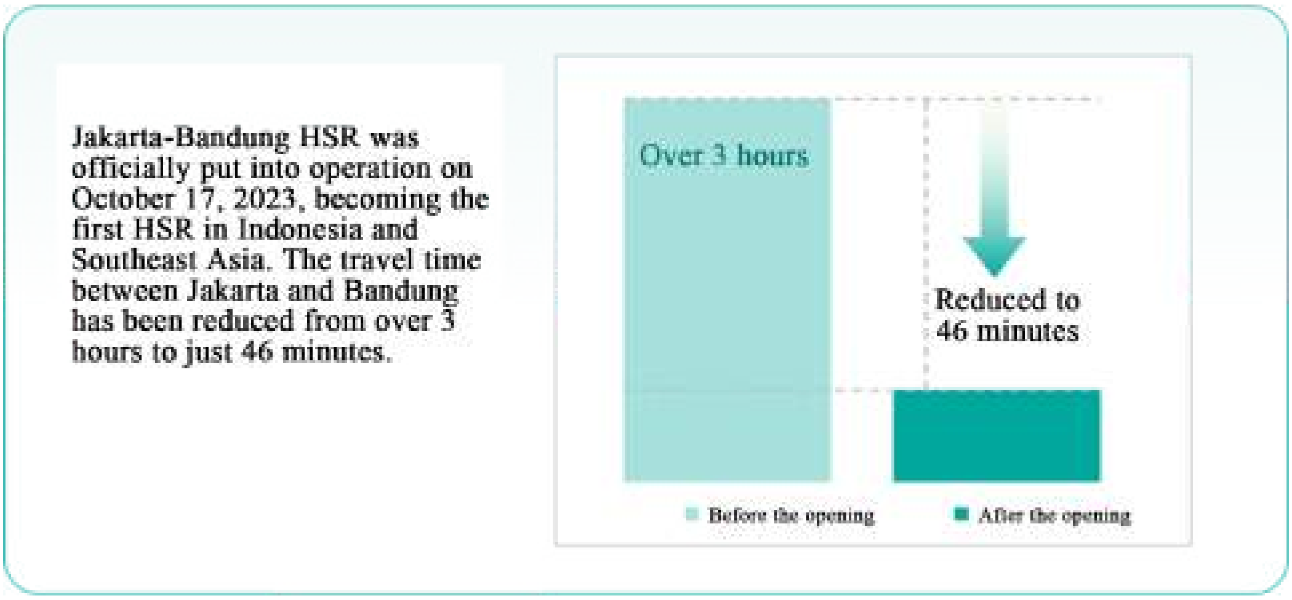
[10] Source: the signed article titled "Building a Bright Business Card of Chinese HSR" by Lu Dongfu, Chairman and Secretary of the Party Leadership Group of China State Railway Group Co., Ltd., published in Qiushi No. 15.

ROLE OF CHINA HSR IN PROMOTING INTERNATIONAL COOPERATION

Jakarta-Bandung HSR

With a total length of 142 km and a design speed of 350 km/h, the Jakarta-Bandung HSR connects Jakarta and Bandung, a famous tourist city in Indonesia. It is a landmark project of high quality Belt and Road cooperation between China and Indonesia. It serves as a golden example of synergising China's Belt and Road Initiative with Indonesia's Global Maritime Fulcrum vision, and bilateral collaboration under the Belt and Road framework.

It was officially put into operation on 17 October 2023, becoming the first HSR in Indonesia and Southeast Asia. The travel time between Jakarta and Bandung has been reduced from over 3 hours to just 46 minutes.



On 17 October 2024, the Jakarta-Bandung HSR celebrated its one-year anniversary. Over this period, the number of passengers increased continuously, with a total of 5.79 million passengers transported and a single-day seat occupancy rate reaching 99.6%. High-speed trains have safely operated over 2.57 million km, ensuring safe, stable and orderly transport while significantly enhancing the railway's impact.

A high-speed train running on the Padalarang-Karawang Section of the Jakarta-Bandung HSR.

Hungary-Serbia Railway

The Hungary-Serbia Railway, a flagship project resulting from the collaboration of China and Central and Eastern European countries, connects Budapest, the capital of Hungary, with Belgrade, the capital of Serbia, over a total length of 341.7 km, with a design speed of 160 km/h in Hungary and 200 km/h in Serbia. It is the first project to apply Chinese railway technology and equipment according to the Technical Specifications for Interoperability of the European Union.

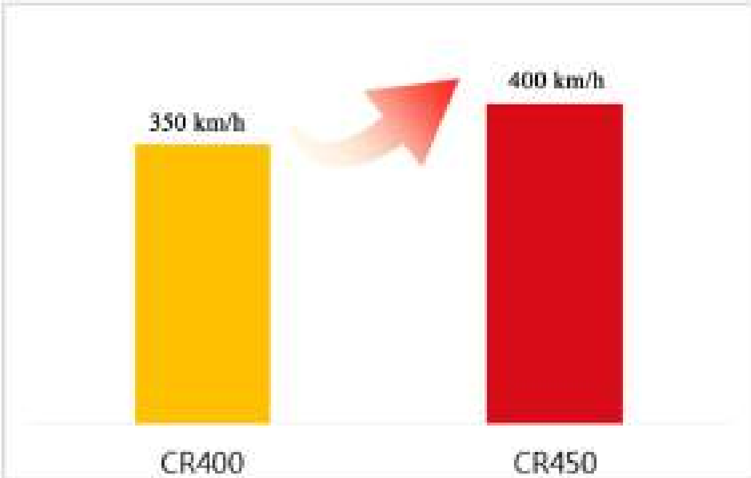
The Belgrade-Novi Sad Section in Serbia of the Belgrade-Budapest Railway opened to traffic on 19 March 2022, reducing the travel time between the two locations from over 90 minutes to approximately 30 minutes. Over the three years since it opened, 62 passenger trains have operated daily on this section, achieving a maximum daily ridership of 15,059 passengers and an annual passenger volume over 3.4 million, with a cumulative ridership of approximately 11 million. This railway has significantly improved travel convenience for residents along the route, and provided significant support for the social and economic development of Serbia.

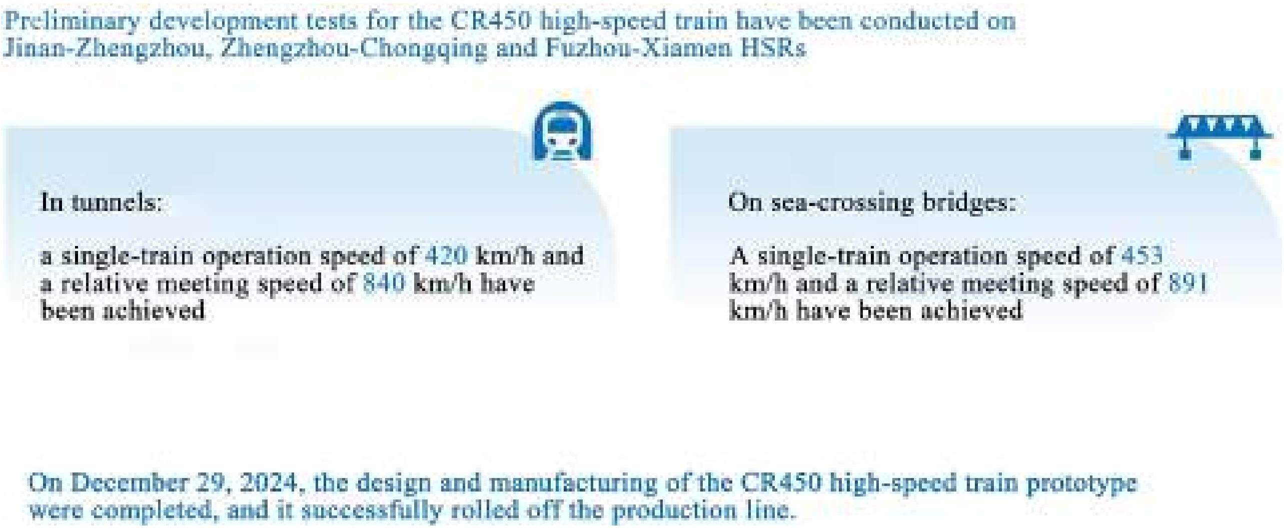
A train hurtling along the Hungary-Serbia Railway

Passengers having a pleasant trip on the Hungary-Serbia Railway

CONCLUSION

As large-scale infrastructure serving China's development, HSR exemplifies the essence of "China speed" in the most intuitive manner. It has successfully established an international brand for China's railway system, becoming an impressive symbol that China presents to the world with pride. On 29 December 2024, the design and manufacture of the CR450 high-speed train prototype were completed, and it successfully rolled off the production line. This marks another technological breakthrough since the Fuxing high-speed train CR400 was introduced in 2017. The operating speed has been increased from 350 km/h to 400 km/h, and it features internationally leading main characteristics such as operating speed, energy consumption, interior noise and braking distance. The CR450 is a faster, safer, more energy-efficient, more comfortable and more intelligent version of its predecessor. Preliminary development tests for the CR450 high-speed train have been conducted on the Jinan-Zhengzhou, Zhengzhou-Chongqing and Fuzhou-Xiamen HSRs. A single-train operation speed of 420 km/h and a relative meeting speed of 840 km/h in tunnels have been achieved, as well as a single-train operation speed of 453 km/h and a relative meeting speed of 891 km/h on cross-sea bridges.





Note: The term meeting of trains refers to the situation in which two trains travelling in opposite directions on parallel tracks of a double-track railway pass each other at the same location. At the point of meeting, the distance between the carbodies of the two trains is typically no more than 2 metres, and the relative passing speed is equal to the combined speeds of both trains at that moment.

Utilising a high-speed comprehensive inspection train as the new technology verification platform, a single-train speed of 453 km/h and a relative meeting speed of 891 km/h were achieved on the Meizhou Bay Sea-crossing Bridge on the Fuzhou-Xiamen HSR.

Prototype of CR450AF high-speed train

Prototype of CR450BF high-speed train

Looking to the future, China will further build and enhance its HSR network to promote the development of HSRs in a wider, faster, safer, greener, more comfortable and more intelligent direction.

- Wider: China will further improve the coverage and reach of its HSR network. It is planned that the HSR system will stretch to a total length of about 70,000 km by 2035, covering all Chinese cities with populations of more than 500,000.
- Faster: China will implement the CR450 scientific and technological innovation project and develop a new generation of high-speed trains, which will hit a higher speed in commercial operation.
- Safer: The HSR system will ensure shorter braking distances and enhanced operational stability.
- Greener: Focusing on HSR construction and operation, China will widely adopt advanced green, clean and low-carbon technologies that are intensive, efficient, eco-friendly and compatible with the capacity of natural resources.
- More comfortable: The HSR system will offer better comfort, reduced interior noise and a variety of diversified, convenient and personalised services for passengers, aimed at providing a better riding experience.
- More intelligent: China will apply advanced modern technologies and implement total awareness, ubiquitous connections, fusion processing, active learning and rational decision-making for information on rolling stock, fixed infrastructure, operation and management, and the interior and exterior HSR environments.

To promote greener, more low-carbon and more intelligent railways, China is willing to collaborate with countries around the globe to jointly enhance infrastructure connectivity by strengthening technical cooperation and talent training in the railway sector, contributing Chinese wisdom and solutions to the development of HSR worldwide.

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