INTERNATIONAL UNION
OF RAILWAYS

HIGH-SPEED AROUND THE WORLD

Historical, geographical, and
technological development

CONTENTS

FOREWORD

Our previous brochure was published in May 2018 for the 10th World High-Speed Congress in Ankara, Turkey. The current edition supports the 11th Congress, which will be held in Marrakech, Morocco, on 7-10 March 2023. ONCF and UIC are jointly organising the congress and have decided that the theme will be “High-Speed Rail: The Right Speed for our Planet”.

The last Congress was held under different circumstances, most notably before the COVID-19 pandemic which affected the whole world and the transport sector in particular.

Trains, and more specifically high-speed trains, remain a major asset and an efficient tool for medium and long-distance travel. Moreover, the pandemic did not stop the development of the global high-speed network, which increased by more than a third from 44,000km in 2017 to around 59,000km in 2022. While China contributed the most to this expansion (with just over 10,000km), other countries have also been very active. No country has become complacent after building the first section of a new line, development continues all over the world.

A chapter of this brochure is dedicated to Morocco and the ONCF, who are hosting the Congress.

It has been proven time and again that speed was and is what makes rail successful for passengers. China is considering another push to increase the commercial speed limit to 400 km/h, which seemed unattainable only a few years ago.

Does this mean that we should adopt this speed as the new standard? This is what UIC and ONCF wish to discuss during the 11th World High-Speed Congress. However, it is also easy to understand that increasing speed has a cost and requires additional energy.

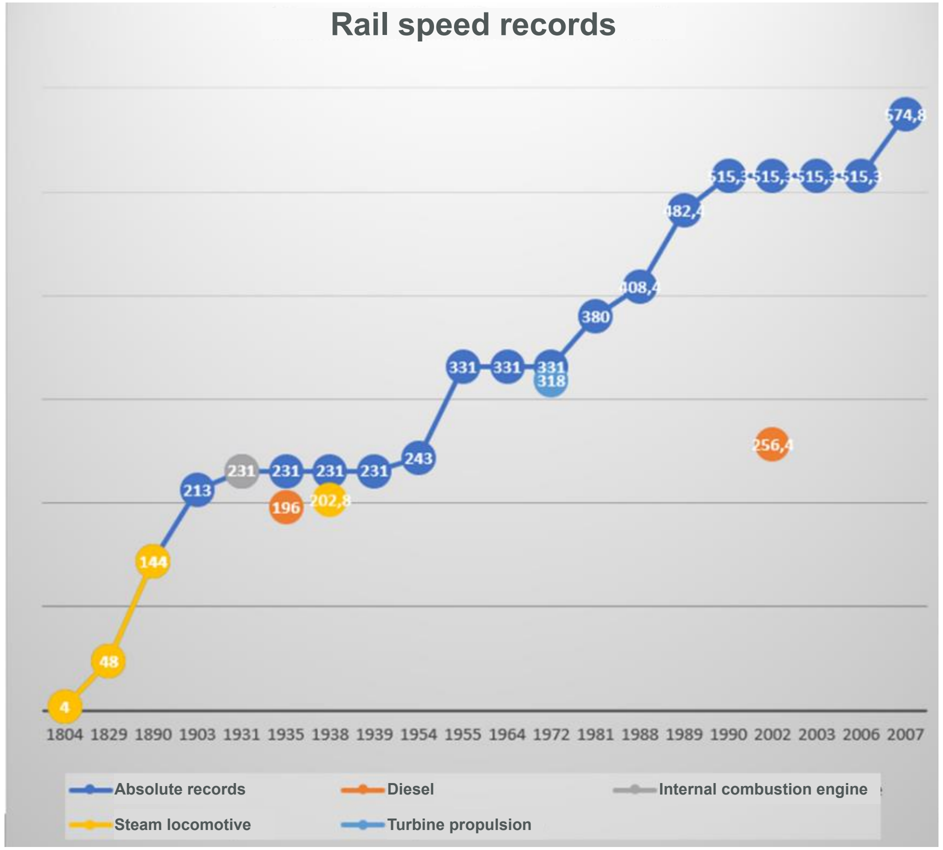
But should we not also think about the relationship between the cost of speed and the expected socio-economic benefits? Should we not review the ongoing race between technological progress and our planet’s deterioration?

I hope you enjoy reading this brochure. The last part deals specifically with the ins and outs of "the Right Speed for our Planet”, in order to give you a preview of what the Congress will hold.

François DAVENNE
Director General

THE RAILWAY: A LENGTHY HISTORY OF SPEED RECORDS

Speed records have been consistently broken since the beginning of the railway, as is shown in the following diagram:



The evolution of High-Speed Rail over time shows that the railway system has constantly improved its performance. Not only upgrading the trains themselves but also infrastructure, signalling, safety, and many other elements.

- **1830** – "Rocket" locomotive by George Stephenson reaches 50 km/h
- **1903** – Siemens & AEG Electric railcar reaches 210 km/h
- **1964** – 1 October, the SHINKANSEN, first HSR system, starts in Japan
- **1981** – The TGV, the first European HS train, operates in France at 260 km/h
- **1988** – Pendolinoin Italy and ICE in Germany
- **1989** – The Atlantic TGV operates at 300 km/h
- **1992** – AVE in Spain
- **1997** – HSR in Belgium
- **2003** – HS1 in UK
- **2004** – KTX in South-Korea

- **2007** – 574.8 km/h New HSR record in France
- **2007** – China HS Rail Corporation
- **2008** – CHR in China
- **2009** – HSR in the Netherlands and in Turkey
- **2018** – HSR in Morocco and Saudi Arabia

THE BIRTH OF HIGH-SPEED RAIL

High-Speed Rail was founded in Japan in 1964…

In 1964, a standard gauge line, the Tokyo-Osaka line, entirely dedicated to transporting passengers, was opened with journeys reaching record commercial speeds of 210km/h.

This was the birth of high-speed rail, with new infrastructure specialised in passenger transport. It also had a larger loading gauge in Japan than the standard, which explains why Japanese high-speed trains have rows of five seats abreast compared to four in other countries.

This is how high-speed rail came to be associated with specialised infrastructure for passenger transport.

Shinkansen in 1964

© DRAGONBALLXYZ - Self-photographed, CC BY-SA 3.0, Wikimedia

… and then developed in Europe.

The Rome-Florence Direttissima 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.

La Direttissima

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

In 1981, the new French Paris-Lyon line was, from the outset, specialised for passenger transport, adopting physical characteristics incompatible with freight transport needs, such as having ramps and gradients of 3.5%. As only highly motorised trains would be able to use it, the distance travelled between Paris and Lyon was reduced by avoiding the valleys that the conventional train network traditionally used and limiting the number and size of engineering structures to be built. The 425km line was fully commissioned in 1983 and has no tunnels, with engineering structures (bridges and viaducts) accounting for only 2% of its length, as the gradients allow it to better follow the natural terrain. The initial commercial speed was 260km/h, which then rapidly increased to 270km/h in 1985, and then 300km/h a decade later.

The Paris-Lyon line rollercoaster

© SNCF

The majority of high-speed lines worldwide 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 times and are restricted to separate time slots.

WHAT IS HIGH-SPEED RAIL?

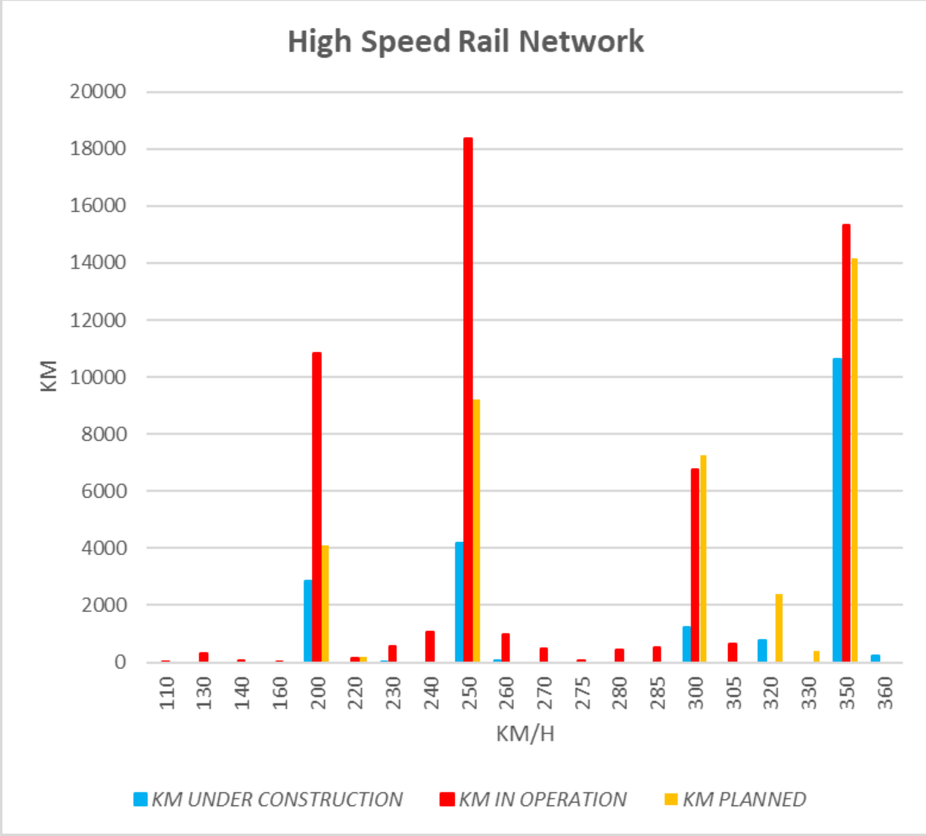
High-Speed Rail (HSR) is a grounded, guided transport system and could also categorised as a railway subsystem. The most important difference, however, is the speed. As travel times had to be reduced for commercial purposes, speed emerged as a decisive factor with HSR providing the necessary improvement, which is why UIC considers a commercial speed of 250km/h to be 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 250km/h, since a lower speed of above 200km/h (any lower is within the capability of a conventional train) and more commonly 220 or 230km/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 200km/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), signalling systems (eliminating trackside signals), operations (long-range control centres), 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.

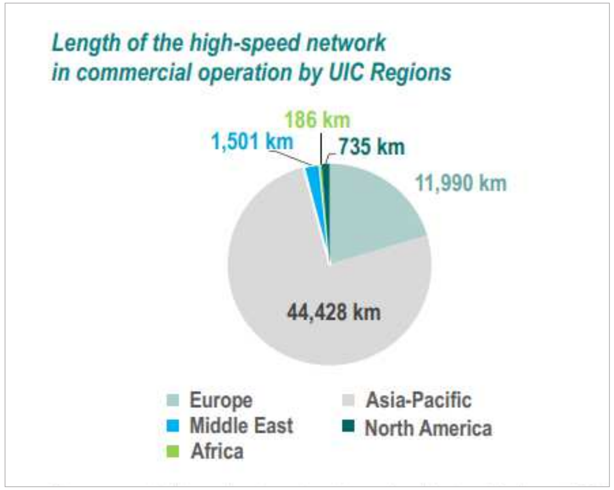


Source: Table according to database of UIC Atlas 2022

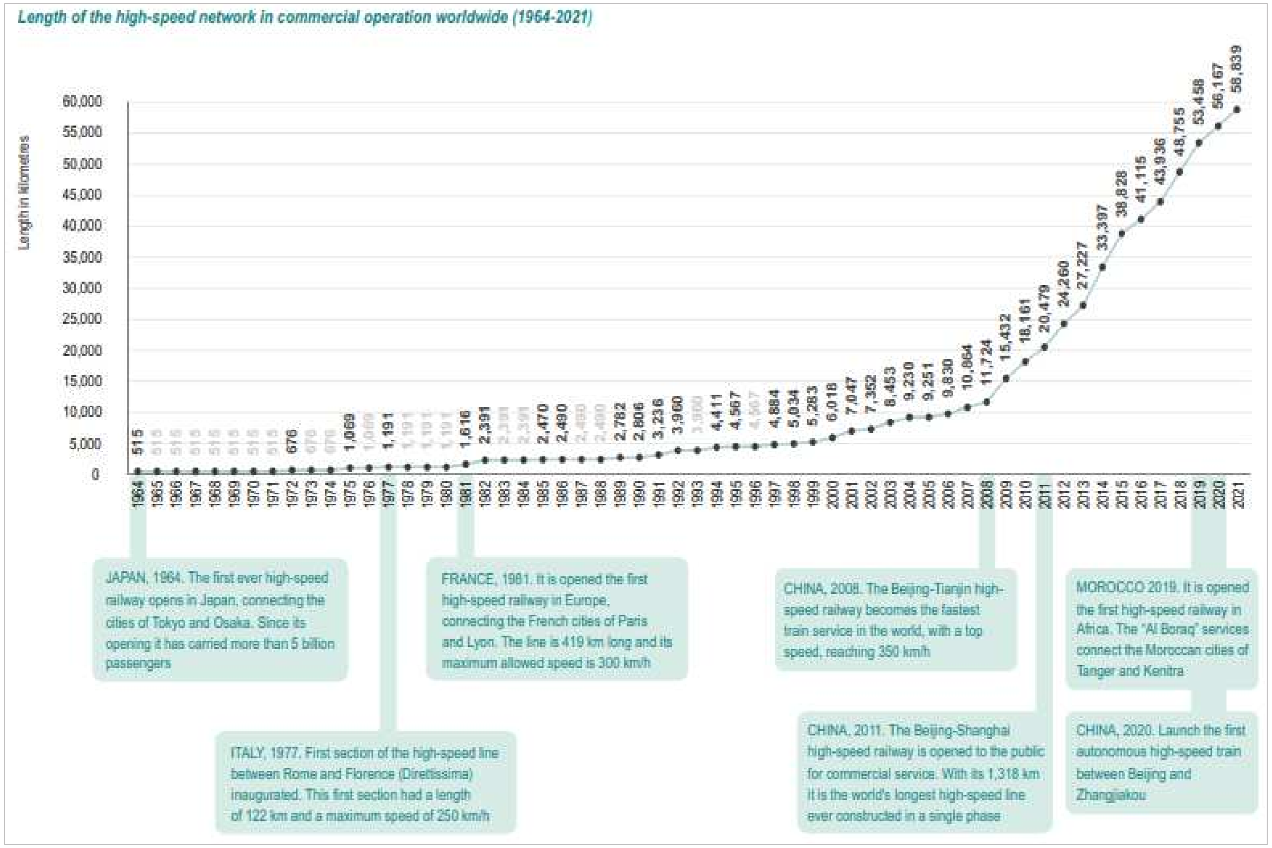
HIGH-SPEED RAIL DEVELOPMENT AROUND THE WORLD

There was steady development in high-speed railway around the world from its beginnings to 2008, when it began to rapidly expand due to the construction and operation of lines in China, with this acceleration continuing to this day.

High-speed lines are especially long in Asian countries:

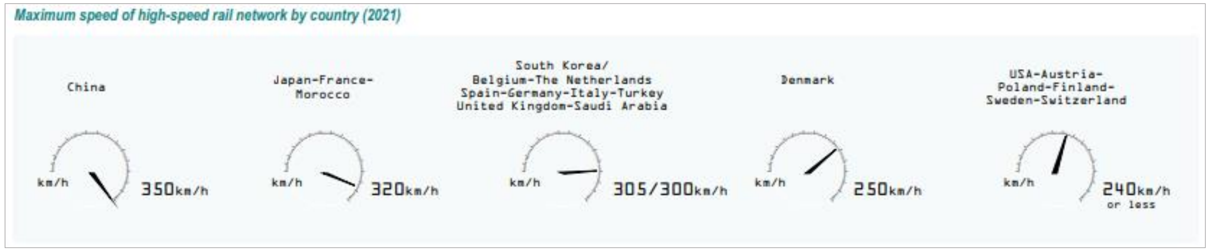


Source: Compiled by authors on Internation Union of Railways, 2022

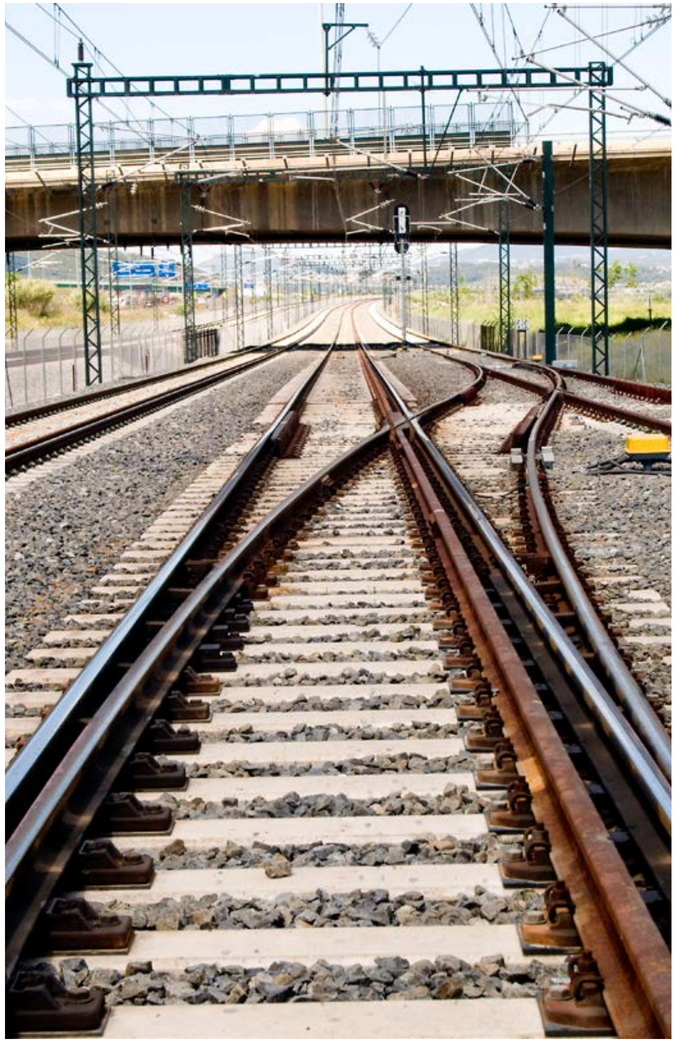


Source: Compiled by authors on Internation Union of Railways, 2022

Each country has opted for a maximum speed which is different to other countries, as the following diagram shows:



Source: Compiled by authors on Internation Union of Railways, 2022



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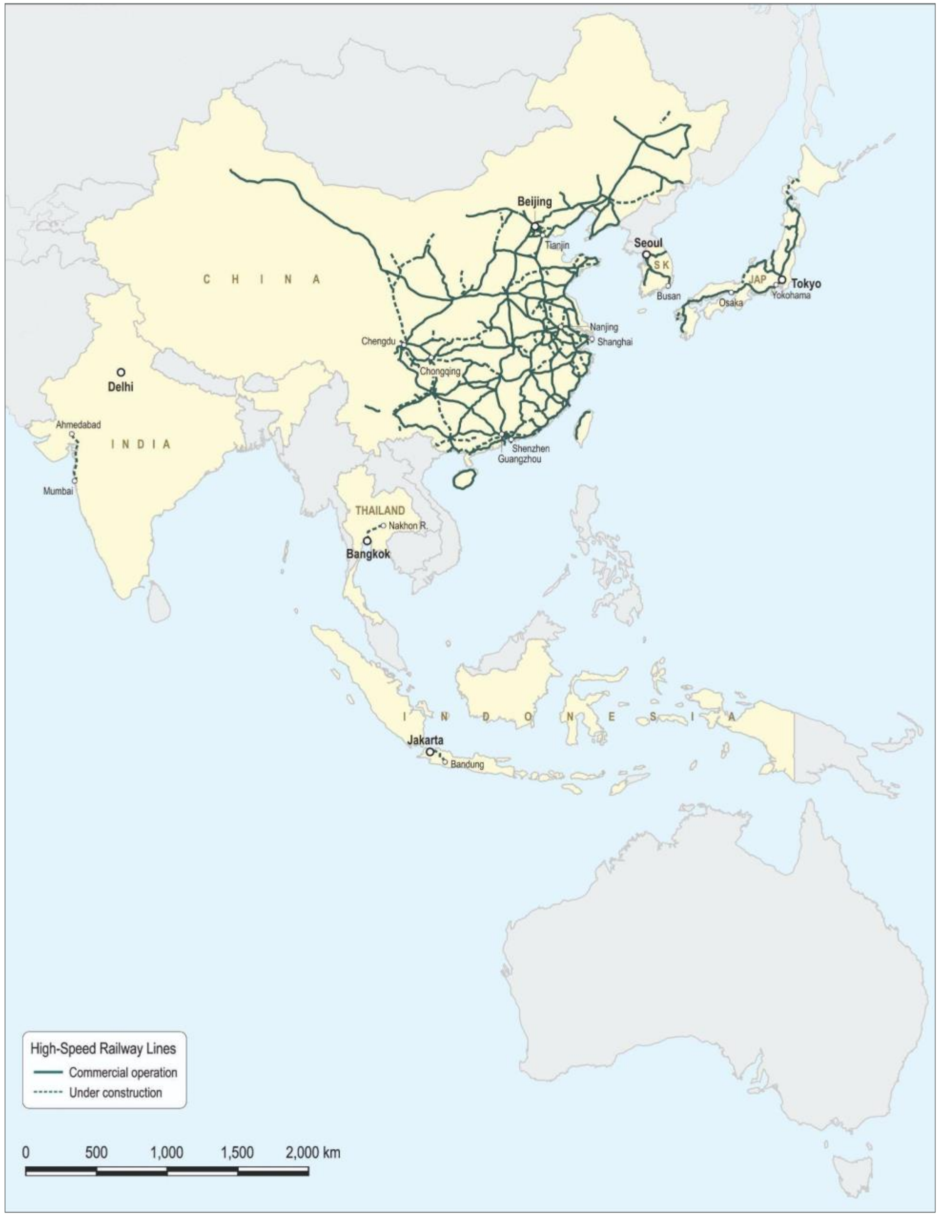
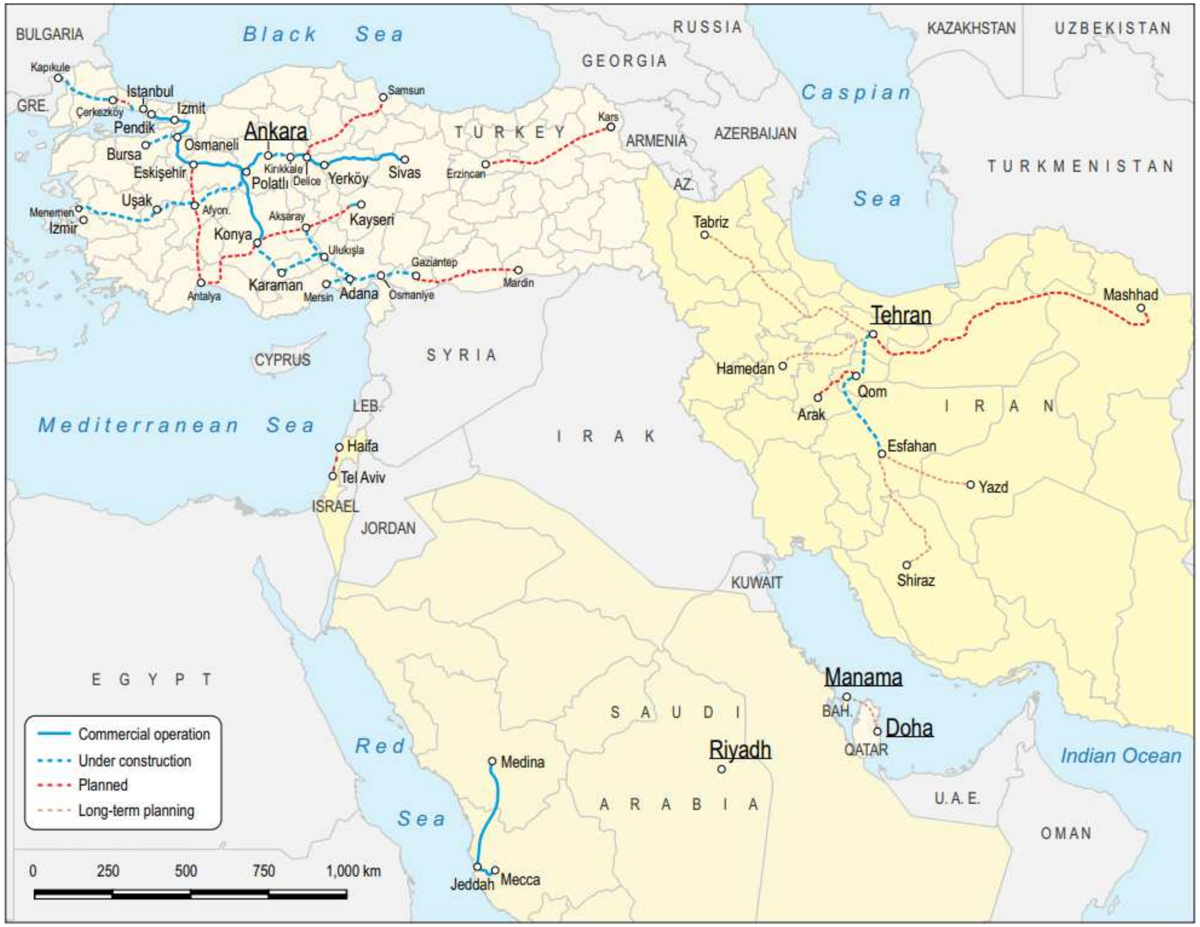


The Asia-Pacific region is incredibly active in building high-speed rail lines. As a form of mass transport, trains are perfect for densely populated countries, which is shown by Japan, and then South Korea, taking the leap and working on constructing a country-wide network. Despite starting the process at a later stage, China has changed the size of the global network through large-scale concentrated investment spanning around fifteen years. This investment in the national network has no end in sight and there will be numerous developments in the decade to come. Other populous countries, such as India and Indonesia, to name just two examples, are now also starting on this journey, with infrastructure projects being planned or already being under construction.

By 2030, the European Union will have a vast transport network to better connect and open borders between Member States with aims to double high-speed rail traffic by 2030 and triple it by 2050, thanks to around 15,000km of high-speed lines, 35 cross-border infrastructure plans, and a multi-billion Euro effort.

Source: Compiled by authors on Internation Union of Railways, 2022

In the Middle East, Turkey has an ambitious plan, which it is gradually implementing, for connections within the country as well as to both the east and west, in order to form a Eurasian corridor. Saudi Arabia has recently opened a link between its holy places, which has proved to be a successful operation, while Iran has a new line under construction and has numerous development plans, and Israel is developing a line linking Haifa, Tel Aviv and Beer-Sheva.



Source: Compiled by authors on Internation Union of Railways, 2022

In North America, the train has played a vital role in bringing the vast spaces between the Atlantic and Pacific coasts closer together. As the population density of the countries is lower than in Europe or Asia, there are no projects to link entire continents but rather to create a series of corridors linking major cities. The best example of this is the Northeast Corridor in the United States of America with another being the line under construction in California. Different long-term plans illustrate the role that high-speed rail could play in the future, such as the vision proposed by USHSR (US High Speed Rail Association) shown on the following map:

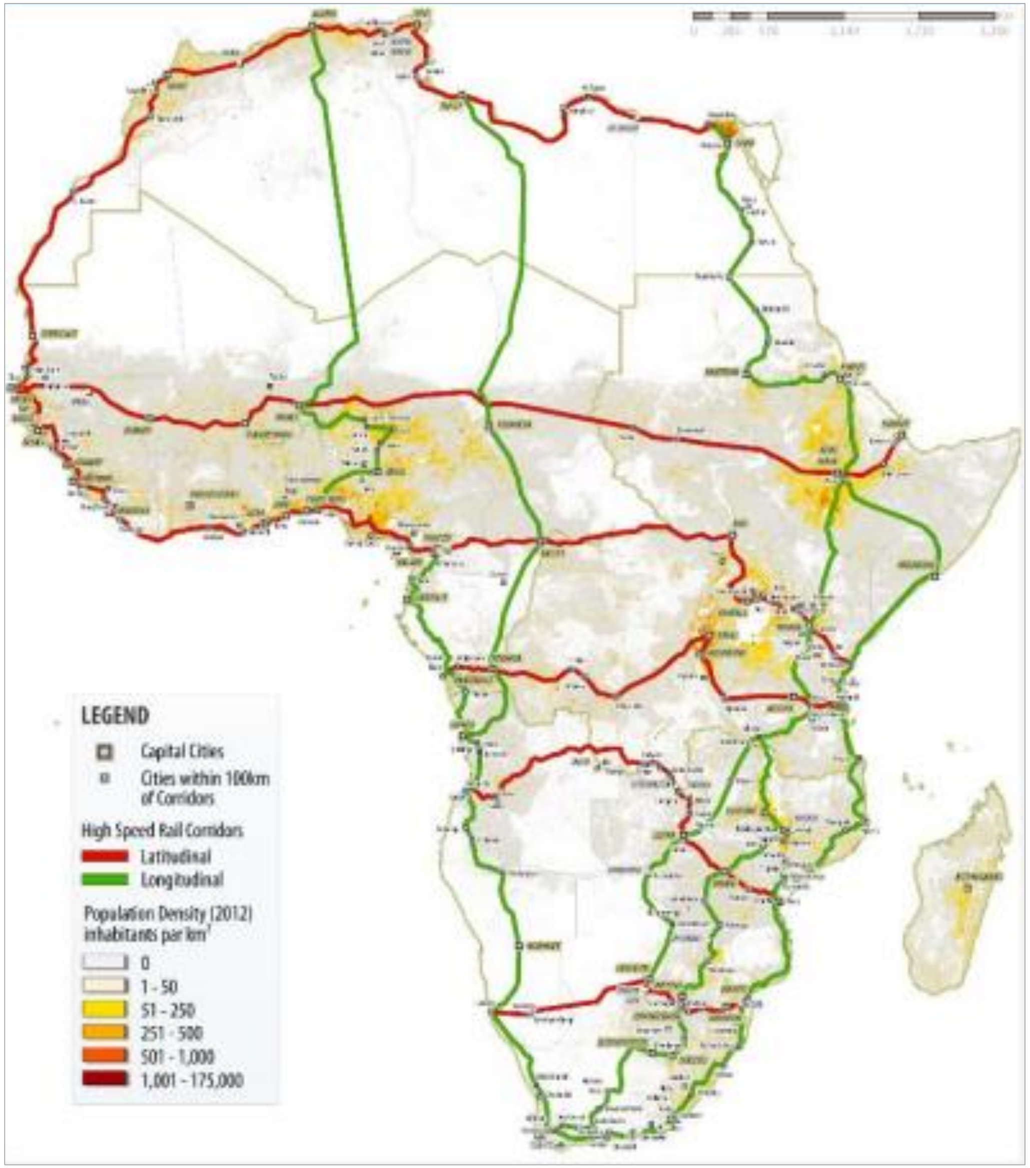
© US High-Speed Rail Association

In comparison to Asia-Pacific or to Europe, the African continent seems quite empty, and was in fact entirely so before 2018, when two countries on the continent, Morocco and Egypt, began the process of building high-speed rail lines.

The African Union also has the ambition of creating an integrated network of high-speed trains, with this being one of the flagship Agenda 2063 projects. It aims to connect African capitals and commercial hubs and is an essential element to be implemented for the African Continental Free Trade Area (AfCFTA) to be successful.

This map shows that regardless of the region, there is great potential for developing the High-Speed Rail network. Effectively the eastern part of Europe, numerous populous Asian countries (such as India or or South East Asia), the Middle East, most of Africa, Australia, and both American continents would benefit from having high-speed rail.

Railway map Agenda 2063



THE COMMERCIAL APPEAL OF HIGH-SPEED RAIL

How appealing an offer is can only be measured in relative terms, by comparing the cost, time, and difficulty of the journey, for a passenger to travel from one place to another. Below are some routes, established with the route finder Rome2rio.com, chosen by their neutrality against other forms of transport. These comparisons provide details of the stages of a journey according to the transport method chosen (coach, private car, carpooling, air, or train), the total cost and the door-to-door time for the traveller.

EUROPE										
O/D pair: PARIS - MARSEILLE (city hall to city hall) Distance as the crow flies: 660 km										
STARTING LOCATION	TRANSFER TO MAIN MEANS OF TRANSPORT		MAIN MEANS OF TRANSPORT		TRANSFER TO FINAL DESTINATION		FINAL DESTINATION TOTAL TIME (HR)		AVERAGE TOTAL COST	
									€	
5 min	20 min	5 min	10 h 20 min	COACH	5 min	10 min	5 min	11 h 10 min	37 €	
5 min	0 min	0 min	7 h 15 min	CAR	0 min	0 min	5 min	7 h 25 min	117 €	
5 min	0 min	15 min	9 h	CAR POOLING	15 min	0 min	5 min	9 h 35 min	50 €	
5 min	40 min	45 min	1 h 25 min	AIR	5 min	35 min	5 min	3 h 40 min	145 €	
5 min	10 min	5 min	3 h 15 min	HSR	5 min	5 min	5 min	3 h 50 min	124 €	

EUROPE									
O/D pair: ROME - MILAN (city hall to city hall) Distance as the crow flies: 479 km									
STARTING LOCATION	TRANSFER TO MAIN MEANS OF TRANSPORT		MAIN MEANS OF TRANSPORT		TRANSFER TO FINAL DESTINATION		FINAL DESTINATION TOTAL TIME (HR)		AVERAGE TOTAL COST
									€
5 min	40 min	5 min	6 h 35 min	COACH	5 min	40 min	5 min	8 h 55 min	45 €
5 min	0 min	0 min	5 h 20 min	CAR	0 min	0 min	5 min	5 h 30 min	100 €
5 min	0 min	15 min	7 h 15 min	CAR POOLING	15 min	0 min	5 min	7 h 35 min	30 €
5 min	35 min	45 min	1 h 10 min	AIR	5 min	20 min	5 min	3 h 05 min	95 €
5 min	15 min	5 min	3 h 30 min	HSR	5 min	10 min	5 min	4 h 15 min	67 €

These comparisons show that taking the train can often be as fast as flying, while also often being less expensive. The same goes for HSR compared with a car, it is often both faster and less expensive. However, despite being much slower, carpooling and coaches are less expensive than trains. This means that, depending on the passenger profile, trains have their own share of the market when it comes to travelling.

EUROPE

O/D pair: AMSTERDAM - LONDON (city hall to city hall)
Distance as the crow flies: 360 km

STARTING LOCATION	TRANSFER TO MAIN MEANS OF TRANSPORT		MAIN MEANS OF TRANSPORT		TRANSFER TO FINAL DESTINATION		FINAL DESTINATION TOTAL TIME (HR)		AVERAGE TOTAL COST
5 min	5 min	5 min	13 h	COACH	5 min	5 min	5 min	**14 h 10 min**	**30 €**
5 min	0 min	0 min	5 h 50 min	CAR	0 min	0 min	5 min	**5 h 55 min**	**175 €**
-	-	-	-	CAR POOLING	-	-	-	**-**	**-**
5 min	15 min	45 min	1 h 05 min	AIR	5 min	10 min	5 min	**2 h 30 min**	**230 €**
5 min	15 min	5 min	4 h 15 min	HSR	5 min	15 min	5 min	**5 h 05 min**	**250 €**

AFRICA

O/D pair: TANGIER - CASABLANCA (city hall to city hall)
Distance as the crow flies: 293 km

STARTING LOCATION	TRANSFER TO MAIN MEANS OF TRANSPORT		MAIN MEANS OF TRANSPORT		TRANSFER TO FINAL DESTINATION		FINAL DESTINATION TOTAL TIME (HR)		AVERAGE TOTAL COST
5 min	5 min	5 min	7 h 30 min	COACH	5 min	5 min	5 min	**8 h 40 min**	**30 €**
5 min	0 min	0 min	3 h 30 min	CAR	0 min	0 min	5 min	**3 h 40 min**	**38 €**
-	-	-	-	CAR POOLING	-	-	-	**-**	**-**
5 min	15 min	45 min	1 h 25 min	AIR	5 min	45 min	5 min	**3 h 25 min**	**130 €**
5 min	5 min	5 min	2 h 10 min	HSR	5 min	5 min	5 min	**2 h 40 min**	**15 €**

ASIA

O/D pair: SEOUL - BUSAN (city hall to city hall)
Distance as the crow flies: 330 km

STARTING LOCATION	TRANSFER TO MAIN MEANS OF TRANSPORT		MAIN MEANS OF TRANSPORT		TRANSFER TO FINAL DESTINATION		FINAL DESTINATION TOTAL TIME (HR)		AVERAGE TOTAL COST
5 min	20 min	5 min	4 h	COACH	5 min	25 min	5 min	**5 h 05 min**	**30 €**
5 min	0 min	0 min	4 h 20 min	CAR	0 min	0 min	5 min	**4 h 30 min**	**55 €**
-	-	-	-	CAR POOLING	-	-	-	**-**	**-**
5 min	25 min	45 min	50 min	AIR	5 min	25 min	5 min	**2 h 35 min**	**50 €**
5 min	15 min	5 min	2 h 40 min	HSR	5 min	15 min	5 min	**3 h 20 min**	**35 €**

UNITED STATES

O/D pair: NEW YORK - BOSTON (city hall to city hall)
Distance as the crow flies: 306 km

STARTING LOCATION	TRANSFER TO MAIN MEANS OF TRANSPORT		MAIN MEANS OF TRANSPORT		TRANSFER TO FINAL DESTINATION		FINAL DESTINATION TOTAL TIME (HR)		AVERAGE TOTAL COST
5 min	15 min	5 min	4 h 20 min	COACH	5 min	5 min	5 min	**5 h**	**45 €**
5 min	0 min	0 min	4 h 20 min	CAR	0 min	0 min	5 min	**4 h 10 min**	**25 €**
-	-	-	-	CAR POOLING	-	-	-	**-**	**-**
5 min	45 min	45 min	1 h 10 min	AIR	5 min	20 min	5 min	**3 h 15 min**	**140 €**
5 min	10 min	5 min	3 h 50 min	HSR	5 min	5 min	5 min	**4 h 25 min**	**130 €**

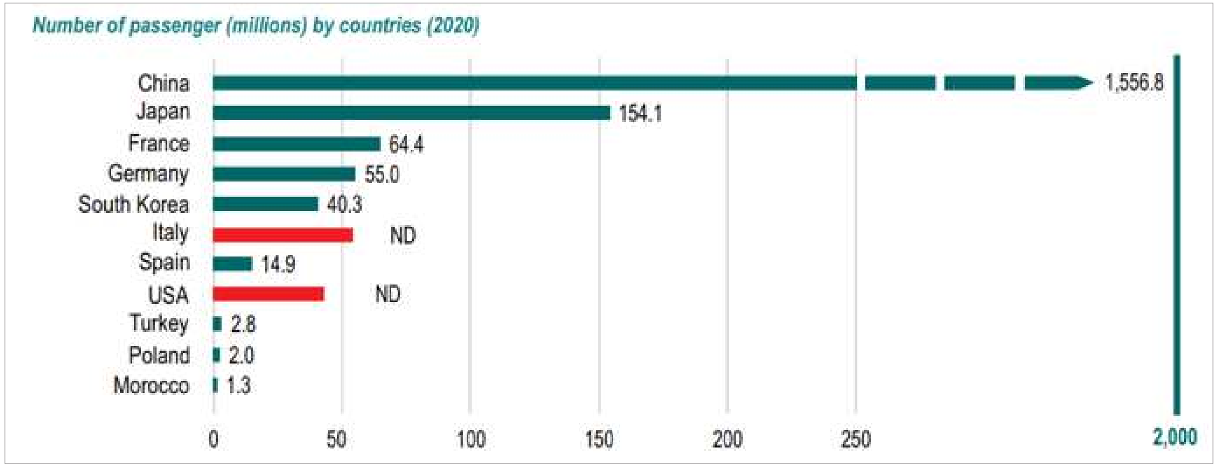
Results from the transport market

When it comes to transport, high-speed rail is a commercial success as the number of passengers travelling with it is increasing faster than the network is expanding, especially as the opposite trend could be expected, given that it makes logical sense to build the first lines where there is already significant business potential.

Two reasons explain this trend:

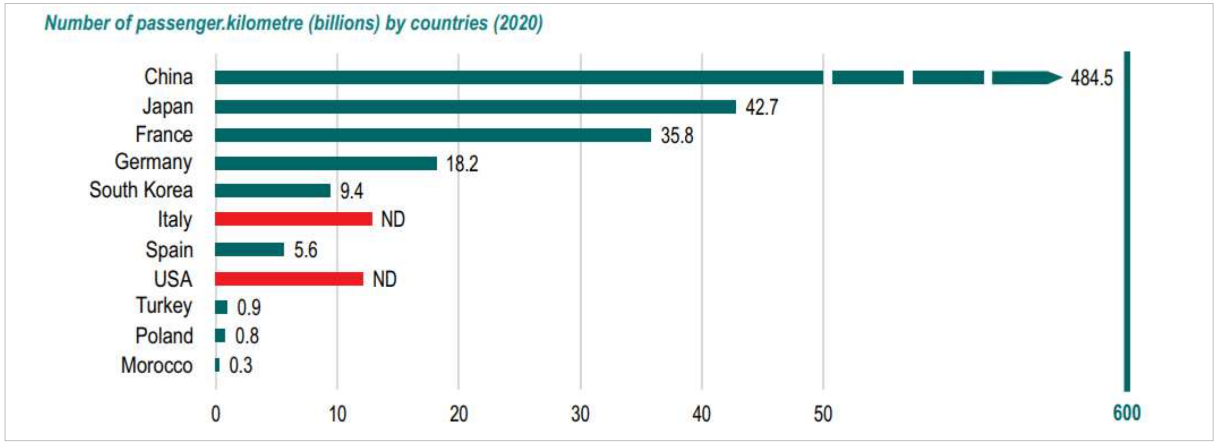
- Firstly, a large part of this new network has been built in China, which is the most populated country in the world.
- Secondly there is a strong 'network effect' where, when a point is added, the journey possibilities multiply.

Global high-speed transport grew regularly between 2010 and 2018 (pre-COVID). For 2020, the most recent statistical year, there were still in excess of 2 billion travellers, despite the slowdown caused by the COVID-19 pandemic as shown below:



Source: Compiled by authors on Internation Union of Railways, 2022

This amounts to 624 billion passenger-km:



Source: Compiled by authors on Internation Union of Railways, 2022

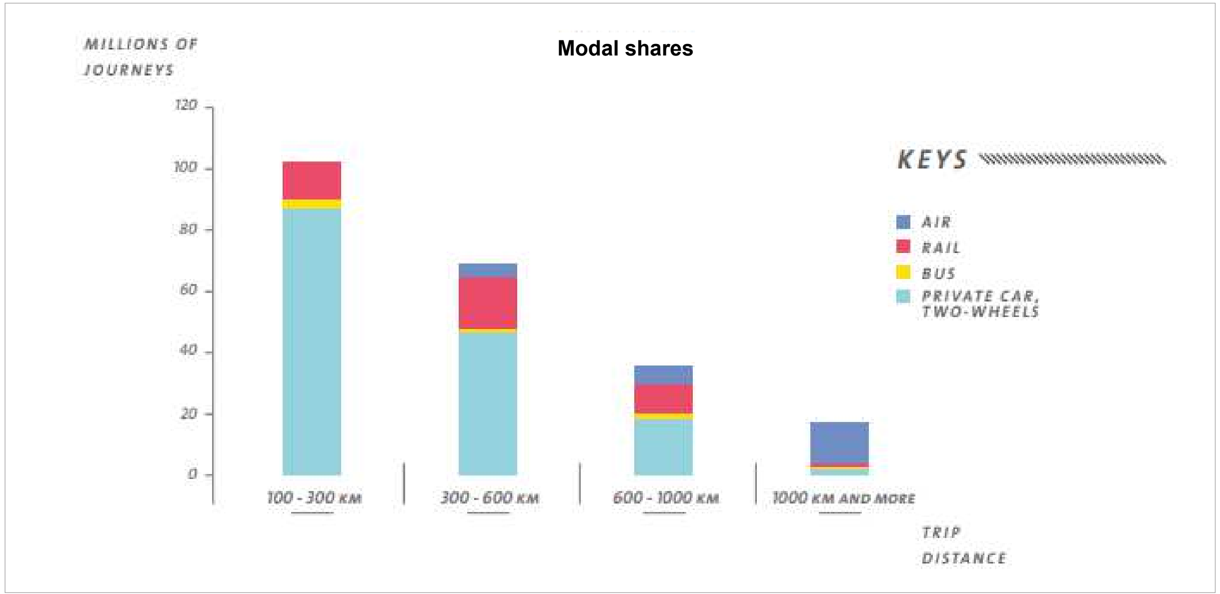
A share of the global market

Wherever high-speed is built, the transport market is transformed. Travel time by high-speed train (and therefore indirectly distance) seems to be the main factor explaining how traffic between competing modes is distributed. It is easy to think that frequency, prices and the quality of service also play a role. This isn't wrong, as once competition starts to affect a market, competing modes of transport mobilise and adjust their fares, frequency, and quality of service to become more competitive. However, this balances the factors out and is also probably one of the reasons why physical supply, and more particularly time performance, ends up being a decisive factor.

Therefore, the road-rail-air transport market is generally divided as illustrated in the figure below. For example, when the travel time by high-speed train is 3 hours, the car has 40% of the market, the train 45% and the plane 15%. Of course, this is rather general as these market shares also depend on which of the corridor's characteristics are considered and also on their use for business or leisure.

High-speed rail has specific strengths that distinguish it from its competitors, including other modes of public transport:

- Its speed
- Accessibility to city centres
- Ease of movement onboard the train during travel
- Passenger comfor



Competition within rail

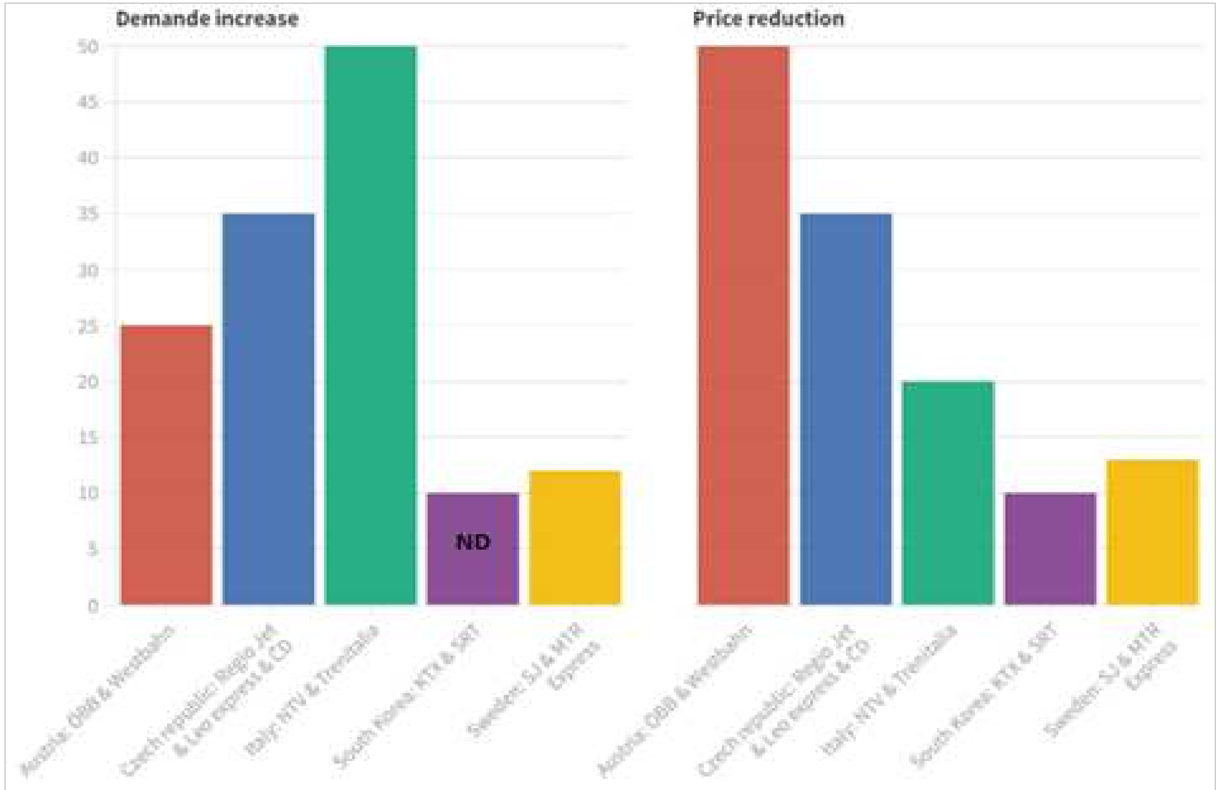
Internal rail competition is emerging in Europe following a change in transport regulations. New players that offer competitive passenger rail services have significantly brought down prices and increased the frequency and quality of service in several cases.

Currently, the countries who have internal open competition within the railway sector over long-distances are: Italy, Austria, Czech Republic, Germany, Sweden, South-Korea and, recently France and Spain.

© ADIF

The competition on the Italian market, starting from April 2012 with the arrival of the private operator NTV (Nuovo Trasporto Viaggiatori now called .Italo) competing with the incumbent public-owned Trenitalia. This represented the world's first case of pure large-scale competition between HSR operators on the same line, which led to a reduction in the average price per passenger of around 20% to 30%, with a resulting rise in traffic of a similar magnitude. The new competitor has not reduced the number of passengers carried by the initial line but has instead generated new possibilities. In socio-economic terms, not only does the consumer benefit from this (via cheaper trips, higher service frequencies, better on-board service, newer rolling stock, etc.), but this opening up of the competition is also advantageous as the infrastructure is more intensively used.

Subsequently, competition in the high-speed sector was introduced in other states with trends matching that of the Italian market:

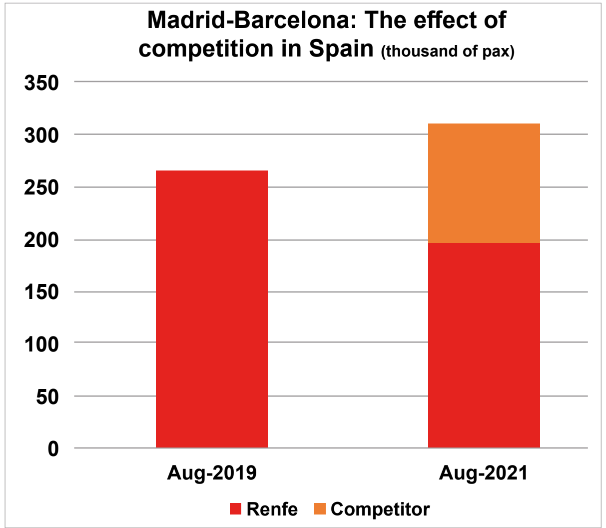


Competition in the high-speed sector. Data refers to several scientific papers

© ADIF

Of course, competition, whether internal (within rail) or external (with other transport modes), relies heavily on the regulations and degree of freedom allowed. Despite the overall positive impact for travellers, there are problems with regards to the legal framework within each state. The current system has a clear system of prioritisation, which may not be compatible with fostering open-access competition. However, the EU's fourth railway package, which was adopted in 2016, introduced substantial reforms for all stakeholders concerned, and is a systematic, large-scale approach for liberalising the commercial long-distance rail market in the EU. Its aim is to remove the remaining barriers to the creation of a single European rail area, including structural and technical reforms. The proposed legislation would reform the EU's rail sector by encouraging competition and innovation in the domestic passenger market.

In this regard, the French rail market is opening up to competition on a clearly defined calendar, and in the Spanish rail market, ADIF AV has allocated capacity between Renfe and both Italian and Spanish competitors. The first statistics below about the impact of SNCF on the Spanish market (in terms of thousands of pax), show an increase of new mobilities.



The impact of open access competition on high-speed rail in Europe, *Global Railway review 28 Feb 2022*

Furthermore, the new competitive situation also forces the original operator to provide better quality which subsequently increases rail's modal share, and has a positive influence on the environment. This is a core element for the EU's strategy to reduce future transport emissions.

However, being the newcomer is not a walk in the park, the current examples of open-access competition demonstrate that there is a long and expensive obstacle course to overcome along with substantial financial investment and high commercial risks.

The success of competition strongly depends on:

- Rail transport's regulatory framework
- Network capacity
- Fair access to existing network infrastructure
- The rolling stock owned by the newcomer
- Maintenance
- Customer habits

However, two overarching factors exist, which affect all others, and therefore determine the success of open-access competitors in a country:

- The existence of an appropriate legal framework, with strong and independent institutions in place. No gaps should be left for interpretation that allow the original operator to discriminate against competitors.
- The existence of a beneficial market environment, with high market potential and accessible financing. For the countries analysed, the political/legal framework has improved over the last twenty years, giving them a good starting position.

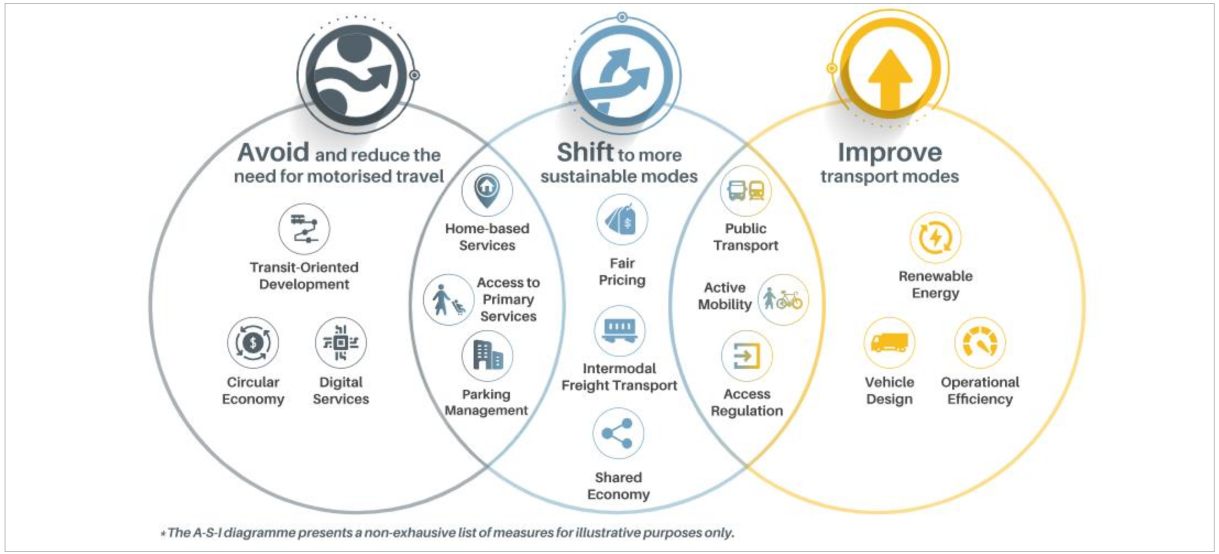
Other countries outside Europe do not intend to open up the competition for long-distance services. The reason for this reluctance is due to increased transaction costs (starting from 1991 in Europe). There is currently little research on the trade-off between the advantages of internal competition and the transaction costs incurred by creating and regulating this competition. Even for Italy, the competition has appeared very recently, and it is therefore too early to draw definitive conclusions on this issue.

A FAST TRACK TO SUSTAINABLE MOBILITY

Strategies for reducing the world's environmental footprint

Widely known as Avoid-Shift-Improve, this approach focuses on significantly reducing greenhouse gas (GHG) emissions, through a holistic and integrated approach to mobility systems.

To do this, three stages can be implemented:



Source: SLOCAT https://slocat.net/asi/

Avoiding unnecessary motorised trips based on proximity and accessibility.

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

Improving vehicle design, energy efficiency and clean energy sources for different types of freight and passenger vehicles.

Rail accounts for 8% of global passenger travel and about 9% of freight activity, but only 3% of transport energy use, with this stagnating at the same level over the last two decades (pre-covid), and if significant investment is not dedicated to high-speed rail, the share of rail passenger transport will be at the same level in 2050. High-speed rail can provide an excellent substitute for short-distance 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.

While the environmental benefits of train travel compared with other modes of transport is undeniable, the gap may begin to shrink as others make progress in reducing their emissions. Railways cannot rest on their laurels and must also become more energy-efficient and less environmentally damaging than they currently are.

Life cycle emissions from High-Speed Rail

High-speed projects are usually appraised in terms of their economic and environmental balance.

For the environmental perspective, it is important to consider the advantages of high-speed rail in terms of its life cycle, meaning from the design stage, construction, operation, and maintenance, to decommissioning.

This means that the footprint includes the carbon emissions when:

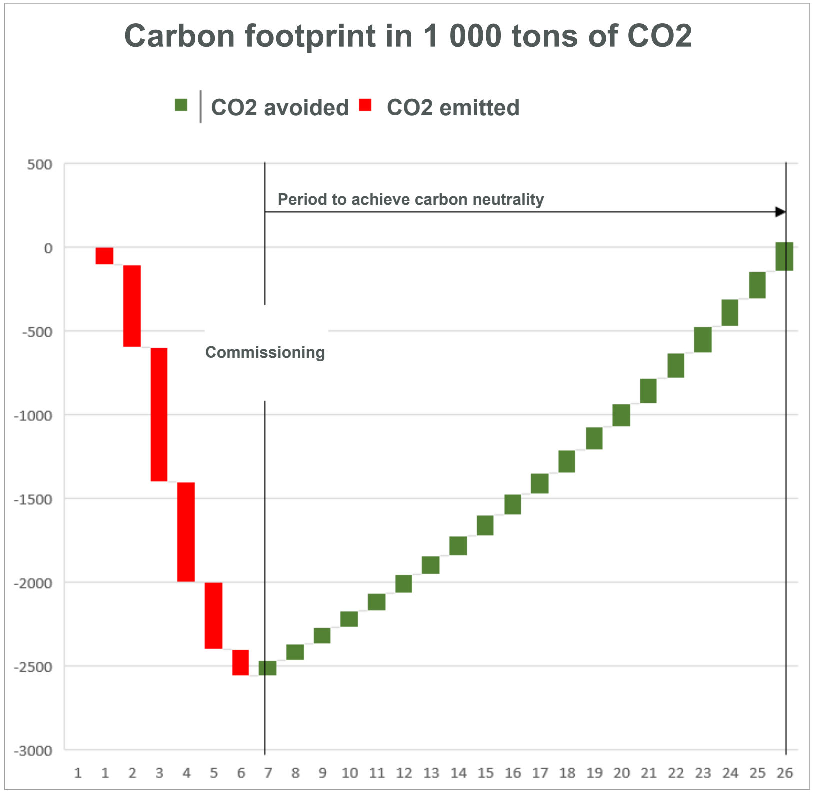
- Designing the line, because the engineers and draftsmen will need buildings and devices to shelter them and provide comfort and heating or air conditioning, fuel for going in the field or to meetings, etc.
- Constructing the line, stations and rolling stock, including the emissions for extracting and shaping materials (e.g. steel or cement), and for their transport (e.g. moving earth or transporting the rails)
- Operating trains and stations
- Maintaining the infrastructure and rolling stock
- Distributing tickets
- Recycling the components of the infrastructure and rolling stock

Carbon footprints have been established for new lines around the world and are made up of the sum of two negative factors and one positive:

- The first negative factor relates to CO_2 emissions from building the infrastructure and rolling stock; it is significant and occurs before the line is even open.
- The second negative factor relates to operating the railway system and becomes an issue after the infrastructure is put to use, while also lasting for the duration of operation and varies 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.

This footprint shows that any emissions from building the system are compensated for when it is operational, as the emissions which are avoided by switching between modes of transport largely exceed the emissions of operating high-speed trains. However, this is only the case after a certain number of years in 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 levelling that is used on the line, the higher the quantity is,
- 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.



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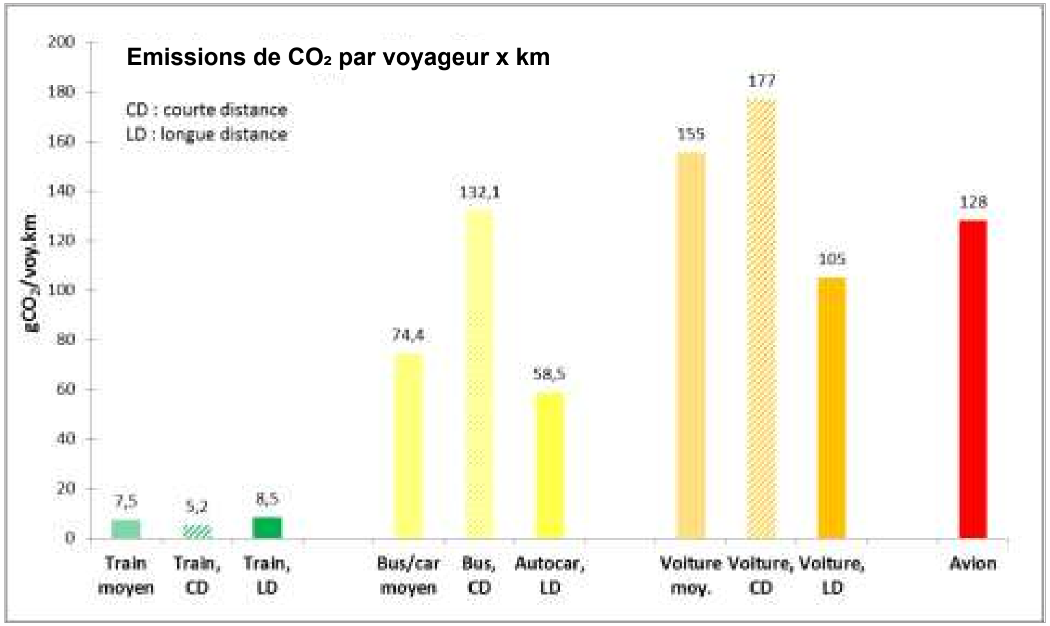
Modal shifts and reducing CO_2 emissions

As an example, here are the CO2 emission values by mode of transport.

	Train			Bus/car			Voiture			Avion
	Moy.	CD	LD	Moy.	CD	LD	Moy.	CD	LD	Moy.
CO_2/voy.km	7,5	5,2	8,5	74,4	132,1	58,5	155,5	177	105	128
kgCO_2/h	0,56	0,18	1,1	3,2	1,8	5,2	6,7	6,5	7,9	90
kgCO_2/trajet	0,19	0,05	1,5	1,2	0,5	18,4	2,4	2,0	30,6	311

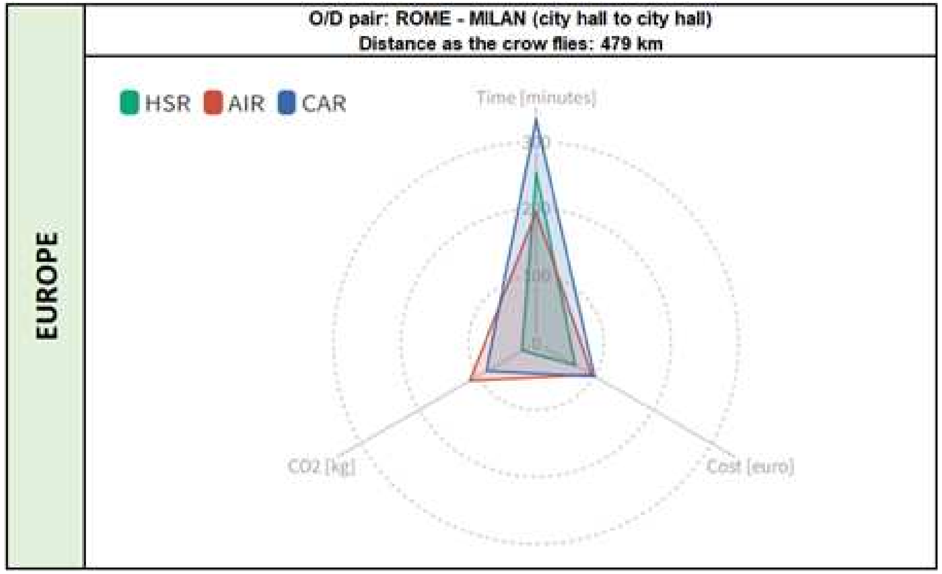


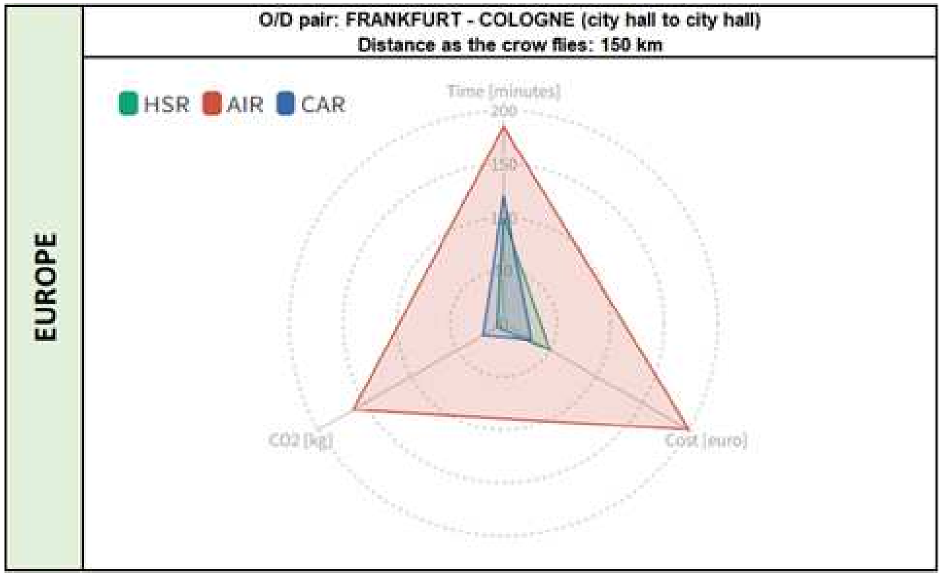
Source : emissions-de-co2-par-mode-de-transport.pdf (chair-energy-prosperity.org)

Overall, these figures clearly show that the railway is the mode of transport which reduces CO_2 emissions the most.

Another way to reach this conclusion is to use the various calculators that environmentally-conscious travellers consult. Using a calculator developed by a transport company, or even by a body such as the UIC, is not the most sensible idea here as some people would expect these to be biased.

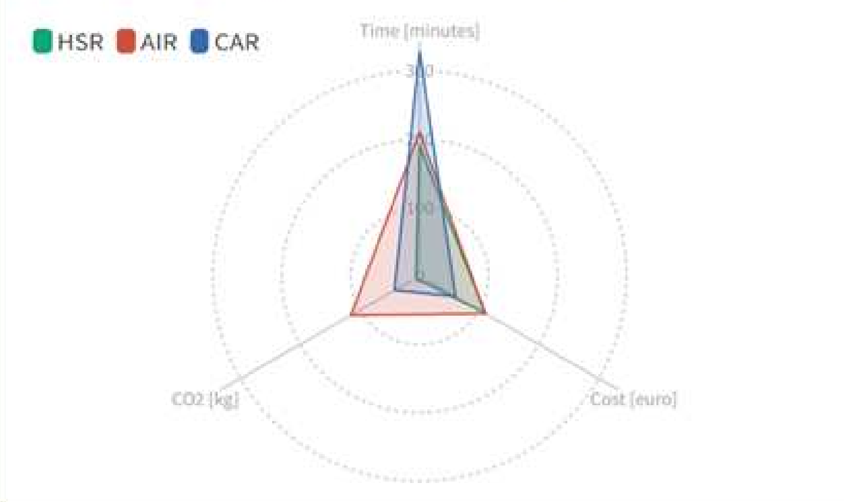
So, we have used a calculator which uses data from the EU Government Agency which is not inclined towards one mode of transport to the detriment of another. These are the results that a number of journeys give. It may be of interest to visit https://www.saveatrain.com/blog/co2-carbon-footprint-calculator/ to find out more or to calculate other trips.





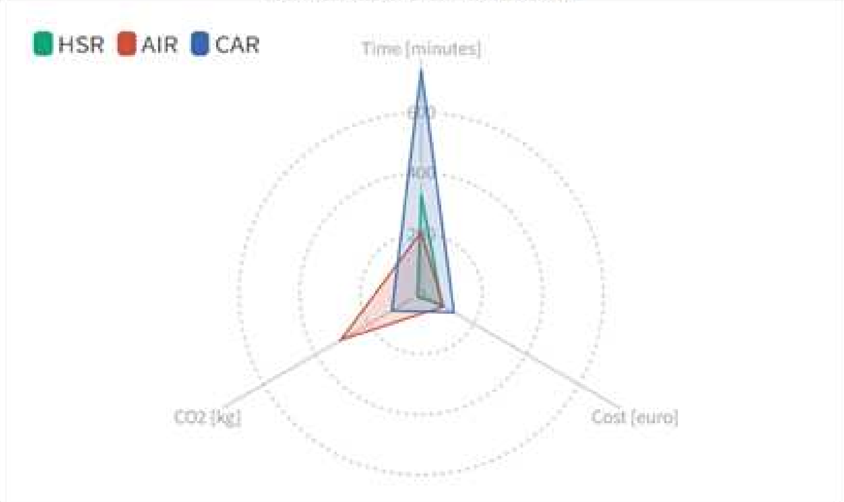
ASIA

O/D pair: TOKIO - OSAKA (city hall to city hall)
Distance as the crow flies: 396 km



ASIA

O/D pair: BEIJING - SHANGAI (city hall to city hall)
Distance as the crow flies: 1068 km



HIGH-SPEED STATIONS

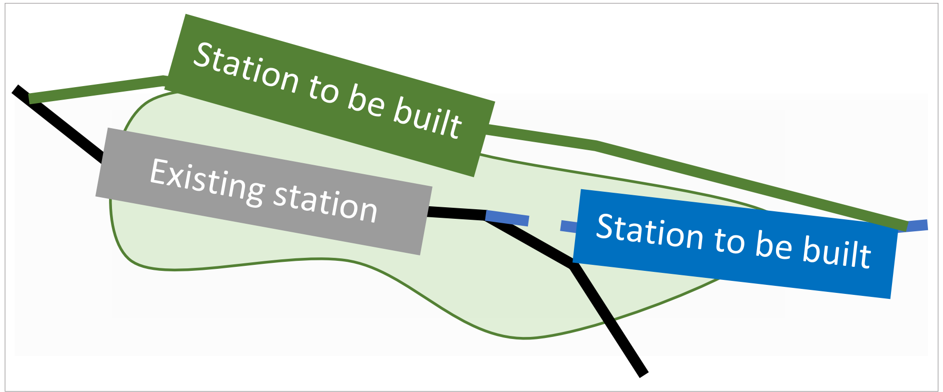
The strategic location of stations

There are two possible scenarios: the station in question already exists or it has to be built.

In general, a new line serves a high-volume mobility market meaning that there is usually already a rail link to existing stations.

In this case, the station is probably relatively conveniently located as railways tend to precede other forms of transport and so will generally be at the heart of both the city and urban transport links (underground, trams, buses, roads, etc.) The station should continue to develop in its urban environment and remain a central hub in the city, while adapting it to new forms of mobility.

However, sometimes due to various operational issues, especially if there is little remaining railway infrastructure capacity, it may become necessary to build a new station in an urban area, or even at the edge of it, so that the whole line can be built as high-speed.



The strategic governance of stations

Stations are a meeting point for four major groups of stakeholders:

- Local governments for whom the station is a symbol of the city, with connections to the surrounding districts, and local authorities who may be in charge of urban and regional public transport.
- The infrastructure manager whose main concern is to optimise the network capacity and who simply sees the station as a nodal point.
- The railway undertakings (train operators) who want passengers to have easy access their trains.
- The 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 services

Stations are not only for passengers. They are also used by other people, who may pop in to buy something, meet someone, or use one of the many services. In other words, they are public spaces that require excellent signage to ensure that everyone can easily get around. People are increasingly using GPS on their smartphones to guide themselves on the street and in public buildings, and stations naturally need to provide WiFi to help people access guidance apps, information and the Internet.

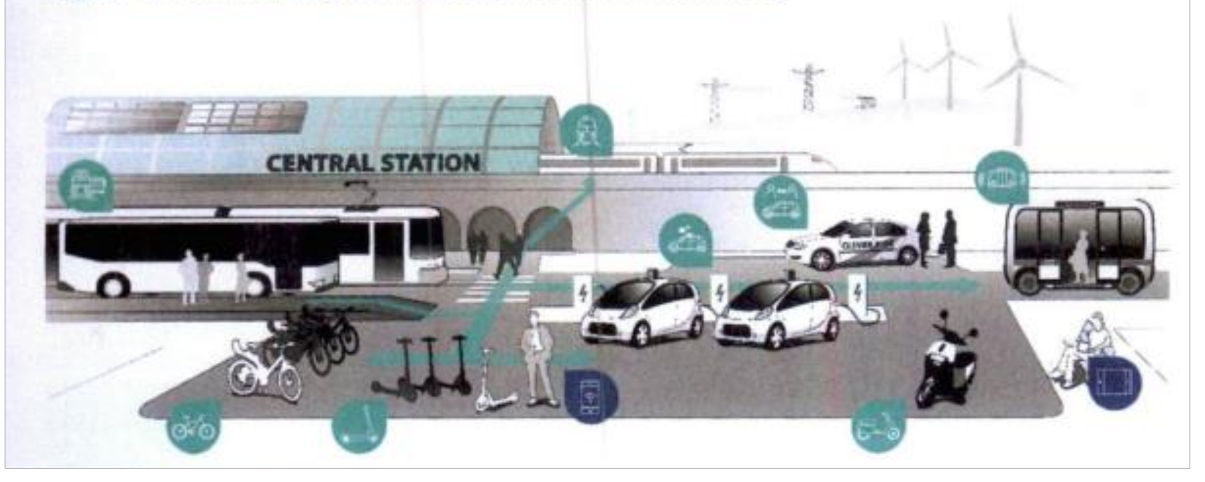
Stations have to be connected and ensure connectivity, which is also is useful for people with disabilities, as connectivity enables access to the necessary assistance apps. Similarly, trains and stations must provide customers with sockets so they can plug in their devices, with the entire railway system aiming to offer customers autonomy, as you are never better served than by yourself.

A station of the future

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

- Be energy positive, using all possible sources of renewable energy, not only to ensure it can operate well, but can also power the batteries of any vehicles that visit it.
- Be adapted to accommodate fleets of self-driving vehicles, as well as being a place where these vehicles can park.
- Host a range of public services, such as health care, as a station's location and accessibility will maximise the use of these services.
- Have co-working spaces due to its role as a hub for varying different modes of transport.

Figure 4. New mobility services and wireless connectivity



Source : InnoZ GmbH (Crössmann)

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ROLLING STOCK

Train types

Articulated or non-articulated

In an articulated train, most of the bogies are located between the carriages, whereas for a non-articulated train each carriage has two bogies.

Bogies or independent wheels

Certain articulated trains do not have bogies but instead have independent wheels (which do not turn at the same speed around 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 adjustable gauges

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

1 or 2 decks

Double-deck trains offer approximately 50% more seating capacity than single-deck 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 multi-signalling

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.

1 or 2 propulsion systems

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.

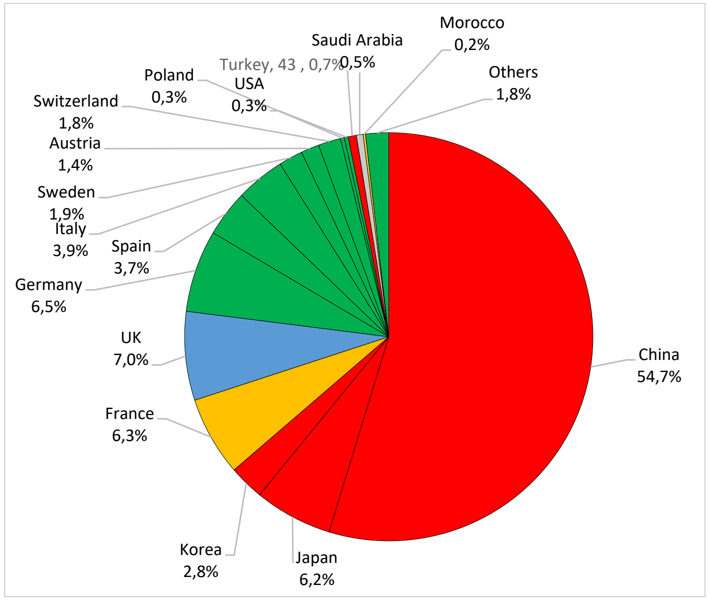
Common characteristics of high-speed trains

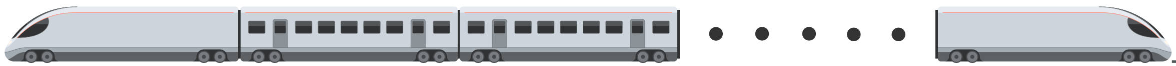
- self-propulsion
- fixed composition and bi-directional operation
- high level of technology
- limited axle load (up to 17 tonnes for 300km/h in Europe)
- high power-to-weight ratio
- control circuits, a Computer network, and an automated diagnostic system
- optimised aerodynamic shape
- in-cab signalling systems
- complementary braking systems
- improved commercial performance
- high level of RAMS (Reliability, Availability, Maintainability and Safety)
- good level of airtightness
- high technical and safety requirements (in compliance with standards)
- compatibility with infrastructure (track gauge, loading gauge, platforms, catenary, etc.)

The global fleet of rolling stock

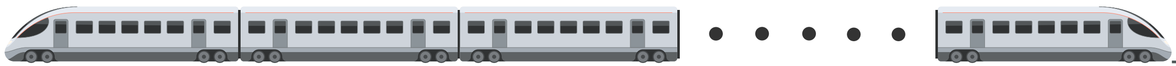
There are more than 6,500 high-speed trains in the world, over than half of which are in China.

Rolling stock fleet divided by country (2022)

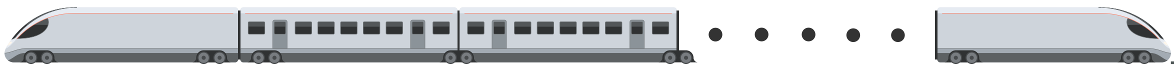




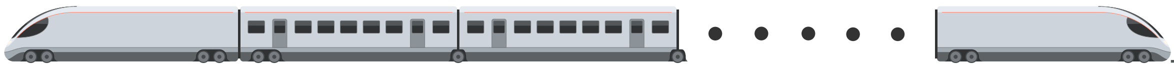
Non-articulated train with concentrated motorisation



Non-articulated train with distributed power



Articulated train with interleaved bogies



Articulated train with interposed independant wheels

HIGH-SPEED RAIL AT UIC

At UIC, High-Speed Rail is coordinated by the Intercity & High-Speed Committee which meets four times a year in plenary sessions, funds and conducts specific studies and research, drafts HSR guidelines, collects data and publishes a HSR Atlas, conducts training sessions and hosts the Alliance of Universities for High-Speed Rail. Below are the details of some of the Committee's major initiatives and most recent projects. All associated studies and reports are accessible to members in the dedicated ICHSC section of the UIC extranet.

Defining the scope of IC and HSR

To understand the specificities of Intercity and HSR and, therefore, to decide in which areas action is to be focused, it is important to first define the purview of their activities (actors, assets, technology, traffic, statistics, etc.).

For stakeholders, a tool has been developed to assess project efficiency and profitability when comparing IC and HSR to other transport projects or other infrastructure projects of the same scale.

For assets, a study was conducted comparing mixed-traffic high-speed lines in order to better understand why this choice is made and what the consequences are.

Customer experience in the railway sector is key to increasing its appeal and profitability. Therefore, a dedicated platform was launched with the aim of exchanging best practices and expertise.

For market developments, a study was conducted which made recommendations to operators and infrastructure managers regarding self-driving vehicles and their potential impact on the business models of long haul and high-speed rail services, as well as how to address the risks and opportunities.

The majority of the statistics used in this brochure come from UIC databases with two deserving a special mention as they are unique worldwide:

- a list of all high-speed lines with their corresponding characteristics. An atlas of the high-speed network is based on this database and provides accurate locations for these lines.
- a list of high-speed rolling stock owned by high-speed operators around the world.

Promoting IC and HSR

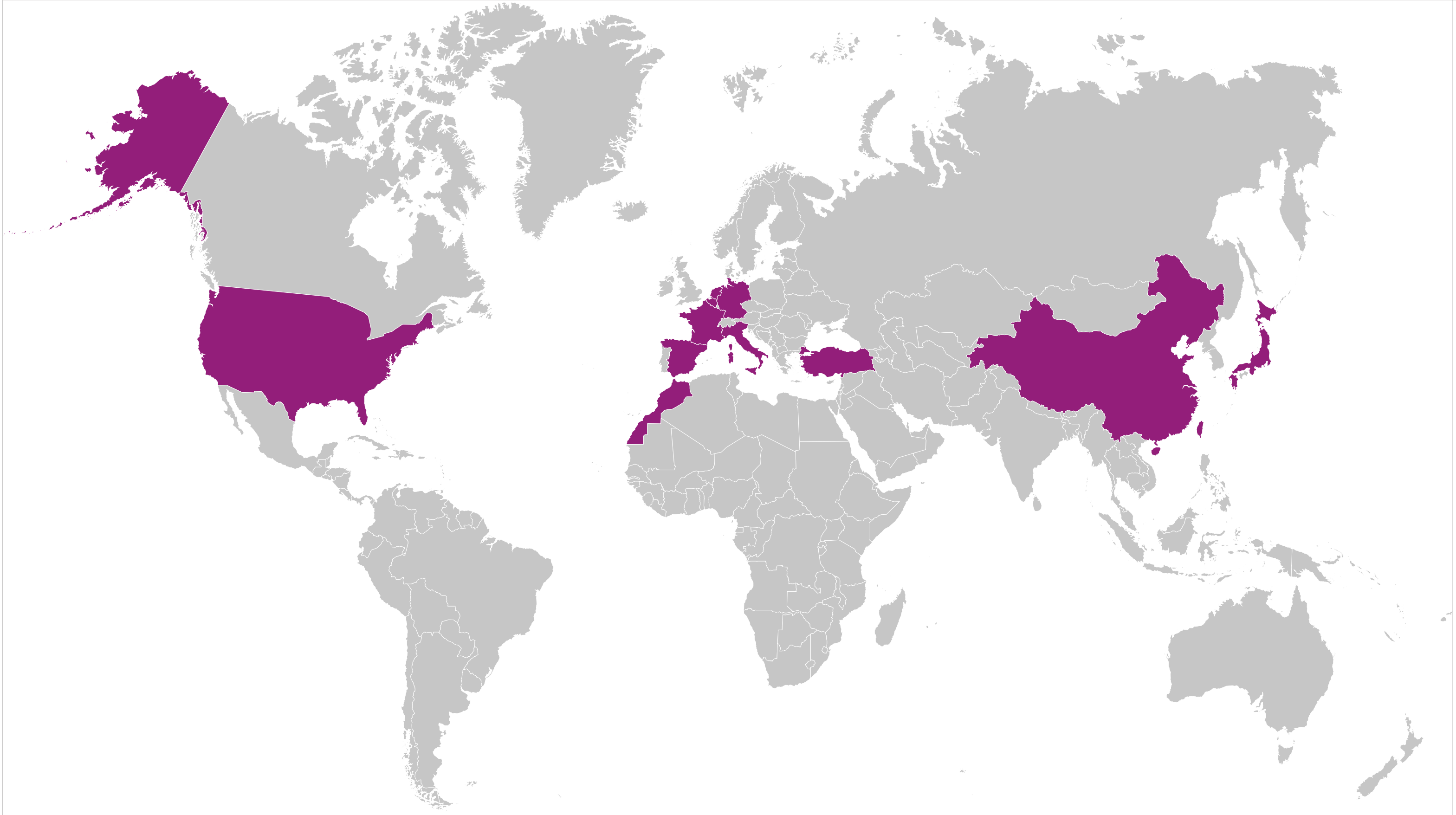
UIC has conducted an extensive survey across Europe in order to provide its members with a fair comparison of rail and air transport in terms of prices for customers. This study shows that in over 80% of cases, when characterised by the purpose of the trip, the group size, when the booking is made, the origin-destination pair, etc., transport by train is significantly cheaper, with exact savings calculations being made. This survey also covers buses as a third mode of transport competing with rail and air, which is often cheaper than the train but has much longer travel times. The scope was then also extended in order to provide examples of how air companies' fare policy changes when a high-speed line is created.

Each year, UIC organises a 2-level training programme for rail managers. This training course starts in Paris with Level 1 and consists of presentations covering all aspects of HSR. It is a unique opportunity for attendees to get a synthesised overview of all the technical, commercial, economic, and financial aspects of HSR. Level 2 is held in Madrid and is based on a case study, supported by a calculating engine, and is aimed at helping attendees to make the necessary strategic choices for a new high-speed line project.

In parallel, UIC organises workshops on topics of interest at the request of its members.

Every two years approximately, UIC, in cooperation with one of its members, holds a World Congress on High-Speed (previously called "Eurailspeed)":

Lille, France (1992)
Brussels, Belgium (1995)
Berlin, Germany (1998)
Madrid, Spain (2002)
Milan, Italy (2005)
Amsterdam, The Netherlands (2008)
Beijing, China (2010)
Philadelphia, United States of America (2012)
Tokyo, Japan (2015)
Ankara, Turkey (2018)
Marrakech, Morocco (2023)



In addition, by identifying and exchanging best practices, UIC has produced handbooks, guidelines and several benchmarks on constructing high-speed lines, for example regarding railway resilience to climate change.

UIC is constantly observing changes in technology and mobility in order to better understand what the future may hold.

HIGH-SPEED IN MOROCCO

Based on the success of high-speed lines around the world, in 2006, Morocco decided to embark on an incredible technological journey by building a network of high-speed lines which would link the country's political, economic, industrial and tourist centres. Accordingly, ONCF looked at implementing a High-Speed Line master plan with the aim of building an around 1500km network, comprising of the "Atlantic" axis going between Tangier, Casablanca and Agadir and the "Maghreb" axis going between Casablanca, Rabat, Fez and Oujda. The first stage of this master plan came to fruition in 2018 with the first high-speed line in Africa linking Tangier to Casablanca coming into operation, with train speeds of 320km/h.

This new line connects two large economic centres, providing a convenient and sustainable solution to a continuously growing demand for transport. Journey times have been considerably reduced: Tangier to Kenitra in only 50 mins (instead of 3 hours 15 mins), Tangier to Rabat in 1 hour 20 mins (instead of 3 hours 45 mins) and Tangier to Casablanca in only 2 hours 10 mins (instead of 4 hours 45 mins).

The Tangier-Casablanca high-speed line has been designed according to a holistic and integrated approach. The development of this line involved various components, including:

- Constructing a new 200km line between Tangier and Kenitra with a double track electrified at 25kV AC (alternating current), with ERTMS (European Rail Traffic Management System) signalling, designed for speeds of 350 km/h and operated at 320 km/h
- Building two work bases (94 hectares) connected to the original and new lines
- Overhauling two terminal facilities at the Kenitra and Tangier stations
- Building a high-speed train maintenance workshop in Tangier
- Obtaining 12 high-speed trains
- Planning new stations at Tangier, Kenitra, Rabat-Agdal and Casa-Voyageurs
- Designing commercial services
- Preparing for commissioning: operations, infrastructure maintenance, and rolling stock

Thanks to optimised financing, frugal investment, optimised pricing in line with purchasing power, and competitive operating costs the line has been a success from the beginning of its operation.

This technical and commercial success was made possible through the implementation of particularly innovative engineering strategies, as well as using the most recent technological innovations for the high-speed line from the outset, such as:

- taking the civil engineering technical requirements and challenges into account, including:
    - How to deal with so-called 'compressible' zones (of more than 30km), embankment instability, flood plains.
    - How to move the equivalent of 60 mountains of earth, equating to around 67 million m3 of backfill (35m tall) and excavated material (60m deep).

- Installing vertical drains driven into the ground (up to 25m deep) to drain the water and dry out the terrain, a process which took between six and eighteen months.
- Replacing poor quality soil composed mostly of pyrite (a rock which crumbles when in contact with air), which is very common in Morocco, with higher-quality materials such as sand, gravel, and pebble.
- Installing specialised detectors, particularly alongside engineering structures to prevent seismic or climate-related incidents (e.g. strong cross-winds) which interact with the signalling to warn the driver of any issues.
- Completing vast structures and their overhead lines, some of which rest on concrete piles driven up to 60m into the ground, with 100km of piles laid along the track.

- The RGVM are Duplex 2N2 3UF trains, the latest in the series produced by ALSTOM and adapted to Moroccan requirements.
- Choosing to use ERTMS level 2 for train control on the high-speed line and ERTMS level 1 on the conventional line between Kenitra and Casablanca.
- Setting up an efficient radio transmission system, dedicated to GSMR railway applications.
- Using computerised maintenance monitoring, with tools for managing track and catenary infrastructure records and computer-assisted management solutions.
- Using remote infrastructure surveillance systems and on-board measurement sensors,
- Having Centralised Network Control (la Commande Centralisée du Réseau), an operational entity responsible for managing, monitoring, and remotely supervising train traffic.
- Having a control centre for the catenary supply substations to ensure that the high-speed line's two substations are monitored.
- Having a National Security Centre (Centre National Sûreté), an entity that collects and records security incidents, processes and shares information, coordinates intervention teams and ensures operational order.
- Having a Passenger Activity Operations Centre (Centre Opérationnel de l'Activité Voyageurs), which supports decision-making on production priority choices in a crisis situation and ensures that customers' journeys run smoothly, while respecting the service standards laid down by ONCF.
- Having a driving simulator, an essential tool for training drivers and for them to attain high-speed training objectives.
- Having a signal box simulator for traffic operators with the capability to design and study different scenarios.

Building such a technologically complex line required an entire project management department to come into being, bringing together 360 Moroccan and French expatriate engineers and experts to worked side by side. In addition, more than 600 employees were recruited and trained for the operational phase.

The high-speed line between Tangier and Casablanca was also a real opportunity to acquire and develop national expertise and know-how in high-speed rail, while national companies were also able to benefit from the incredible opportunity, given that they carried out 90% of the project's civil engineering work.

Furthermore, special attention was paid to developing skills, which was not only necessary for the development of the railway ecosystem as a whole, but also to have the necessary proficiency for future railway projects at both a national and international level.

A commitment to sustainability

Even during the design phase, the new line was planned with the environment in mind. In July 2010, the National Committee for Impact Studies (Comité national des études d'impact) granted the project the label of being 'environmentally acceptable' which, despite it being standard procedure in Morocco, was an important step before construction began. Every possible precaution was taken to respect the flora and fauna on the sites crossed by the line, and concrete action was taken by ONCF to avoid any pollution or disturbance to the ecosystem during the work.

Since January 2022, ONCF has taken its Corporate Social Responsibility strategy and energy policy a step further by running all its high-speed trains on clean energy. They are doing this progressively, starting with shifting 25% of energy consumption to green sources, reaching 50% in 2023 with medium-term goals of reaching 100%.

Through this environmentally friendly transition, ONCF is in line with Morocco's national energy strategy, which is focusing on the use of renewable energy, as 50% of installed capacity is planned to be renewable by 2030. The Kingdom of Morocco is therefore one of the most committed emerging countries to developing wind and solar energy.

As ONCF is using clean energy provided by a national supplier, it is contributing to the national rail network as a whole becoming greener. In the short-term this will allow it to reduce its carbon footprint by around 120,000 tonnes of CO_2 per year, which is the equivalent of planting 4 million trees.

Therefore, travelling by train is one of the best ways for a person to reduce carbon emissions, as a train emits 25 to 30 times fewer greenhouse gases than any other mode of transport.

While ONCF's aim is to eventually solely power all of its trains with clean energy, high-speed trains were the first to offer environmentally responsible travel using 100% wind power.

HIGH-SPEED RAIL: THE RIGHT SPEED FOR OUR PLANET

Protecting the environment is at the heart of this slogan. The implication is that this does not have to be the fastest possible speed that technology currently allows but may be more moderate or better adapted to regions and economies to better respect the environment.

Common sense might suggest that speed and respect for nature are mutually exclusive, that going slightly slower would save energy and therefore be better for the planet.

However, the railways' history appears to contradict this, as whenever a new mode of transport emerged to compete with and endanger the railway, such as cars or airplanes, speeding up was the way to regain or even increase the rail's share of the market.

So, what the 'right speed' is, is neither intuitive nor straightforward.

This part of the brochure explores the idea of different speeds, which will also be the central topic for debate at the 11th UIC World Congress on High-Speed Rail in Marrakech (7-10 March 2023).

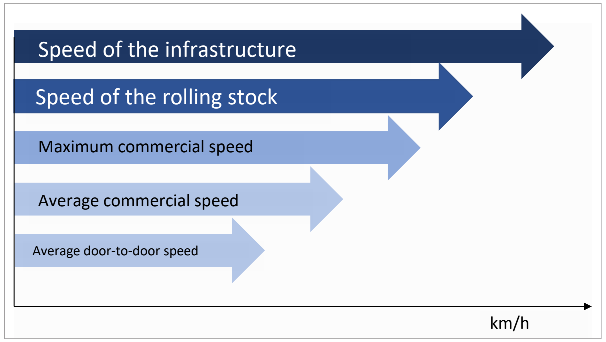
How fast are we talking?

High-speed train technology has now reached the stage where it can offer customers commercial speeds of up to 350 km/h with China aiming to increase this to 400km/h which would raise the upper limit of the possible passenger commercial rail speed.

But does this speed have to reach the limits of what technology can offer everywhere?

UIC has suggested five different definitions of 'speed':

- **The speed allowed by infrastructure**: the maximum speed that a sufficiently powered train could reach given the physical characteristics of the infrastructure, including the associated curvature and gradient radii. This may be different along different sections of the line if parts of the infrastructure are built where the terrain is difficult.
- **The maximum speed of the train operating on this infrastructure**: the speed is inevitably less than or equal to what the infrastructure can allow (see previous definition). This speed may vary according to the line's longitudinal profile and be lower on ramps than on slopes.
- **The maximum commercial speed**: the maximum speed chosen for commercial services which is inevitably less than the previous two speeds. It is the result of a commercial decision for a given market or an operational decision to optimise the flow of traffic on the infrastructure.
- **The average commercial speed**: the average speed obtained by dividing the distance between two stations by the time taken for the train to cover this distance. It determines the railway timetable.
- **The average door-to-door speed**: the average speed that a customer experiences between the actual origin and destination of their journey using their chosen mode of transport.



The right speed, in relation to what?

As railway investment only makes sense in the long run, the ‘right speed’ is bound to vary over time as railway technology, like its road and air competition, develops quite quickly with a region’s socio-economic conditions changing over time too.

There are at least five criteria to consider:

- **Time** (short, medium or long-term)
- **Environmental factors** which depend on political decisions being made taking the current and future state of the planet into account
- **Socio-economic factors** because high-speed rail infrastructure always has two sources of funding (the user and the taxpayer) and it is a question of deciding how their financial burden will be shared
- **Capacity** depending on the type of traffic that will use the infrastructure: high-speed trains only, or a mix of high-speed passenger trains and slower regional trains, or a mix of passenger and freight trains
- **Historic/geographical factors** which consider the above criteria in the specific context of a country, a region, or even a continent.

	Time	Environmental factors	Socio-economic factors	Capacity	Historic/ geographical factors
Speed allowed by the infrastructure	Long long-term	Minimising environmentally damaging emissions and in particular greenhouse gases during construction	Minimising construction and maintenance costs	Adapting the shape of the infrastructure to the traffic using the line	Respect for human and natural heritage
Maximum speed of the rolling stock	Medium term	Minimising life cycle greenhouse gas emissions Maximising how much is recycled	Optimising the cost of ownership over the life cycle Ability to operate at a market appropriate commercial speed throughout its life cycle	Operational choices on whether to separate types of traffic by time or not	Adapting speed in relation to distances and the number of stops
Maximum commercial speed of trains	Short term	Optimising the overall carbon footprint	Spreading the cost fairly between users and taxpayers	Optimising the line’s capacity according to the operating schedule	Finding the speed that maximises the train's market share

The right speed is also about average commercial speed. The difference between maximum commercial speed and average commercial speed depends on the train's regularity margin. Train timetables cannot be built only using a train's so-called 'base run', which is the best performance it can achieve at the maximum commercial speed. This regularity margin increases the journey time to include a margin to cover an hazards en-route and is the result of a compromise between passengers' quality expectations and the journey time.

Finally, **the right door-to-door speed can be calculated via different combinations of access and travel times.** For a door-to-door journey, it may have the same result to facilitate access to the station by having better urban transport and saving a few minutes, or to speed up the high-speed train's journey on its main route.

The right door-to-door speed does not just depend on the speed of a high-speed train.

Ultimately, other factors also affect the environmental and socio-economic performance of a new line:

- The **commercial appeal of the service** does not only depend on speed but also the quality of on-board and station services. This appeal is always measured in a relative way, by comparing competing offers.
- The accessibility of the service in terms of distribution and reservation in addition to physically accessing the station.
- **Real-time information** given to the passenger.
- The geographical location of stations, which dictates **land-use planning** policies.

Finally, it is important to note that speed influences production costs and therefore, indirectly, ticket prices which means that the 'right speed' is also determined by economic factors.

Applying these criteria does not necessarily result in a well-defined solution as there are so many different factors involved. The building and operating of a line, as well as the resulting service is almost always a **matter of compromise or choice**.

The role played by time

High-speed rail is only economically and environmentally viable if it is attractive within the passenger transport market and remains so in the long term. This quality is based on the relative appeal of its service compared with that of its virtual, road, and air competitors. Therefore, for any given journey (from origin to destination) the following come into play:

- Journey time
- Frequency of trains taking the route and the timetable adapted to the purposes and constraints of the journey
- Transport price
- Service quality including on-board and at the station, as well as sales and after-sales
- Environmental impact (e.g. CO_2 emissions from travel)
- Quality of information before, during (in real-time) and after the journey
- Accessibility (to the departure station and from the destination station)

These qualities cannot be judged in absolute terms because, in a market, consumers make trade-offs by comparing the offers available to them.

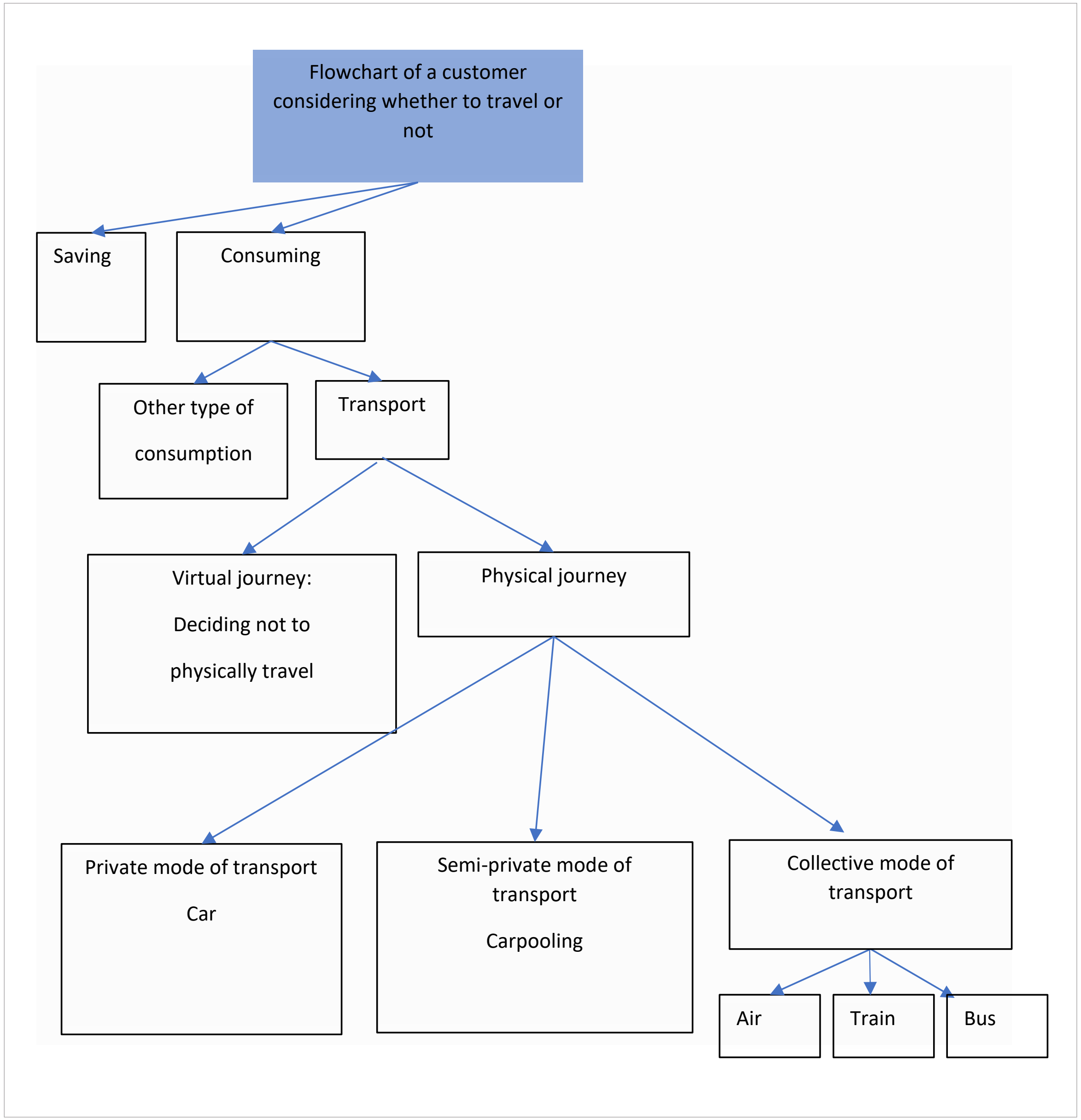
These qualities are also not always fixed as transport and technology is constantly changing.

Additionally, they are partially opposed as increasing one of them may lead to another being reduced, for example, we may be tempted to reduce the speed to consume less energy and therefore reduce greenhouse gas emissions, but the cost is a reduced appeal regarding travelling time.

This is the reason why 'the Right Speed for our Planet' is always a compromise for a given moment in time, for a given market with economic, environmental, and technological factors taken into account. Effectively, what is appropriate today may not be at all or may be less so tomorrow. The strategy for high-speed rail must be to take these factors into account and incorporate potential developments in long-term decision-making, so that, in the decades to come, investment occurs in the right places and that mistakes from an overly narrow vision of the future are avoided.

More precisely, the situation has and will continue to change with new developments in consumer choices (assumed to be rational) given the following trade-offs between:

- Consuming and saving
- Moving and a different type of consumption
- A physical or virtual journey
- Collective, individual or private, and semi-private transport (carpooling)
- Different modes of collective transport, e.g. plane, coach or train



The consumer has to implicitly calculate the practicality of each possibility and choose the one that maximises this, meaning that practicality is a quantitative concept which regulates the person's behaviour, and can therefore be seen as the opposite of a generalised cost. It takes the fact that the consumer is confronted with scarcity into account and that they are aware of having a finite budget, and finite time, meaning that they give monetary value to how enjoyable a means of transport is when making a decision. For example, travelling to a doctor's appointment is a **generalised cost** with three considerations:

- The price to pay for the transport needed for the visit, for meeting the doctor, or for having tests carried out
- The value of the time needed to travel and for the visit or tests to take place
- The perceived benefits of the visit or tests to maintain or improve health

Even if nothing else changes, for the same person with the same reason for travelling, these trade-offs shift over time for at least three following reasons.

1. The transport market becomes more diverse

Two new innovations have already become commonplace: virtual transport and carpooling.

The COVID-19 pandemic has greatly increased and spread the use of software to enable private or professional meetings to be held remotely. It is also possible to have virtual visits, for example, to work sites and to certain museums. Virtual travel has become established as a fully-fledged alternative to the physical movement of people and is now its competitor. It's main advantage is that travelling time is reduced to effectively nothing, with the associated costs also being zero, especially as physical relationships between individuals are now considered to be less important than they were in the past.

Carpooling is an intermediate step between private and public transport. For the driver of a car, compared to a strictly solo trip, carpooling has more constraints (for example, waiting at the meeting point) but reduces the cost of the trip as it is split between more people. For the passenger there are also certain constraints (for example, being on time at the meeting point or limiting the amount of luggage) in return for a lower cost than if they used their own vehicle. Therefore, it can be considered to be a new mode of transport as it combines certain advantages from private transport with certain disadvantages from public transport.

Therefore, the appeal of a newly built railway line (or the market share increase) is not as pronounced as it was 20 or 30 years ago when virtual transport and carpooling barely existed.

2. Technology for the different modes of transport develops

Looking into the more distant future, it is likely that the car of the future will differ significantly to those from today. Firstly, it will be self-driving and can therefore be used by people who currently are unable to (too young, old or disabled), which will capture some of the public transport market. The value of the time spent in a car will change as the need to concentrate on the road will disappear. Instead of being the driver's property (generally the case at the moment), i.e. spending most of its time parked somewhere, it could be owned by a company and used more efficiently because people will hail it by phone. Therefore, the fixed costs will be spread across a number of consumers and, due to being self-driving, safety will increase, and insurance will cost much less. In short, the generalised cost of car transport will have an overall lower marginal cost and carpooling will also have disappeared as it was rendered obsolete by the shared self-driving car.

Within this future, aircrafts will probably also have converted, for example, to hydrogen propulsion, which would both reduce the environmental and usage costs, as finite fossil fuels would have been replaced by renewable energy.

Of course, at the same time, rail technology will also have progressed.

In the 21st century, the transport market is expected to undergo the same upheaval as in the 20th century, when the train had to face the emergence of competition from roads and then civil aviation.

There is no longer any question about whether these developments will happen, but instead about how quickly they will appear and what their quantitative impact will be on travel times and customer costs.

Today, there have been enough technological developments for it to be clear that transport will change much sooner than it was thought when the infrastructure managers decided to invest in building the current lines, or when a railway operator decided to buy the current rolling stock.

3. The value of time itself changes over time

Many econometric studies show a correlation between the value of users' time and the standard of living as measured by GDP per capita. For example, the European Union, in its guide for socio-economic transport infrastructure assessments, recommends using an elasticity of between 0.5 and 0.7 for the correlation in the increased value of users' time and GDP growth.

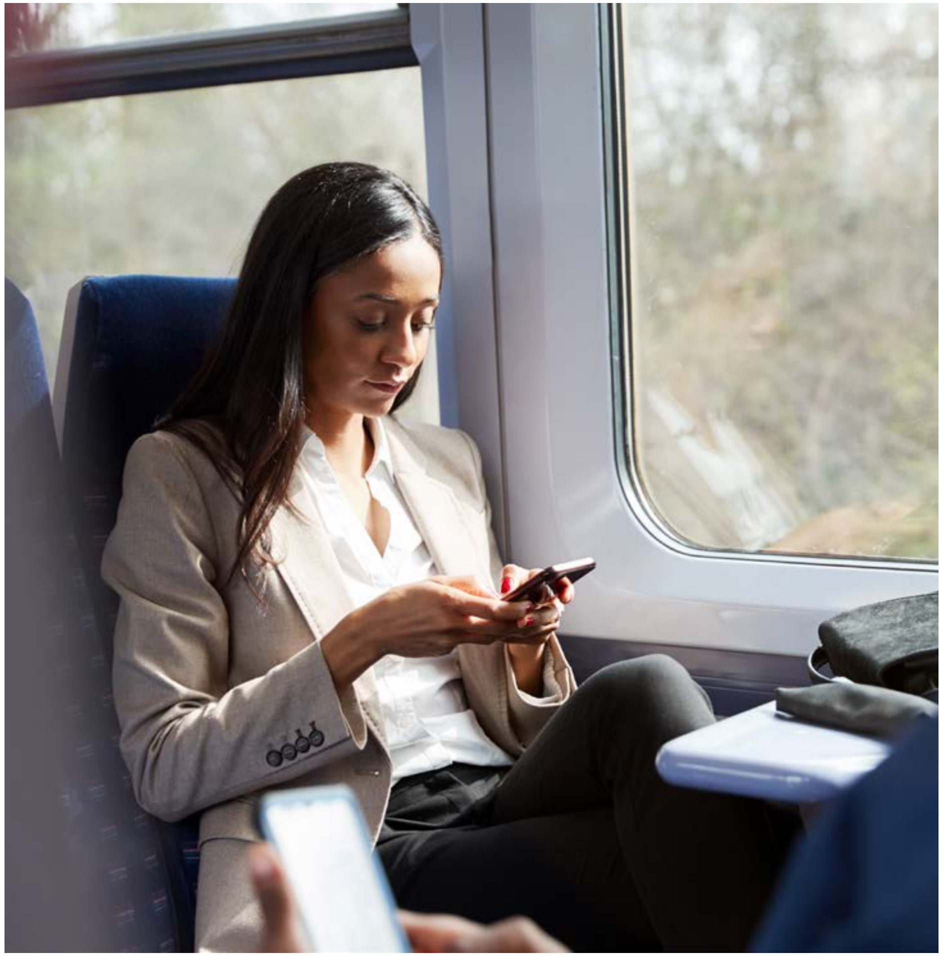
When the value of an individual's time increases, they tend to prefer faster transport, which means that they will travel by train instead of coach, then by plane instead of train as this saves time, provided that everything else in a door-to-door journey remains the same.

GDP is not the only thing that affects the value of time, as an individual actually has several different values of time that characterise the reason for which they travel. Accordingly, the same person may value their time more when they are on a business trip versus travelling for leisure, or for example, during the COVID-19 pandemic, some people decided to move due to the possibilities offered by remote working, meaning that they reorganised their time management which evidently also had an impact on how they valued their commute time. This suggests that an essential aspect of the generalised cost of transport (and therefore the intermodal distribution of demand) is influenced not only by wealth but also by societal use.

The outcome of this analysis shows that the two major supply-side variables for each mode of transport, namely **speed and cost**, correspond exactly to the two predominant factors which determine demand: **time and price**.

The 'right speed' is therefore a doubly important factor, as it enters directly into the consumer choice equation through transport time, and also indirectly influences production costs and subsequently price.

Given the speed of developments in the market, technology and usage, time plays a major role in supply strategy and in determining the right speed for our planet.



The role played by environmental factors

Environmental factors are important, and even more so when populations are aware of the effects and avoid taking the plane (flight bashing) in favour of more environmentally friendly modes of transport.

In this case, the acceptable duration of travel for passengers may be longer, which favours railways over flying.

1. The overall environmental impact of high-speed rail

For high-speed rail infrastructure, the impact can be simply summarised by three phases.

The first is that building the infrastructure has to degrade the environment in some way, and that is why impact studies have to precede construction. The larger the degradation is, the longer it will take for the second phase, the operational phase, to 'repair' the damage. The third phase is renewal, as it is a major factor in investment recycling rates.

In contrast to air and waterways which only need single-point infrastructure (airports and ports), roads and railways require infrastructure along the whole length of the route. The main disadvantages of this infrastructure are:

- Its practically unchangeable quality
- Its length and linearity, which impose severe constraints on the route, causing expropriations, and having significant consequences on natural areas, agriculture, housing, and heritage
- Its very strict physical characteristics linked to the grip, power and speed of the vehicles using it
- Its high cost

There is however also a positive: regions will see increased development through more frequent and precise service as opposed to air travel.

2. The role of speed in defining railway infrastructure

Speed has two opposite effects on the vertical and horizontal profile of new high-speed infrastructure.

The more powerful the trains running on the line are, the better they can cope with steep gradients, as when conventional lines were limited to gradients of 1.5% or less, they had to be laid out in plains or valleys. New lines exclusively for high-speed trains can tolerate steeper gradients of up to 3.5% or even 4.0% (which is the case for both the Paris-Lyon and Cologne-Frankfurt lines). By having these gradients and slopes, a line is therefore no longer necessarily set in valleys, is less winding, and crosses regions with fewer natural and human constraints.

Steeper gradients are also advantageous as they reduce the need to move soil as well as the need for bridges and tunnels. Where a deep ditch or high embankment would have been necessary with a conventional line, a steep slope (or ramp) reduces the depth or elevation of the earthwork, or even makes this unnecessary by accommodating the natural terrain. At the same time, a viaduct or tunnel may be shorter due to having a more pronounced longitudinal section, or they may not even be needed at all.

The higher the speed, the more the curvature radius of the level track must be increased and the straighter the line should be. This makes it more difficult to avoid singular points, whether they be dwellings or factories, or human or natural heritage sites, although these singular points are less numerous as the line rises in altitude.

The physical characteristics of the new lines, built for mixed passenger and freight traffic, are usually determined by the most demanding trains, which are usually freight. Consequently, a mix severely limits the gradient of ramps and slopes, and forces compromises for cant deficiencies, so that in general more steel or concrete structures, more tunnels, more earthworks and more investment are required. However, it does make freight transport possible.

3. The role of speed in operations

It is obvious that the faster a train goes, the more energy it will use, and the laws of physics also dictate that energy consumption varies as speed squared and the installed capacity of the rolling stock as speed cubed.

However, in compensation for this excess consumption, two things occur.

The first relates to greater appeal generated by a faster journey time, so that as a consequence, a part of car or plane demand will shift to the train, which overall reduces greenhouse gas emissions.

Another effect is that speed increases accessibility to areas served by the new infrastructure, leading to higher mobility and more people to transport. In theory, this should increase energy consumption and run counter to the previously mentioned reduction in greenhouse gas emissions. However, due to their success, it has also been observed that high-speed trains have a better occupancy rate than conventional trains, and the improvement in this productivity ratio fully or partially offsets the greenhouse gas emissions from:

- New mobility
- Passengers shifting from slower but less busy conventional trains to high-speed trains

The key point in this calculation of greenhouse gas emissions generated or avoided is the extent to which traffic is shifted from fossil fuel-intensive modes of transport to high-speed rail. The volume of traffic shifted from air to rail depends primarily on journey time:

- When train journey times are less than or equal to 2 hours, the train has in principle already taken control of this part of the market, with the airplane withdrawing except for connecting routes for long-haul flights.
- When train journey times are between 2 and 5.5 hours, the shift elasticity from air to rail is at its strongest, meaning that any train acceleration pays for itself by shifting a significant number of passengers to it.
- When train journey times exceed 5.5 hours, air travel remains predominant, and few passengers are shifted.

Therefore, this analysis shows that, when looking at shifting air-to-rail, the optimal speed depends on the travel time for the competing railway. Under 2 hours or exceeding 5.5 hours, people are unlikely to shift modes of transport, whereas between these two limits the train has every incentive to go as fast as it can.

Moreover, the price of a train ticket must be competitive, as in many countries this is the main factor for choosing a mode of transport.

The train and car are more likely to compete over shorter distances, as unlike the competition between air and rail, which is mainly based on the journey time of the main train, rail-road competition (for customers not captive to either mode) is strongly influenced by three factors:

- The frequency of railway services
- The door-to-door journey time
- The ticket price

Effectively, air and rail are both collective modes of transport which are characterised, on the one hand, by their use of timetables or their service frequencies (inevitably limited in number), and on the other by their inability to offer direct door-to-door solutions.

The train and car have bigger differences:

- One is entirely private while the other is a collective mode of transport
- The other can only travel from station to station and needs to be complemented both inbound and outbound by a short or medium distance means of transport, while the first offers a journey from true origin to final destination.

However, as a train is on average 2x faster than a car, it ultimately compensates for its inability to run door-to-door. In other words, the longer the distance, the better the chance a train has of outcompeting a car, so that speed is not as crucial for long-distance travel, but is so over short and medium distances. Under 100 kilometres, it becomes difficult to beat a car, except for daily or frequent journeys, such as a commute to work or school.

It also seems that the optimal speed for competing with air and road travel does not generally overlap. The right speed will therefore be the one that maximises a function which is the sum of two parts, with each part being the resulting volume of passengers shifted to the train and the corresponding CO_2 savings made.

Finally, there is the passenger shift from conventional to high-speed trains, with the latter often replacing the former. Common sense tends to view this transfer negatively, as there is the preconceived idea that a passenger who uses a high-speed train over a conventional train on the same route will consume more energy and therefore damage the environment. However, it is more nuanced than this.

A high-speed train will attract customers that a conventional train does not, meaning that the two markets are brought closer together. On the one hand, it is also fuller, and on the other, it needs less stops to reach capacity, which allows for less acceleration and braking as well as its energy consumption to be spread over more passengers.

Numerous different calculations have been carried out which show that energy consumption per passenger-kilometre is often lower when the passenger travels by high-speed train than by conventional train.

The role played by socio-economic factors

There are three effects which engender a positive socio-economic impact: new demands made on the economy, traffic flowing between different modes of transport, in a first instance where general mobility hasn't changed, and in a second where mobility has increased.

1. New demands made on the economy

Many see the investment required to build a new line, and purchase rolling stock to operate it, as a way to boost the country's economy. This is true on two conditions: if a new demand on the economy has truly arisen and if development is financed by increasing its debt.

However, if investment is made at the expense of another investment with a constant budget, there is not any real new demand made on the economy, as a choice is being made between two expenses of the same amount at the same time. Taking the example of the railways, the economy will only see a positive effect, per unit of money, if the rail investment is more employment-orientated and reduces imports more than the other reference investment.

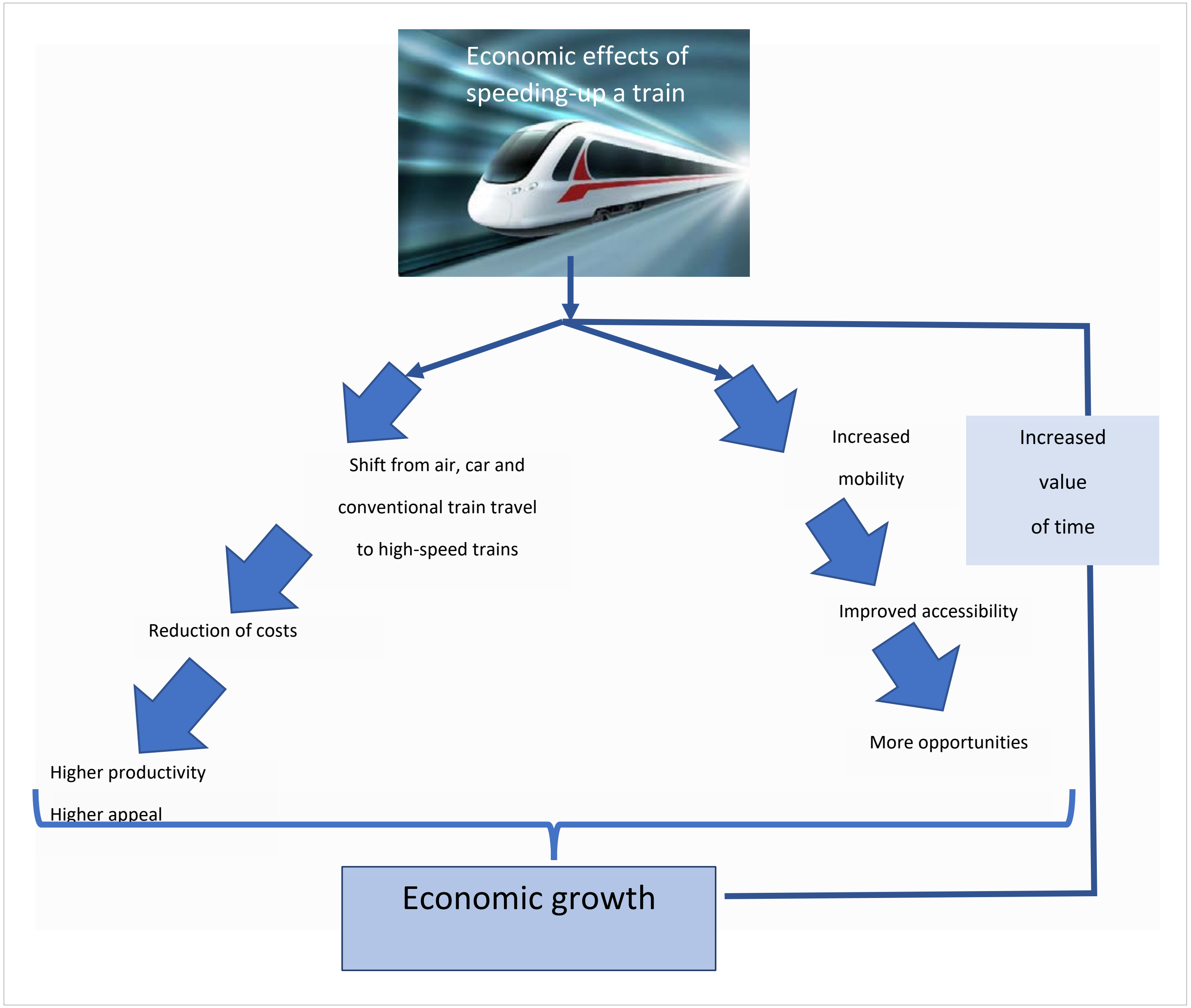
Otherwise, the other discarded (reference) investment would have been a better choice, which is why, when an investment is debt-financed, it has every chance of being a new demand made on the domestic economy, but with the disadvantages brought by all new debt.

In this case, there does not seem to be a link between the importance of a new demand on the economy and the 'right speed' of trains on the new planned infrastructure. However, this link does subtly and indirectly exist, when it comes to how the investment is phased in order to streamline the financing needs. A railway project can be divided into phases on several conditions, given that:

- the infrastructure sections to be built in stages can be connected to the existing network, otherwise they cannot be used
- they offer a sufficient leap in quality in order to have a significant effect on demand

Therefore, the 'right speed' may turn out to be higher while the project is still incomplete, as with only one or two operational sections, it may not deliver the quality of supply that drives demand, whereas this may easily happen once the line is completely in service. As a consequence, if the right speed is skilfully chosen, it can make a project feasible in phases, which also makes it easier to finance with the related risks being mitigated.

Beyond the short-term effect of building a new line, faster trains have a lasting medium- and long-term effect because of the changes they bring to the mobility market.



2. Traffic flowing between different modes of transport

The transfer of traffic between modes of transport generates savings for passengers, and more precisely a reduction in the overall cost of transport. If this was not the case, as rational agents in the economic sense, users would have no reason to change mode of transport. The saving can then be transformed by:

- Being saved
- Being used for consumption elsewhere
- Being transferred to another economic agent

In the first case, this saving does not generate growth except if it is then invested.

In the second case, the saving stimulates domestic demand and contributes to GDP growth.

In the third case, for a business trip for example, the saving is transferred to the business or organisation whose production costs are then lower and who can therefore reduce their selling prices and become more competitive in both domestic and international markets. Therefore, GDP and the external trade balance are improved.

In summary, traffic flowing between modes of transport generates growth.

Consequently, the 'right speed' here minimises generalised transport costs. However, this right speed also incurs a cost for being produced which is normally reflected in the ticket price and reduces the time saved. This is where part of the high-speed line will not be paid for by the user but instead financed by the taxpayer (via outright grants). The bigger this part is, the more reasonably priced the ticket will be, and the larger the positive effect on the economy will be. This is arguably the aspect which should be most taken into account when charges for accessing this new infrastructure are calculated.

3. Developing mobility and land-use planning

There are two ways to plan land-use.

The first consists of creating poles of attraction that aim to overcome resistance to moving people. In other words, creating these poles generates new transport to reach them. This short-term effect may also blend into the medium and long term when economic agents consider it important to avoid this transport by relocating their housing or centres of activity.

The second consists of investing in means of transport to make certain areas more accessible. By following these policies, economic agents are given the chance to:

- Either have better access to tourist areas or nature
- Or look for and find a job or education further from their home
- Or be able to meet or socialise more with their family, friends, etc.

High-speed rail is therefore one of the most powerful direct tools for influencing mobility.

However, it also indirectly effects land-use planning. The arrival of high-speed trains to an area has often been the catalyst for a certain level of ambitious urban renewal or development projects. This ease of access also tends to change how the high-speed train destination is perceived as tourism flourishes, companies, higher education and research institutions are established, and the choice of residence changes, even leading to dual residency.

However, the effect on a region is very varied and largely depends on the size and layout of the urban area, the distance between the cities served by the line, the choice of the station's location and the quality of regional and local transport, how involved and coordinated local players are in supporting regional development, and especially, the train timetable and ticket prices.

Therefore, some of the towns served by the line, end up changing from being predominantly rural to becoming drivers of growth for the city, mainly in the tertiary sector, or becoming tourist attractions if they already had some pre-existing demand before the arrival of the high-speed rail link, whether it be general or business tourism.

High-Speed Rail is also a means of boosting the influence of a region without changing its status as it can change the economic face of the region, without really transforming it.

The arrival of high-speed trains can be an opportunity and a catalyst for reconfiguring neighbourhoods around the station and strengthening the heart of the urban area, as the station is where the effects of high-speed rail are both concentrated and spread. These programmes help to revitalise old town centres and encourage internal relocation with more suitable premises. Mobilising local stakeholders is decisive on the potential these effects have, as it affects the routes, the location of stations, how the services are provided, and the financing of the infrastructure.

The arrival of a high-speed line, therefore, has four types of effect:

- On mobility and accessibility, which is the most direct and decisive effect. Traffic flows significantly increase, as journeys are made at high-speed which were not previously possible due to long travel times.
- On urban planning and real estate, mainly through neighbourhoods around stations being redeveloped, to regain their title as appealing centres of urban development, and through urban services being redistributed
- On image and on tourism, with urban or rural tourism already existing beforehand
- On businesses and the local economy being established, which are generally measurable in the longer term, unless local players have anticipated the arrival of high-speed rail in their area.

Obviously, cities that are already thriving benefit more from these development opportunities and therefore, some critics of high-speed rail argue that it creates regional inequalities. Two of these are easy to identify.

The first is the "tunnel effect" which arises from the fact that a high-speed train cannot have stops which are close to each other, which disadvantages the areas between the stops without any of the benefits, as they are crossed but not stopped at. This effect can be mitigated by creating new stations, but these new stops also slow down trains and affect their average commercial speed, negatively impacting the ‘right speed’.

The second effect is temporary. Countries that have adopted high-speed rail inevitably start by building a section of line which then benefits that part of their region, and therefore the perception of travel time is very quickly influenced by the high-speed train in operation. As a result, passengers on conventional trains, where there is no new line (yet), experience a sense of being downgraded which is sometimes expressed as a "two-speed rail network". One way of mitigating this is to extend high-speed services beyond the new lines by interoperating them with the conventional network. Consequently, for the inbound and outbound routes of the new lines, the ‘right speed’ consists of saving time on part of the route. *In other words, the right speed should not only take the market of the exact cities located on the new lines into account, but also a wider area including a part of the old interoperable network*.

4. Pricing policies

The previous paragraphs have only addressed the issue of how affordable high-speed services are from a cost perspective, particularly in terms of the proportion of the capital charge that is or is not included in the ticket price, via infrastructure charges.

But the price of the ticket itself is also a result of market policy and the way supply and demand are balanced. The different pricing models in use revolve around three main criteria to regulate the price:

- The socio-economic circumstances of the passenger (in other words their purchasing power)
- The share of the risk between the passenger and the operator
- Customer loyalty

Since, without a doubt, pricing affects the level of demand, a price factor has to be introduced into the equation for defining the ‘right speed’. This is all the more true, as experience has repeatedly shown the link between price and volume of demand, which partly explains the appearance of ‘low-cost’ trains, which above all have low prices, as inter-rail competition in Italy, France and Spain has recently shown.

The role played by capacity

Capacity plays a fundamental role in the search for optimal speed.

1. The balance between speed and number

Firstly, it is important to note that increasing speed means increasing braking distances and therefore reducing the number of trains. However, the higher the speed, the more appealing it is to take the train, the more demand increases, and the more trains are needed to absorb this, meaning that speed argues for more trains while at the same time reducing the possible number which can run.

The increase in physical numbers can be achieved by increasing the train capacity itself and optimising the train headway system. Digitalising the network and using artificial intelligence should help progress to be made and the limits between which the ‘right speed’ might be found to be overcome.

Another effect of this paradoxical number problem is the economic scarcity that it creates. From the moment that capacity becomes limited, infrastructure management tends towards a pricing system which takes this scarcity into account. It is evident that the optimal commercial speed is not the same for peak or off-peak periods of the day.

More importantly, the bottleneck effect is often due to the junctions where the lines end, rather than congestion on the lines themselves, so that this type of scarcity which even marks lines entirely dedicated to high-speed trains, is often because of external factors, meaning that the right speed can be the result of a compromise between regional and high-speed trains.

2. A mix of services

The performance of the line depends on the uniformity of the traffic's commercial speeds, as if all the trains run at the same speed and have the same number of stops then the performance is maximised. However, if the trains have different purposes, so that they run at the same speed but do not have the same stops, or they have different speeds, but all have the same stops, then maximum performance is achieved by slowing down the faster trains. Therefore, a mix of services counteracts the appeal of the fastest trains.

This means that the 'right speed' depends on which services are using the infrastructure.

When this mix goes beyond the range of passenger trains and extends to freight, the train speed is affected, not due to limited numbers but due to compatibility. In the vast majority of cases where passenger and freight trains 'cohabit' on a new infrastructure:

- The physical characteristics of the line are chosen differently, notably by limiting the vertical gradients to a maximum of 1.5%, which makes investment more expensive.
- trains do not run at the same time (e.g. passengers during the day and freight at night), which has implications for track maintenance.

Therefore, the mix of traffic using the line is a critical choice that significantly impacts the speed of the fastest trains and also results in a lower "right speed" being chosen than if there was only the passenger market to consider. However, while it is more expensive to build a mixed freight-passenger high-speed line than a dedicated passenger line, it is much cheaper than building two parallel lines, one for passengers and the other for freight, and this is especially so when it comes to crossing natural barriers (large mountain or underwater tunnels, large viaducts, etc.).

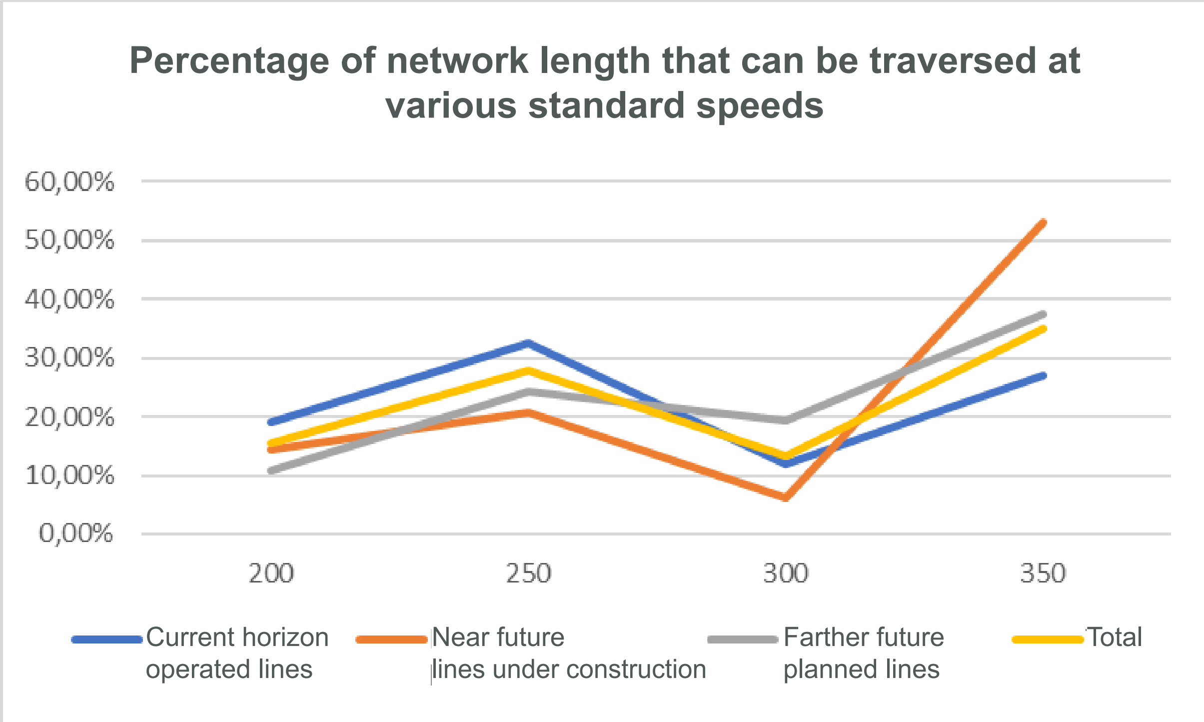
The role played by historical/geographical factors

1. Analysis

Unfortunately, the world's high-speed rail network is far from being uniform in speed. The following table details the commercial speeds adopted for three time periods (current: the network currently in operation, near future: the lines under construction, and far future: the plans).

km/h	km in operation	km under construction	km planned
110	4		
130	313		
140	76		
160	23		
200	10854	2865	4118
220	145		203
230	583	28	24
240	1059		
250	18370	4163	9205
260	965	66	
270	471		
275	79		
280	426		
285	515		
300	6742	1219	7262
305	643		
320		782	2384
330			385
350	15314	10617	14169
360		225	
Total	**56583**	**19964**	**37750**

For our three time periods, there are four standard speeds lead the pack: 200, 250, 300 and 350 km/h.



2. The weight of history

As it already has in the past, the distribution of standard speeds across a network will vary. The previous graph shows that time is a vital factor which enters into the equation for determining speed, and is partly because some of the high-speed network is made up of old lines designed to run at least 200 km/h.

So, as time goes by, the pool of lines that can still be developed for high-speed is shrinking and the high-speed network is of course not being built independently of the existing conventional network but alongside it. After all, the whole point of interoperability is to be able to operate a new section of line with both inbound and outbound trains and high-speed rail develops by building on existing infrastructure to access dense areas (cities) and to expand its market to more destinations.

In certain countries, the weight of history, otherwise known as heritage, is therefore a fundamental part of choosing speed as high-speed trains don't just run on new but also on older lines, so that city-to-city journey times on new sections are very much reduced, while more traditional speeds are reached on old sections.

The art in the phased construction of a high-speed network is precisely to take advantage of this interoperability between the network of the past and the projects of the future, nor can we ignore the fact that rail technology is constantly advancing. For example, the commercial speed has recently reached 350km/h in China, which shows that, perhaps in the near future, 400 km/h will also be reached. Japan is another good precedent, where in 1964 high-speed rail began by operating at 210 km/h between Tokyo and Osaka, whereas today trains on this route run at 285 km/h.

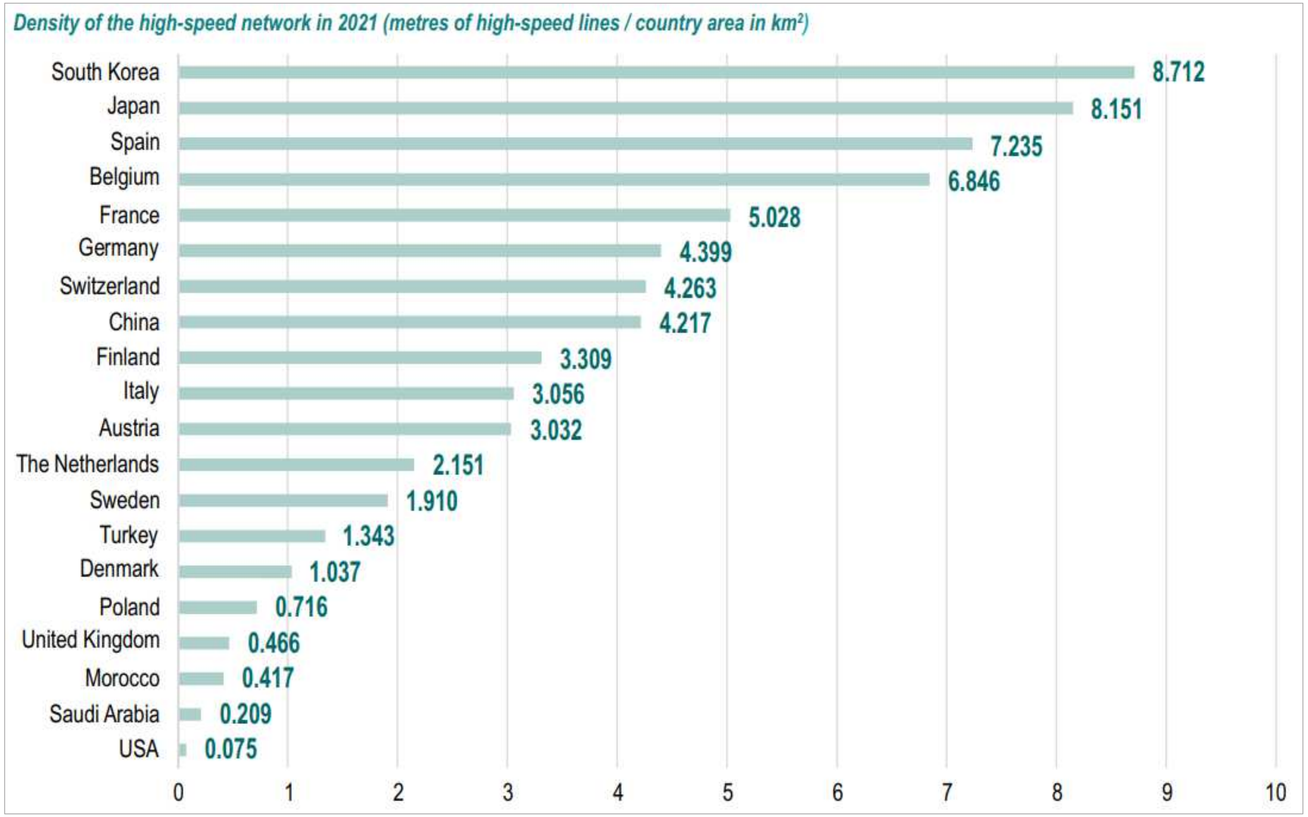
Another telling example of how important heritage is, is the Northeast Corridor in the United States, where the historic infrastructure is combined with the technological evolution of the rolling stock. On the 735km-long line between Boston, New York and Washington DC, the maximum speed of 240 km/h is only possible on a short section (between Mansfield, Massachusetts and Richmond, Rhode Island), the average speed on the whole corridor is only about 110 km/h. In the future, the use of new trains (with Alstom's Avelia Liberty active tilt system), combined with a parallel modernisation of the infrastructure, will make it possible to reach 300 km/h, once again proving that the right speed is not fixed in time.

Beyond the American Northeast Corridor, there are numerous other examples of the maximum commercial speed increasing. This is one of the reasons why the design of high-speed lines should not ‘insult’ the future, as it is difficult to change once it has been built. It makes more sense to be generous with the design standards, even if it is marginally more expensive, to avoid making mistakes later on, or even making it impossible to improve i.e. running faster, when future technology makes it possible.

Other countries operate point-to-point high-speed lines without extending to conventional lines. This is particularly the case when the cities called at are megacities for which a ‘shuttle’ service is needed to connect them. This is the case, for example, with China’s first high-speed line which links Beijing to Tianjin.

3. The weight of geography

Network density varies greatly from country to country and there are two main factors which explain this: population density and the national investment effort of a country. Effectively, the more scattered a population is, the less the transport market will hit the critical mass needed to justify the investment to build a high-speed line. Physical geography also comes into play, either because some parts of the territory are deserts or near-deserts, or because natural obstacles reduce the possibilities for new infrastructure to be built, and this also needs to be considered when determining the right speed.



Note : The ratio of Denmark has been calculated excluding Greenland area

Source : compiled by authors based on Internation Union of Railways, 2022

Countries or corridors can be classified into at least four categories with regard to their network structure:

- Linear countries and corridors, such as the American Northeast or the Taiwanese corridors, the Japanese, Moroccan (a North-South axis followed by a West-East axis connected to the North-South line to form a "Y" leaning to the right) or Italian (T-shaped) networks, or even those in Portugal (North-South) and South Korea.
- Countries with a central point (usually the capital) and axes extending from this centre to the four cardinal points, such as Spain, France, or Poland.
- Countries with an urban framework comprising of numerous densely populated nodes dispersed over all or over a very significant part of their territory, such as Germany or China.
- Isolated corridors like in Saudi Arabia.

The highest speeds can be expected on the longest routes and isolated corridors, except where the inertial weight of historic lines prevents this from happening (as is the case in the eastern United States) and except where they are interspersed by cities of equal importance requiring trains to stop frequently.

When distances are reduced, speed becomes less important. This is typically the case in Switzerland, where speeds between the main cities are not very high, but where a great effort has been made to improve longer international links, notably by digging tunnels designed for speeds of 200 km/h.

It is interesting to compare the speed strategies of different countries by examining how many lines in their respective networks can be travelled at different intervals of the maximum commercial speed. The following table shows the percentage of a country's network that allows a given speed range.

Speed interval	200-249 km/h	250 - 299 km/h	300 - 349 km/h	350 km/h et plus
China	20,2%	40,6%	0,9%	38,3%
Germany	27%	43%	30%	0,0%
Spain	14,0%	22%	64,0%	0,0%
France	0,0%	0,0%	100,0%	0,0%
Japan	11,5%	64,9%	23,6%	0,0%

China has clearly separated its network into the following:

- Incredibly fast axes (350km/h) representing 40% of the new lines
- a more moderate high-speed network of equal relative importance (40%)
- and a network of lower speed links corresponding to 20% of the lines

The other countries do not offer commercial speeds of 350 km/h and divide their network between the other three speed bands in varying proportions.

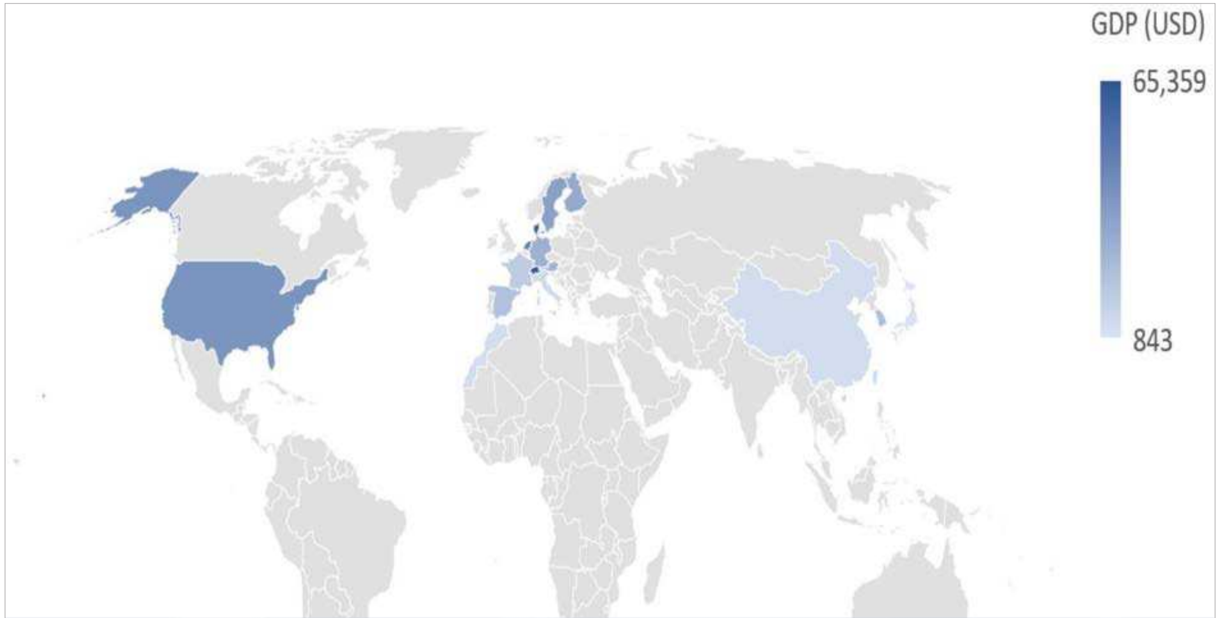
If a country (or region) is large enough, it will have geographical differences which will require the speed to be adapted to individual scenarios. France is an exception, having first imposed a speed standard of 300 km/h and then 320 km/h.

From this analysis it can be concluded that since physical geography and populations are not uniform, the right speed cannot be uniform either.

The economic aspects also remain to be analysed: is wealth a determining factor in the development of high-speed rail?

For a long time, the view has been held that high-speed is a luxury for rich societies only, however the most significant high-speed network expansions are currently taking place in countries which do not have the top 10 highest GDP per capita.

The main reason for this is that high-speed is very productive, precisely due to its speed. It can therefore offer train tickets at accessible prices and at a level comparable to, or sometimes lower than, the equivalent in conventional trains.



This table clearly indicates that there is no direct link between wealth per capita and how economically feasible a high-speed network is, and therefore contradicts the idea that high-speed rail is a luxury product. The main reason why this link does not exist is that most of the investment to create a high-speed network is dedicated to building the necessary infrastructure. However, this infrastructure is also built locally with people being paid the normal wages of the country in question, which means that there is inevitably a correlation, or more precisely a proportional relationship, between the amount of investment and the local purchasing power, so that the train tickets will stay at a reasonable price for the population who will buy them. This is reinforced by the fact that the system benefits from high productivity resulting from the speed of the trains which lowers the cost price, despite superstructures and rolling stock being more expensive.

Therefore, theoretically no region is systematically excluded from high-speed rail because of its level of economic development. Market volume remains the key factor, as the investment must be spread over a sufficient volume of passengers to ensure that the mode of transport is appealing.

Country	Train	Year of HSL activation	GDP (USD)
Japan	Shinkansen	1964	843
Italy	La direttissima	1977	4 603
France	TGV Sud-Est	1981	11 104
France	TGV Atlantique	1989	17 694
Austria	Linz-Wels	1990	21 680
Germany	ICE	1991	23 357
Spain	AVE	1992	16 112
Finland	Helsinki-Turku	1995	26 271
Sweden	Stockolm-Orebro	1999	30 941
United States	Acela Express	2000	36 334
South Korea	KTX	2004	16 496
Netherland	Hoofrddorp-Rotterdam	2006	44 863
Switzerland		2007	65 359
China	CHR	2008	3 468
Morocco		2018	3 226
Denmark		2019	60 213

Conclusion

The previous paragraphs show that the **right speed for our planet** depends on geographical, commercial, sociological, and operational considerations. They demonstrate that investment must be substantial enough to avoid costly mistakes in the future due to an overly narrow view regarding the development potential in rail transport and technology, which is yet to be exhausted.

Therefore, a variety of factors will continue to determine the right speed for our planet.

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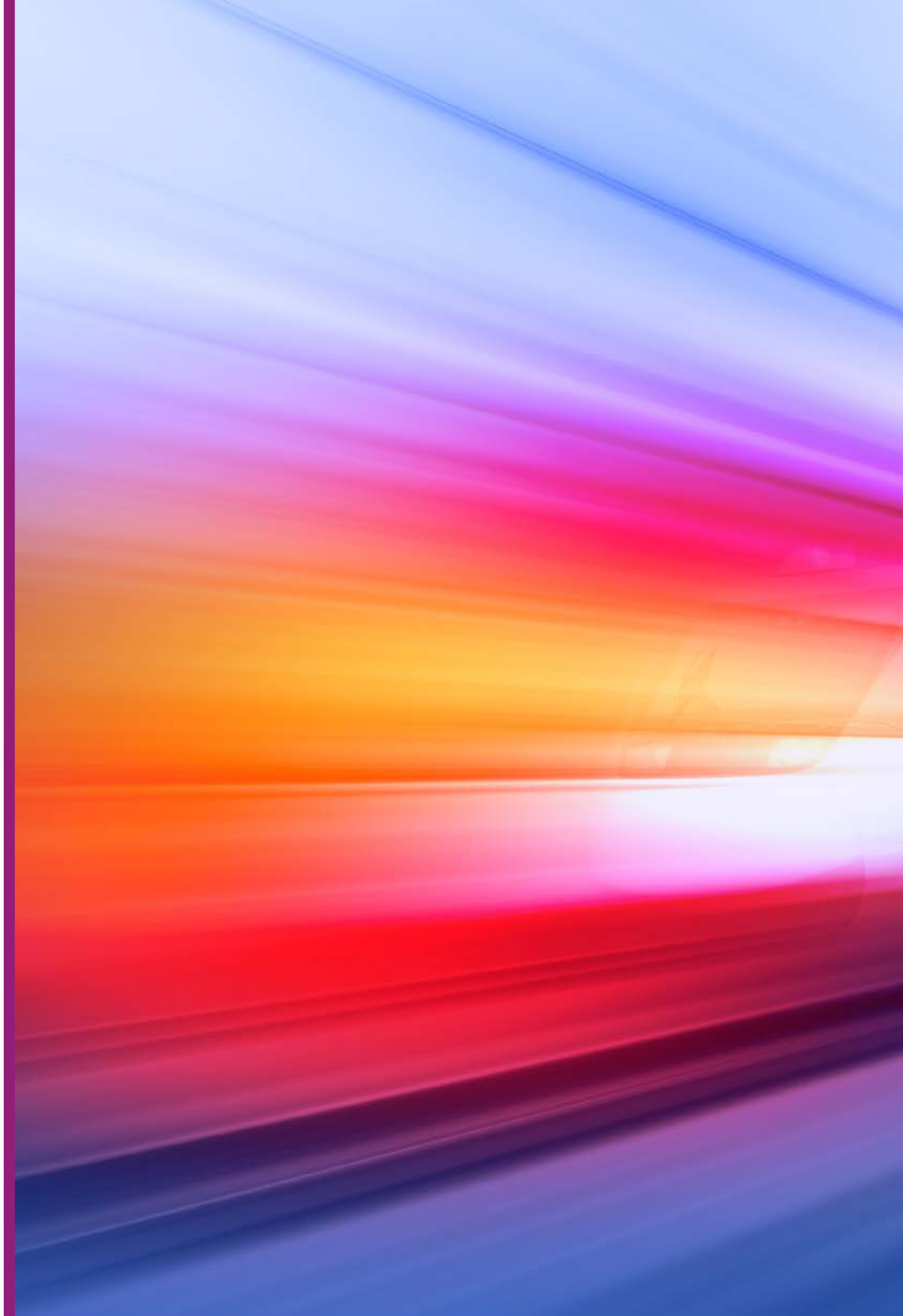

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