

HIGH SPEED RAIL

FAST TRACK TO SUSTAINABLE MOBILITY

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FOREWORD

High speed rail (HSR) encompasses a complex reality involving many technical aspects, such as infrastructure, rolling stock and operations, as well as strategic and cross-sector issues including human, financial, commercial and managerial factors.

High speed has proven to be a very flexible and attractive system that can be developed under various circumstances and in different contexts and cultures. This is the result of four main and very important characteristics offered to customers and society: safety, velocity, capacity and sustainability. As a result, HSR is a rapidly expanding new transport mode, often described as the "transport mode of the future".

This brochure aims to communicate and disseminate high speed characteristics, performances, improvements, innovations and potential applications.

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> Jean-Pierre Loubinoux Director General of UIC

HIGH SPEED RAIL : PRINCIPLES AND DEFINITION

Rail is a grounded, guided, low grip transport system

It needs specific ground infrastructure which is costly to implement and maintain but contributes greatly to efficient land use.

The rails provide the guiding system. By controlling the direction of the train, they allow it to go very fast. However, this means that trains cannot overtake one another.

Low grip refers to the contact of a steel wheel on a steel rail. As the train glides on the track, it is easy to carry very heavy loads with a low environmental footprint, but very difficult to brake and stop, or to accommodate steep gradients.

Because of the huge investment required, rail can only be commercially attractive and financially acceptable as a mass transport system. This is just as well, as it is typically a heavy haul system.

Classical rail

Classical rail networks are largely spread worldwide. They comply with various gauge standards, but the best performance is achieved using the 1.435 m track width.

Most of these networks are made up of mixed-traffic tracks. The maximum speed never exceeds 200 km/h (exceptionally 220 km/h). Built during the 19th century, many stations are now located in the centres of large cities where most urban transport lines converge, facilitating door-to-door trips.

When compared to other transport modes, classical rail has proven to be very safe and environmentally efficient. However, the aviation and automotive sectors have introduced many improvements and are still introducing innovations in their respective systems. This has had a strong negative impact on rail market shares for medium- and long-distance trips.

More than 50 years ago, Japan, followed by France and many other countries, decided to stop the decline of classical rail in this market segment by introducing brand new concepts for the rail mode rather than upgrading existing structures. This represented the birth of high speed rail.

THE LIMITS OF CLASSICAL RAIL

The speed increases of conventional lines is limited by several factors :

The mix of traffic and particularly of speeds because the bigger the difference between the fastest and the slowest trains the smaller de capacity of the line,

- The constraints due to the route and particularly the radius of the curves and the human density of the surroundings,
 - ▶ The cost of the investiments for the upgrading,
 - ► The necessity to adapt all the rolling stock fleets using the infrastructure,
 - The difficulty to upgrade while operating



The definition of high speed rail

HSR is still a grounded, guided and low grip transport system :

it could be considered to be a railway subsystem. The most important change comes from the speed. As travel times had to be reduced for commercial purposes, speed emerged as the main factor. HSR means a jump in commercial speed and this is why UIC considers a commercial speed of 250 km/h to be the principal criterion for the definition of HSR.

However, a secondary criterion is admitted on average distances without air competition, where it may not be relevant to run at 250 km/h, since a lower speed of 230 or 220 km/h or at least above 200 km/h (since under this speed conventional trains can do) is enough to catch as many market shares as a collective mode of transport can do. This also applies in very long tunnels whose construction cost depends on the diameter linked to the square of the speed, at least.

For such speeds above 200 km/h, the infrastructure can be categorized in "High-Speed" if the system in operations, complies with :

- ► track equipment,
- rolling stock (generalisation of trainsets),
- ▶ signalling systems (abandonment of trackside signals),
- operations (long-range control centres),
- the geographical or temporal separation of freight and passenger traffics,
- ▶ and more globaly with the standards for High Speed.

This definition is coherent with the definition of High Speed Rail given by 96/48/EC European directive



Commercial speeds and speed records



High speed rail requirements

Although increasing the speed has entailed many technical and operational changes, HSR still fulfils the same quantitative and qualitative requirements as classical rail :

- Ability to accommodate various contexts and cultures
- ► Interoperability,
- Capacity,
- ► Reliability
- Safety and security
- Sustainability

This evolution has also made it possible to benefit from many other innovations beyond those simply enabling higher speeds, as there is no point improving one aspect of a journey chain (travel time) if the other links in the chain remain weak.

In addition, a thorough review of all the interfaces between the system components and of all the operating and maintenance procedures is necessary, as time gained for the passenger by the increased speed can be cancelled out by an unacceptably high ticket price.

OF HIGH SPEED RAIL

19th – 20th century : From the birth of the railway to HSR

Because the rail mode is a guided and low grip transportation system, the history of the railway is an endless history of speed. Since the origins of rail in Europe, during the Industrial Revolution at the beginning of the 19th century, the speed of passenger trains was of the essence for competition - not necessarily with other transport modes, but with other rail companies. It also provided concrete evidence of technological development in the most advanced countries at that time. If, in 1829, the 50 km/h reached by the impressive "Rocket" locomotive from George Stephenson was understandably regarded as high speed rail, it did not take long to achieve even more impressive performances: 100 km/h before 1850, 130 km/h in 1854, and even 200 km/h at the beginning of the 20th century. However, these are just rail speed records. The maximum speed in revenue operation was much more modest but nevertheless important. In the 1930s, the top and the average speeds between two cities using steam, electric or diesel power were 180 km/h and 135 km/h respectively. However, the emergence of other transport modes, such as aviation (faster) and private cars (point-topoint private travel at any time), prompted railways to take further steps to keep up with competition.



1964: The birth of Shinkansen

After some significant speed records in Europe (in Germany, Italy, UK and particularly in France - 331 km/h in 1955), the world was surprised when, on 1 October 1964, the Japanese National Railways began operation of a brand new, 515-km, standard gauge line (1 435 mm, unlike the conventional metre-gauge lines previously built in Japan) : the Tokaido Shinkansen, from Tokyo Central to Shin Osaka. This line aimed to provide the transport system with a capacity commensurate with the impressively rapid growth of the Japanese economy. JNR promoted the concept of not only a new line, but a new transport system, which was later extended to the rest of the country and became the backbone of passenger transport for future generations in Japan. Tokaido Shinkansen was conceived to operate at 210 km/h (this was later increased), with a broad loading gauge, electric motor units powered at 25 kV AC, Automatic Train Control (ATC), Centralised Traffic Control (CTC) and other modern improvements.

High speed rail was born.



1964 – 1981: The advent of TGV

After the huge technical and commercial success of Shinkansen, several European countries, particularly France, Germany, and Italy, developed new technologies and innovations aimed at overcoming the decline of rail market shares. Despite an uncertain future (introduction of Concorde, political opposition, the first petrol crisis in 1973, etc.), SNCF, the French national railway company, began operation of the first high speed line between Paris and Lyon on 27 September 1981, at a maximum speed of 260 km/h.

The new European HSR rapidly proliferated and expanded its services, thanks to its interoperability with the existing rail network.





1981 – 2018 : HSR services spreading throughout the world

Encouraged by these French and Japanese success stories, several European countries began looking to establish a new generation of competitive long- and medium-distance passenger rail services, either by developing their own technology or by importing it. Italy and Germany in 1988, Spain in 1992, Belgium in 1997, the United Kingdom in 2003 and the Netherlands in 2009 joined the club of countries offering high speed rail services in Europe. In the meantime, some similar cases began appear in other countries and regions, such as China in 2003, South Korea in 2004, Taiwan in 2007 and Turkey in 2009. After the 120-km high speed line from Beijing to Tianjin was commissioned in August 2008, **China changed scale and moved towards a much wider strategy by implementing more than 20 000 km of new high speed lines and acquiring more than 1 200 trainsets, eventually taking the global HSR lead.**

Following the example of China, many new high speed systems are now under development, under construction or just starting operation (Morocco, Saudi Arabia, USA, etc.), demonstrating that HSR can operate worldwide regardless of the geography, the demography, the climate, the economic and political context, and the culture of the country.

HIGH SPEED RAIL TODAY

The high speed network

The high speed network began its development in 1964 in Japan. Its extension, mainly driven by Japan, France, Spain, Italy and Germany, was slow until 2000. At this point an acceleration could be felt, but it was only in 2008 that, thanks to heavy investment by China, the scale of the whole network changed dimension. Today more than half of all high speed lines are in Asia.

Some countries or regions, such as Belgium, the Netherlands and Taiwan, have completely finished building the extent of their high speed network. Some countries are continuing development but have already carried out the bulk of it, such as Spain, Italy, France, Germany and Japan. Some countries are still planning significant extensions, such as UK, South Korea and China. Some countries have just started developing and implementing HSR, such as Saudi Arabia, Morocco, USA and Russia. Finally, some countries plan to implement high speed rail in the future, such as several Eastern European and Asian states.

It is worth noting that not all high speed lines are run at the same speed. Several factors come into the explanation. Firstly, there is the distinction between the design speed and the operational speed. The most recent lines are designed to run at 350 km/h (and even 400 km/h), i.e. the infrastructure and the superstructure can withstand this speed. However, the maximum commercial speed (operational speed) may be lower than the design speed because the rolling stock is not suitable for it. The operational speed is determined by the certification process during which evidence must be provided that the rolling stock can successfully run on the line at the targeted speed plus 10%.

Secondly, some so-called high speed lines are designed for speeds lower than 250 km/h. This can be due the mix of traffic or the network consistency. If the infrastructure is to be run by freight and passenger trains or by long-distance and regional trains, the line capacity is increased by reducing the maximum speed. In addition, some lines are sometimes built predominantly to provide networks with consistency by, for example, linking different sections. In this case the maximum speed may be lower.

The outcome of this is that the global high speed network is not homogeneous in terms of speed.











KEYS www.www.

CAPITAL

- ----- HIGH SPEED LINES ABOVE 250 KM/H
- HIGH SPEED BETWEEN 220 AND 249 KM/H
- HIGH SPEED LINES UNDER 220 KM/H
- HIGH SPEED LINES UNDER CONSTRUCTION
- PLANNED HIGH SPEED LINES



3.

250 500 750 1000 км

© Input UIC members





KEYS www.www.

CAPITAL

300 км

© Input UIC members

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South Africa

mmmm

- HIGH SPEED LINES ABOVE 250 KM/H
- HIGH SPEED BETWEEN 220 AND 249 KM/H
- HIGH SPEED LINES UNDER 220 KM/H
- PLANNED HIGH SPEED LINES



KEYS www.www.www.

CAPITAL

- HIGH SPEED LINES UNDER 220 KM/H
- HIGH SPEED LINES UNDER CONSTRUCTION
- PLANNED HIGH SPEED LINES

High speed rail network



KEYS www.www.

- KM UNDER CONSTRUCTION
- KM IN OPERATIONS
- KM PLANNED

High speed rail network length





- TOTAL
- ASIA
- EUROPE OTHERS





COMMERCIAL APPEAL OF HIGH SPEED RAIL



The only objective when building a high speed rail network is to attract enough customers to break even in socio-economic terms and not be too much of a burden for the taxpayers who may not use it. So, the issue of the number of users is crucial. It is excellent if these users come from other transport modes, as high speed rail is environmentally friendlier than other modes, but a portion of the traffic will also come from an increase in mobility, i.e. people will consume fewer goods or save less money in order to travel more.

This means that high speed rail has to be more attractive than the other transport modes for some segments of the market and has to create its own demand. As a high speed line is usually built to last at least a century, these two characteristics (be attractive and generate mobility) must be perennial.



The commercial appeal

In traffic terms, high speed rail has proven to be very successful, as passenger growth is faster than the network extension, when normally the opposite evolution would be expected, as once the best are built the latest ones will have a lower marginal appeal. **The countervailing facts are grounded on two aspects, insufficiently highlighted**:

► The latest huge network development is taking place in China which is the most populated country in the world;

► Elsewhere, as in China, the network effect works to provide customers with more travelling possibilities.

China has taken the global lead in passenger traffic volumes. This completely refutes the long-standing prejudice according to which high speed rail is only for rich people.

If China is factored out, a steady traffic growth between 2010 and 2018 demonstrates the appeal of high speed rail in every geographic, demographic, economic, political and cultural context; in other words, it is universally appealing.

High speed rail versus air transport

The competition between high speed rail and air transport has been tested in many places, all over the world and around the clock. The major outcome is that, regardless of the rail and air companies involved, modal shares are driven by the relationship between the respective doorto-door travel times.

Furthermore, on most Origin-Destination (OD) pairs, the rail and air market shares can be accurately predicted using just the high speed train travel time :

► Where rail travel time is less than 2h, HSR completely dominates the market and air companies often give up competing. A good example of this is the Paris-Brussels route;

► Where rail travel time is between 2h and 3h30 minutes, rail is the dominant mode;

► Where rail travel time is between 3h30 and 5h, air is the dominant mode;

Where rail travel time is more than 5h, rail becomes a marginal actor compared to air. Of course, this traffic split can be affected by other parameters, such as the location of stations and airports, ticket prices and service frequency. This is particularly the case when high speed lines first open to revenue services, as air operators try to react and resist. However, in the long term the market stabilises around the previous ratios because rail is always cheaper than air, as demonstrated by recent European research carried out by UIC, even when considering lowcost air companies and tour operators who sell complete packages (including accommodation and visits, shows or fairs) better than trips.



Rail market share on the rail + air market in France (PASSENGERS)



High speed rail versus buses

Nowadays, competition from bus operators is widespread in all countries. In many cases, it existed before high speed rail services were commissioned.

Bus travel is characteristically cheap and able to serve several stops within a city, consequently reducing access or egress times.

Generally, when high speed services start operation, the bus offer changes and develops into a low-cost offer, based on economic competitiveness and better on-board services, e.g. free WiFi. This kind of competition can prove quite aggressive towards high speed rail and can give rise to a response in the form of a similar low-cost service. This is the case in France, where SNCF has created Ouigo, a special low-cost TGV service which offers very low-price tickets and also targets families by offering €5 tickets for children, whatever the destination.



High speed rail versus the private car

Competition with the car is much more complex than with other public transport modes because the private car has assets that no public transport mode has. Privacy is the primary asset, together with the ability to offer a full door-to-door trip, the choice of the departure date and hour (full availability), the choice of the route, the ease of handling luggage, the absence of any constraints linked to ticket distribution and reservation, etc.

In addition, car transport is rapidly evolving due to two nascent possibilities enabled by the collaborative economy : car-pooling and car-sharing. These two new uses of the car strike a balance between the fully private system, in which the driver is the owner, and public transport with its constraints (meeting places, contracts replacing ticketing and timetables, etc.).

In the face of this ever-moving competition, high speed rail remains very efficient over long distances. Over shorter distances, HSR needs to be very inventive but has proven capable of this, with fares based on the phone system (unlimited subscription) or on-demand trains. The market is progressively moving toward a digital-oriented and multimodal market, particularly for the younger generation.

Global market shares

The respective market shares of rail, air and road depend on many parameters, such as geographic context, national regulations, etc. However, in most European countries where HSR is in operation, the car is still the main transport mode for short and medium distances and air is the most popular mode for very long distances. Rail and bus have many assets over medium distances. The following graph illustrates the situation in France, as an example of a relatively large European country.



High speed rail retains some assets that distinguish it from other public transport modes, including :

- ▶ ground speed,
- access to city centres,
- ▶ freedom of passengers on-board trains (possibility
- of standing and walking during travel),
- ▶ passenger comfort.



COMMERCIAL APPEAL OF HIGH SPEED RAIL

On behalf of UIC, surveys have

been conducted and focus groups have been consulted in three European countries (France, Spain and UK) in order to identify the main parameters that drive the modal choice of travellers.

This process encompassed :

- ► A sample of 2 000 respondents per country, representative of the national population;
- ► A focus group in each country.

The statistical requirements have indeed been fulfilled with 2,000 valid guestionnaires filled for each country. Statistical adjustment has been performed so that the final data set is representative of the national population in each country in terms of gender, age, social grade, region of residence and car possession. One of the numerous outcomes of this survey is about the criteria driving the modal choice in three different European countries which look very similar. The following graph illustrates one aspect of the survey in which each respondent selects 5 criteria at the most among 14. In the case of UK for example, the "price" criterion is selected by 77% of the respondents, but the "luggage" criterion by 4% of them only. The lesson drawn from this poll is that time ("travel time" + "wasted time " + "reliability" and "accessibility" to a lesser extend + "timetable" as a marker of frequency) and price govern the modal choice.

- ► Travel time,
- ► Wasted time,
- Reliability (to a smaller extend),
- ► And timetable (as a marker for frequency and waiting time).

AS internal rail competition is going to be enforced in Europe, incumbent operators and new comers will struggle to offer better on-board services for the upper market segments and lower costs for the lower market segments. In any case the norm will be to allow the client to be self-autonomous by providing him with electric plugs to fill up on energy his own devices.

In first class the on-board catering will remain as distinguishing feature.

For customers privileging the price and for families low cost services is the best asset of rail against the ever-changing competition from all forms of car uses: private car, carpooling, car sharing and autonomous car in the future. Ouigo in France, Izy by Thalys and Eva in Spain are pioneering this kind of low cost services.

Criteria chosen in the modal choice (percentage)





Following the change in the transport regulation, internal rail competition is emerging in Europe. It already exists in Italy where the incumbent high speed rail company (TRENITALIA) faces a newcomer NTV (Nuovo Trasporto Viaggiatori), which started from scratch by acquiring a fleet of high speed trainsets and creating a new depot (near Naples). This competition is now well installed and has had some important effects on both competitors because of the war on prices it has triggered (about minus 30%), with a resulting rise of traffic of similar magnitude. The consumer is not the only winner (cheaper trips, higher service frequency, better on-board service, newer rolling stock, etc.), in socio-economic terms, this opening of competition is beneficial for all because the infrastructure is more intensely used.

Similar competition is also being experienced in South Korea, between the incumbent company (KNR) and a new public company in which KNR holds shares. A particular feature of this market is that each competitor has their own terminal station in the Seoul area.

In South Korea, internal rail competition has been introduced between the incumbent rail operator, KORAIL, and a new public company whose shares are partly (41%) owned by KORAIL, for high speed trips. The particularity of this competition is that KORAIL with its KTX serves the Seoul central station while SRT (the competitor) uses the Suseo station newly linked to the high speed network by a very long tunnel. In 2017, Korail and SRT have transported respectively around 60 and 19 million passengers in high speed trains.

Of course, competition, whether internal (within the rail mode) or external (with other transport modes), relies heavily on the regulation and degree of freedom allowed. Things are rapidly evolving. In Asia, China and Japan do not allow internal competition and South Korea is only now opening the door. In Europe, the unbundling of infrastructure from operation is leading to competition on or for the market.





Level of liberalisation by country and mode in March 2016

	GREAT BRITAIN	SPAIN	FRANCE
BUS AND COACHES	LIBERALISED	LIBERALISED	RECENT LIBERALISATION
RAIL	LIBERALISED	GRADUAL LIBERALISATION	GRADUAL LIBERALISATION
AIR	LIBERALISED	LIBERALISED	LIBERALISED



Nascent competition with new business models

The digital revolution is transforming the passenger transport market into a perfect market, with a multiplicity of service providers together with the total transparency and immediate availability of information. It has also led to unexpected new business models. Among these, new web actors are trying to carve out a place in the field of train ticket distribution. Through various channels, they take the opportunities provided by the marketing policies of incumbent rail companies or by their yield management systems. Some of these new players also act as

trip comparison sites and provide customers with information on trip alternatives and the environmental footprint of trips.

More aggressive competition is provided by the big data actors who have made some people addicted to their search engines. These companies try to intervene between the customer and the rail companies and sell tickets through their own channels, just like web operators who reserve hotel rooms. Naturally, they act for commission, which may reduce profitability for the rail operators who have invested in the assets for the physical transport.

The changes in regulation may also allow the introduction onto the market of actors like ROSCOS, as in aviation where some companies do their business by simply renting aeroplanes.

FAST TRACK TO SUSTAINABLE MOBILITY

Strategies for reducing the environmental footprint

Three strategies can be implemented in this context:



Avoid

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Limiting the transport demand can be obtained by enforcing quota systems, by creating transport alternatives or by reducing the transport needs.

The first lever is mainly in the hands of national governments. However, HSLs are sometimes shorter than conventional lines and consequently shorten rail trips.

The second lever is already largely enhanced by the digital revolution which has allowed people to communicate without having to move.

High speed rail forms part of the third lever when implementation of the HS network boosts better land use through the relocation of housing, commercial and industrial real estate, the reorganisation of the local urban transports, or the promotion of new ways of life. The creation of co-working spaces in new stations illustrates this last aspect, while also providing access to a wide range of services and shop facilities.

Shift

The advantages of HSR in terms of energy consumption and Green House Gas (GHG) emissions, compared to its competitors, are one of the main drivers for reducing the carbon footprint of the transport sector. A UIC study on HSR in France and China concluded that the carbon footprint of HSR can be up to 14 times less carbon intensive than car travel and up to 15 times less than aviation travel, even when measured over the full life cycles of planning, construction and operation of the different transport modes.

As a result, shifting passengers to high speed rail from air and road transport reduces CO₂ emissions. Expectations of a modal shift to rail regarding the corresponding CO₂ reductions have been proven by experience across a very large number of corridors.

In Europe, the Transport White Paper stipulates that most medium-distance passenger traffic should be carried by rail by 2050.

Improve

Since 1964, HSR has constantly introduced improvements and innovations aimed at reducing high speed rail externalities: vibrations, noise, CO₂ emissions, etc. Much has also been done to recycle infrastructure and rolling stock components. Energy efficiency is at the heart of the problem. **Numerous measures have been taken to**:

- ► build lighter vehicles;
- ▶ streamline trains;
- increase on-board seat capacity;
- ► use more efficient engines;
- introduce energy regenerative systems;
- increase the share of renewable energies;

 improve all ancillary systems such as air conditioning or lighting;

etc.

Paradoxically, the energy consumption per passenger of high speed trains is usually lower than that of conventional trains running between the same stations, according to several parameters such as a more homogeneous speed profile.

Carbon balance of a high speed line

High speed projects are usually appraised by means of two important balances : economic and environmental.

The environmental balance spans the life cycle of the infrastructure from the very first design to final recycling of its components, through the construction and operation periods.

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, the stations and the rolling stock, including the emissions for extracting and shaping materials (e.g. steel or cement), and for their transport (e.g. moving the earth or transporting the rails);

- operating trains and stations;
- maintaining the infrastructure and the rolling stock;
- distributing tickets;

recycling the components of the infrastructure and the rolling stock.

For a 300 kilometers HSL :

CO₂ emmission for the construction

THOUSAND TONS 500 450 400 350 300 250 200 150 100 50 n Lord bollos tran and and road equip ud distrib iestoui 10 strut Cumulated CO₂ emmissions THOUSAND TONS 1500 1000 500



Calculation of the CO2 emissions for a high speed project



It is clear that all these emissions lead to a substantial footprint spread along the life of the project (from 50 to 100 years), but this is strongly concentrated at the beginning of the period due to the impact of construction. In the case of a 300-km long HS line (such as the Oceane Line in France), the CO2 emissions amount to 1.5 million tonnes.

However, these emissions are offset during the revenue period because of the CO2 savings due to the traffic shift from road (50 000 tonnes per year) and air (80 000 tonnes per year) to rail. This means that the carbon balance, which is heavily negative at the end of the construction period, improves year on year of operation. In the previous example, the carbon emission break-even (carbon neutrality) will be achieved in 2029, i.e. 12 years after the line was commissioned.

Therefore, a high speed line project is only environmentally feasible if there is a strong certainty that the traffic diversion volumes will be significant. This is even more important where there are predictions of changes to the technology of all transport modes, such as cars, and even aeroplanes, powered by electricity.

Protection of the environment during the design and construction phases

A second study evaluates when and in what proportions the project contributes to the protection of the environment and in particular, the climate. As most of the CO₂ emissions relating to a high speed line are released during the construction of the infrastructure, new methods are now employed to reduce the corresponding carbon footprint of railway infrastructure. When different technical solutions can be envisaged for earthworks or engineering works (bridges and tunnels), the decision-making process now takes the volume of GHG emissions into consideration.

One typical example of the reduction of greenhouse gas emissions is the laying of an asphalt concrete finishing layer. This innovative solution has already been used in the design and the construction of the railway platform. It consists of replacing the conventional solution of a foundation layer of "as dug" gravel (GNT) with a solution that includes a road base asphalt (GB). Not only is the environmental balance better than with the previous thick layer of materials, but durability is also improved. In addition, this asphalt layer makes it possible to reduce the thickness of the ballast beneath the rail.

This also applies to the environmental optimisation of the components of the rail platform and superstructure.





Combining carbon offset and modal shift on the California high speed line

A carbon-free project has been designed on the new high speed line in California. The project will intrinsically emit 170 000 CO₂ tonnes of GHG. However, these emissions will be offset by 520 000 tonnes due to a commitment to plant 4 600 trees and to grant \$20 million for the replacement of old school buses.

In addition, modal shift will help reduce the carbon footprint of the corridor, as planes produce 57 times and cars 43 times more GHG pollution than high speed trains.

The calculations of the California High-Speed Rail Authority show that when all the carbon corrective measures envisaged so far are considered, the high speed line will be globally carbon positive.

A good example of friendship between HSR and environment

Some HSR infrastructure and services produce and consume their own renewable energy. An innovative example is the Schoten Rail Tunnel in Belgium, primarily designed for the protection of wildlife in a forest area and to reduce noise from the rail and highway. Here, the infrastructure manager Infrabel has installed 16 000 solar panels on the roof of the railway tunnel of the high speed Antwerp-Amsterdam, line. This covers a total length of 3.4 km and an overall surface area of 50 000 m² (approximately 8 football pitches), has a total installed power of nearly 4 MW, and generates 3.3 GWh of electricity each year.

The energy is used to provide both power to fixed infrastructure (e.g. railway stations, lighting, heating and signalling) and traction to trains. The electricity produced by the solar panels powers about 4 000 trains per year. This means that the equivalent of a full day's worth of Belgian rail traffic is able to run entirely on solar power generated by the equipment.



Renewable energy in high speed rail operation

HSR, as a 100% electrified system, is compatible with renewable energy without the need for further technological improvements. Nowadays, HSR is the only transport mode to consume significant proportions of renewable energy in the intercity and long-distance transport market.

Decarbonised electricity mix is the main driver of reducing CO₂ emissions: the higher the percentage of electricity from renewable sources used for traction, the lower the CO₂ emissions.

One of the advantages of being electrically powered is that, unlike other transport modes, high speed undertakings can easily utilise the main forms of renewable energy (such as on-site renewable power plants) or can purchase Green Certificates through the procurement of Renewable Energy Certificates (GO or REC – market tools defined by European Directives to promote investment in green energy power plants).

In this context, some rail companies have recently initiated "green electricity" procurement as they aim to increase their share of renewable electricity. For example, in Scandinavia, Switzerland and Austria there are entire rail networks which run on electricity that is completely carbon free. Similarly, the Dutch railways have signed a contract to purchase all their energy requirements from newly built renewable energy sources.





Environmental information

Many high speed operators provide environmental information on their website and tickets. In Italy, FS Trenitalia provides a comparison of average CO₂ emissions for the same journey by train, car and aeroplane on its long-distance tickets.

The UIC EcoPassenger website provides potential travellers with an environmental footprint calculation for international rail journeys throughout Europe (www.ecopassenger.org). It compares the main competing modes (aeroplane and car) and demonstrates the advantages of rail when it comes to minimising CO₂ emissions.

Equivalent consumption and CO2 emission for a 600 km trip



CARBON DIOXIDE EMISSION

Average external cost (€ per 1,000 passengers*km)



KEYS minimum



CAR

HIGH SPEED RAIL AND TERRITORY MANAGEMENT

Much has been said on the subject of HSR and territory management, but the logic of their relationship is rarely explained. Failure to understand this relationship may lead to overestimating or underestimating the real effects of HSR on the served territory.

Going fast means saving time. What do people do with this saved time? Surveys have shown that the time gained is generally spent in travelling more. Scrutiny at the sources of HSR traffic regularly shows that, for typical HS lines, new rail traffic is made up of three main parts: shifts from road, shifts from air and induced traffic. Induced traffic corresponds to people who would not have travelled or would have travelled less frequently if the HS line had not been created. In other words, induced traffic comes from an increase in mobility. The two pie charts below show that the volume of new traffic depends on the travel time saved and illustrate the respective shares for road and air diversions and induced traffic. They also show that induced traffic is often the main source of new traffic.

The increase in mobility means that people find it advantageous to travel more along the corridor served by the HS line. Why is there more travel along the corridor ?

Several factors explain this behavioural change :

- access to a wider employment area,
- benefiting more often from a natural zone or a touristic zone,
- more frequent visits to family members and friends.

These advantages may cause people to move into the corresponding corridor. Similarly, companies may consider transferring some of their activities towards the corridor or establishing new production locations in the corridor to benefit from the employment basin. Regions and cities, as well as hotels and holiday resorts, may also try to attract tourists and clients by investing in the corridor, as the flows of people are greater.

So, the logical relationship between speed and territory evolution is a consequence of the mobility increase which is itself a consequence of the time saved by the speed.



Rail travel time reduced from 4h to 3h

Rail travel time reduced from 4h to 2h



A very explicit representation of the territory shrinking due to faster travel is given by anamorphous maps. Such maps have been drawn for France for 1980, the year before the first HS line between Paris and Lyon was commissioned, and 2018, after 2 700 km of HS lines have been commissioned. They show that the physical geography of the country and its travelling geography do not coincide. The physical map is implicitly based on the assumption that the time spent to travel x km from any point in any direction is always the same. The anamorphous maps reduce the distance between points if the travelling speed is higher and reciprocally increase the distance between points if the travelling speed is slow. One lesson to be drawn from such maps is that it is easier and quicker to travel through regions benefiting from HS corridors than it is to travel through non-equipped regions. Naturally, the latter are unhappy with their situation and put a lot of pressure on the national government for HS investment in their area. This is probably the main reason for the progressive extension of the HS network north and south, west and east, once a country has built its first successful HS line. The Japanese, Spanish and Chinese examples all support this theory.

Anamorphosis map of France and China

KEYS

- 1980 - 2018 ______

An anamorphous map shows how a territory changes when distances are replaced by travel times. If the global shape remains the same, as if through an homothetic transformation had been made, it means that every part of the country draws the same benefit from the new network. If some parts of the map shrink while others remain constant, it means that the network effects do not have the same impact on the various areas. Here, we can see that having built a grid of high speed lines China has preserved its relative geography whereas in France the West- Southern end of country is still missing high speed infrastructures.





Spain Development

KEYS www.www.www.

- CAPITAL
- HIGH SPEED LINES ≥ 250 KM/H
- HIGH SPEED LINES < 220 KM/H
- PLANNED & LONG TERM PLANNING HIGH SPEED LINES









Japan Development

KEYS www.www.

- CAPITAL
- HIGH SPEED LINES ≥ 250 KM/H
- HIGH SPEED LINES 220 KM/H TO 249 KM/H
- HIGH SPEED LINES < 220 KM/H
- UNDER CONSTRUCTION HIGH SPEED LINES
- PLANNED & LONG TERM PLANNING HIGH SPEED LINES







Of course, the territorial impact is most visible around stations served by HS trains. There are multiple examples of huge changes in districts around stations, as the increase in traffic requires the adaptation of the station and its surroundings.

In many cases, the territorial impact is planned well in advance to ensure it is maximised, as in China-Taiwan (where huge areas have been reserved around new stations for real estate development) and in Birmingham, waiting for HS2.

The most spectacular case comes from China where new cities are planned to emerge from scratch around new HS stations.



HIGH SPEED STATIONS



Strategic location of stations

The location of high speed stations is strategic for the success of the system because travellers like to optimise their doorto-door trip. Environmentally and economically, a high speed line only makes sense with very high traffic volumes (to offset the GHG emissions and the initial financial investment for the construction) and few intermediate stops to provide fast trips to customers. As a result, high speed stations are necessarily few and in general, relatively infrequent. Consequently, it is not possible for most passengers to walk to these stations and their location must be optimised to take advantage of urban and regional complementarity and to enable convenient access for cars and buses. Stations may also be well connected to airports. In other words, the accessibility of stations is key. In view of this, most high speed stations are constructed in city centres or consist of old stations that have been revamped and adapted for high speed traffic. As access and egress times form part of the door-to-door trip, these need to be reduced to a minimum. Sometimes, in very large urban areas, it can be worth having more than one station.

High speed lines are normally implemented on heavy passenger traffic corridors where high speed trains are not only competing against other public transport modes (air and buses) and private cars, but also against car-pooling or car-sharing schemes, which provide a combination of private and public transport. The following graphs portray the different doorto-door timings for a passenger using the different transport modes for a typical trip from one town A to another town B, about 250/400 km far away. They include access (from the origin of the trip to the main means of transport) and egress (from the arrival point of the main means of transport to the ultimate destination). These examples highlight the significance of access and egress for high speed rail and consequently the importance of the location of stations.

Example of door-to-door travel



KEYS www.www.www.

WITHOUT HSL

WITH HSL



Strategic governance of stations

Stations are the intersection point for four major groups of actors :

► Local governments for whom the station is an emblematic totem in the city with many interfaces with 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 sees the station simply as a nodal point;

► The railway undertakings (train operators) who take care that passengers can easily access their trains;

► The customers and the general public who want to find out all the required information and seek an easy way through the station, whatever their reason for being there. The following graph show the intricacies of the relationships between these actors. The station governance plays a crucial role in organising and managing the function of all these actors, including high speed rail operators who share the station with all the other actors and have to fulfil their own specific needs and constraints to successfully attract long-distance travellers.

High speed rail stations - Relationships between station's stakeholders



Strategic location of stations

Infrastructure managers, or station managers, and cities have followed several strategies for the locations of large stations.

In most cases, there is one large through station in the city centre and all urban and regional transports means are spread around the station star-style, or they go from north to south or from west to east, serving the station in the middle of the line.

In very large cities, there are sometimes several large deadend stations that are very well served by the urban and regional network. In this situation, each station is oriented toward one or two points of the compass. In such situations, although the city is equipped with two or more stations, customers are only interested in one of them at any time : the station which serves the destination chosen for each particular trip. For example, passengers wanting to go north will necessarily go to the Northern station because there are no high speed trains heading north from the Southern station. This example shows that having several stations in the city does not actually help with station access as, from the traveller's point of view, there is essentially only one station in the city. Two strategies have been developed to improve this situation of providing customers with just one access point to catch a high speed train heading towards a given destination.



The first one consists of transforming the two dead-end stations of the city into through stations by linking them, usually by means of a tunnel. Madrid is a typical illustration of this principle and this gives customers arriving on high speeds trains from the south the option to alight in either Attocha or Chamartin, depending on their final destination. Antwerp provides another good example of a main dead-end station that has been transformed into a through station to provide access in the opposite direction.

Paris and Seoul have followed the second strategy, according to which new stations are located in areas poorly served by railway. In the French capital, three high speed stations have been created on a rail ring around the eastern end of the capital.

Seoul has chosen to bore a very long tunnel giving access to a new dead-end station.



High speed rail nodes

aină KEYS ● Depot ■ IN OPERATION

UNDER CONSTRUCTION PLANNED

Station capacity

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High speed rail only makes sense if it increases traffic volumes. Consequently, high speed stations are expected to handle high traffic flows. "Flow" must be understood to cover trains of all categories, customers, private cars, taxis and local public transport modes. In addition, stations and their nearby surroundings provide the location for railway operators to carry out technical operations, such as replacing crews, cleaning and inspecting trains, water refilling, turning around seats, refurbishing catering, etc. Furthermore, commercial operation in stations requires space in the station for information, ticketing, vending, and in some cases, access control, post-travel services, etc.





Strategic value of stations

The station is the place where passenger flows, commercial activity and industrial operation are simultaneously dealt with, while preserving the fundamental values of the railway (environment, energy, safety, security, civil protection, etc.) As high speed stations are generally located in city centres where land is scarce and expensive, planning what, where, why and who is to perform these operations is an essential input for the functional design, productivity and asset management of high speed rail. Where possible, moving commercial or industrial rail activities out of major terminals and city centres into places where land is less expensive may prove a good economic and land use policy, as well as optimising the quality of operation and service.

UIC has benchmarked 32 major stations in various countries around the world, comprising a mixture of through and dead-end stations, of new and old ones, and of those fully dedicated to high speed and those shared by many different kinds of traffic.


When a station is exceptionally well located within the city with all transport modes converging to it, it gains strategic value on a number of levels :

- The station is an ideal place for retail shops, restaurants, hotels and leisure conveniences (cinemas, theatres, etc.), as the value of a flow of persons is proportional to the volume of this flow;
 - The station can take advantage of the coincidental presence of several energy producers and consumers (for example, using the braking energy of trains to power electric cars);
 - Medical businesses grouping together different health domains can benefit from the context provided by the station in order to achieve the critical mass needed for their economic justification;
 - In view of the digital revolution and as more and more people work remotely, the station is the best place for co-working offices;
 - etc.



Intermodality in HSR stations

Number of HS / total number of stations



HIGH SPEED STATIONS

Modal coordination

All the main high speed stations benchmarked are located at the very epicentre of a metro or light rail network and benefit from very efficient feeding and spreading of their long-distance passengers. Most often the access to the metro network is within the station and all facilities are provided (escalators, for example) to make the transfer between high speed trains and metros as easy and as fast as possible, particularly for people carrying or wheeling luggage, with children, etc.

The same principles apply for taxi ranks and car rentals. For the former, the unloading zone and the loading zone are usually distinct, in order to ensure greater proximity to the station's high speed arrival and departure platforms. For the latter, car parks can even be located within the station, as in Beijing South station, which is optimally linked to the road network.

In some stations, car-pooling meeting points are now being created as this transport mode plays a similar role to taxis and car rental agencies.

It is worth noting that in many large stations great care is taken to encourage soft mobility, particularly bicycles. Parking areas dedicated to bicycles are strategically and conveniently placed. Rail-air complementary is also very much sought after because large stations and airports fulfil the same hub function. Superposing two such hubs is beneficial for both transport modes. Sometimes air companies will even "fly" trains instead of aeroplanes when a high speed line is linked to the airport. Frankfurt is a crowning example of this kind of modal complementarity.





Architecture and urbanism

High speed stations can be used to promote a high level of architecture. Very new high speed stations are architectural marvels. There was a period when nobody could see a future for rail travel, because people wanted to own their own cars or travel much faster by aeroplane. This trend was typical of the WW2 post-war period and railway stations consequently became far less important for people. Now, however, while airports are still totemic places for large urban areas, the car has to some extent lost its appeal, as people are more conscious of the environmental damage it causes. At the same time, rail travel has evolved to produce high speed trains, and stations are becoming legitimately more spectacular. One of the great disadvantages of having a railway station in a city is that the tracks divide the city into two separate parts that can be difficult to adequately link. High speed rail often provides the ideal occasion to overcome this separation by creating an underpass or overpass, thus eliminating the isolation of some districts. Such urban operations are rarely limited to this "joining" function. In most cases, the modification of the station becomes the stimulus for a deep real estate and renovation development plan. New housing areas, offices, retail shops and public conveniences emerge around the restructured and revamped station, largely beyond the station perimeter.

Station and services

Stations are not only for passengers. They also play host to plenty of other people, who pop in to buy something, or 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 achieve their goal with ease. People are increasingly using the GPS on their smartphones to direct themselves in the streets and in public buildings, and stations naturally need to provide WiFi to help people access guidance apps, information and the Internet.

High speed services need to take advantage of the WiFi and facilities provided by a good station, because access to the web is no longer seen as an extra but as a given. Customers are at a loss when they are deprived of access to the virtual world. They consider the station to be an extension of their home in terms of virtual navigation and even when boarding a high speed train, they resent any disruption to the connection with their service provider. For modern customers, trains are no different to the street, their home or their office – but on the move.

So, stations have to be connected and ensure connectivity. Incidentally, this connectivity is increasingly useful for disabled people as it enables ac cess to all the apps that can assist them. Similarly, trains and stations must provide customers with sockets so they can plug in their devices. More broadly speaking, the entire railway system should aim to offer customers autonomy. As you are never better served than by yourself, the best service the railway system can offer is to help customers be autonomous.



INFRASTRUCTURE

The six key stages for implementing a high speed line

1 - The emerging phase, during which existing and potential traffic is ascertained, determines the main project characteristics and functionalities to achieve the performances to be used as assumptions for the transportation development master plan and the travel demand estimation. A pre-feasibility study is carried out, including traffic forecasts, with an overall consideration of the socio-economic characteristics, the status quo of the transport network, current supply and demand of all transport modes, etc. The preferred corridor is determined through technical and economic comparisons, and initial cost estimates are made.

2 - During the feasibility phase, detailed research on the project plan is conducted considering the emerging phase. This phase is divided into six sub-stages: feasibility studies, environmental assessment, financial and economic analysis, multi-criteria analysis, preliminary design, and empowerment. Its target is to provide robust support for the decision process.

3 - The design phase builds on the feasibility phase and supports the construction phase. It is divided into two parts: operation and maintenance planning, and detailed design.

4 - The construction phase turns the HSR project into reality. This phase is divided into three steps: construction planning, construction, and testing and commissioning (including authorisation).

5 - The operation phase refers to the period during which lines open up to traffic and begin passenger transport after the completion of acceptance tests and upon the receipt of operation certificate. Operation and maintenance are the main priorities during this phase.

6 - The project ex-post evaluation is generally carried out during the first operating decade.



Construction of a high speed line

Most high speed lines are built within five to six years of taking possession of the required land, so long as tunnels and viaducts are not numerousor long.

Before construction beings, several administrative procedures are compulsory, though these vary from one country to another. **However, there are key stages that cannot be avoided whatever the context :**

Public enquiry aiming at checking that there is an appropriate balance between the public interest and private interests.

Environmental assessment stating the environmental situation before the project and providing the list of environmental measures to be performed.

Administrative enquiry focusing on the compatibility of the project with other public projects.

Institutional and financial scheme to determine who will be the project owner and how the project will be financed, followed by a financial closing.

► Introduction of the project in official documents and procedures such as treaties (or, if the project crosses a border, National Act) permitting and setting the conditions for the works.

Most of the superstructure equipment is stocked at base stations and hauled to the platform by train once the track is laid. These construction bases need to be strategically located to reduce the travel time of the various trains responsible for the work along the line. Such work bases are frequently retained after the line is commissioned and serve as maintenance bases.

Infrastructure - Construction planning



Typical railway work and maintenance site



Typical geometric characteristics for high speed lines

Maximum gradient (depending on geographic characteristic and operating conditions)	Passenger traffic only: up to 35/40 mm/m (with suitable rolling stock) Mixed freight and passenger traffic: up to 12/15mm/m	
Minimum curve radius	Ideal: 200 km/h: 2500 m 300 km/h : 5500 m	Recommended: 200 km/h: 3500 m 300 km/h : 7000 m
Track centre distance	200 km/h: 4 m 300/h: 4.5/5m	
Maximum cant	150/170 mm	

One of the most important innovation brought into the rail system by high speed rail are switches that allow trains to deviate from their current direction at 220 km/h (previously 160 km/h), thanks to movable crossing noses.

Dedicated versus mixed-traffic high speed lines

One of the major strategic choices to make when implementing a high speed line project is whether the infrastructure will be dedicated solely to long-distance passenger traffic or open to passenger and freight traffic (mixed traffic). In the first case, the power of the trainset allows for steep gradients of up to 4%, as on the Köln HS line. In the second case, the geometric characteristics of the line are driven by freight train capabilities and the permitted gradients are much lower, entailing more or longer tunnels and viaducts, i.e. the infrastructure will be more expensive.



HSL Köln - Rhein/Main (2002) : Passenger trains only 300 km/h



An alternative track technology

When it comes to rail track, technological progress has been intense for decades. Ballasted track has largely improved its efficiency, in particular by improving the selection of ballast quality and the method of laying it along the track. At the same time, ballastless solutions have appeared whereby the track is laid directly onto concrete slabs. Both solutions are now commonly used worldwide as they each provide the same level of performance for operation.



Ballasted track :

Pros :

- Less costly in investment terms
- Good track elasticity
- Long-term experience proven

Cons:

- Permanent maintenance of the track geometry
- Periodic renewal of ballast
- ► Gradient limited to 3,5%

Slab track :

Pros:

- Almost no maintenance
- Better availability
- ► Gradient up to 4%

Cons :

- Noisier
- Costlier in investment terms

As track in tunnels (and other engineering works) is often laid on concrete slab, the transition between ballasted and slab track segments must be smoothed out. Such transitions are usually achieved by building a block to provide a gradient of ground elasticity at each border between the ballast and the concrete slab. If the line encompasses a very large number of such borders, it is better to select the slab track method.

Monitoring and maintenance of fixed installations

The safety of operation largely depends on the maintenance of the fixed installations and particularly of the track and the electrification system. With this in mind, special trains, able to record the current parameters of the track and the catenary while running on high speed lines, have been designed, built and are in operation. As capacity is key, these comprehensive inspection trains are sometimes able to do their measuring and recording at the same speed as commercial trains. With the IRIS trainset able to run at 320 km/h, France has pioneered this process and is now being followed by other countries, especially China (CIT 400A). Essentially, these trainsets, based on the original commercial designs, are equipped with special devices to monitor the condition of the track, the wheel-rail force, the catenary, the pantograph, the communication system and the signalling system. They may also have cabins for staff who remain on board for several days or weeks. These trains are also sometimes used for speed tests. All the recorded measurements are transmitted to the corresponding departments and teams to help with planning maintenance works.







ROLLING STOCK

Typology of high speed trainsets

Articulated or non-articulated trains

On articulated trains, most of the bogies are between the carriages, whereas on non-articulated trains each carriage has two bogies.

► Trains with bogies or isolated wheels

Some trains are articulated with independent wheels which are not linked by an axle and therefore do not run at the same speed in curves.

Concentrated or distributed power

Concentrated power means that all the motors are located at each end of the train, whereas with distributed power, motors are spread all along the train.

Tilting or non-tilting

A tilting train is equipped with a mechanism enabling increased speed through curves by counteracting the discomfort due to centrifugal forces. Through a left-hand curve, the train tilts to the left to compensate for the force pushing to the right, and vice versa. The train may either be constructed so that inertial forces cause the tilting (passive tilt) or it may have a computer-controlled power mechanism (active tilt).

Single or multiple gauges

A multi-gauge train can change the width between the wheels on each axle.

Single or double decker

Double-decker trains provide approximately 50% more seating capacity than a single-decker train.

Mono or multiple electric current

Most high speed trainsets are multi-voltage and/or multi-current in order to run on all sections of a network.

Mono or multiple signalling

Most high speed trainsets can read several signalling systems in order to be interoperable.

Dual-power trains (electric and diesel engines)

Some high speed trains are both electric and diesel powered.









Common characteristics of high speed trains

- ► Self propelled
- ► Fixed composition and bi-directional
- High level of technology
- ▶ Limited axle load (11 to 17 tonnes for 300 km/h)
- ▶ High traction power (approx. 11 to 24 kW per tonne)
- ▶ Power electronic equipment: GTO, IGBT
- ► Control circuits. Computer network. Automatic diagnostic system
- Optimised aerodynamic shape
- ► In-cab signalling systems
- Complementary braking systems
- Improved commercial performance
- High level of RAMS (Reliability, Availability, Maintainability and Safety)
- Airtight structure (sometimes)
- Technical and safety requirements (compliance with standards)
- Compatibility with infrastructure (track gauge, loading gauge, platforms, catenary, etc.)

Rolling stock manufacturers

There are not many rolling stock manufacturers producing trainsets that can run at 300 km/h or more.

Hitachi is the main manufacturer in Japan and bought Ansaldo-Breda in 2015. Mitsubishi supplies the electrical components.

Other manufacturers are Alstom Bombardier, Caf, CRRC, Kawasaki, Mitsubishi, Rotem, Siemens and Talgo.



Manufacturers

Interoperability

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As it is very costly to change fixed installations, such as the width of the track, the electrification mode (voltage or type of current) or the signalling system, rail interoperability is mainly obtained using rolling stock. The most interesting or spectacular solutions include:

► Talgo trains are able to change gauge and therefore run on both standard gauge high speed lines and conventional lines with Spanish gauge

► Cross-border Thalys trains can be powered by four different currents: 25 kV AC -50 Hz; 15 kV AC- 16 2/3 Hz; 3 000 V DC; or 1 500 V DC, and are fitted with European Train Control System Level 2 signalling equipment, French TVM430 and KVB, German LZB, and Belgium TBL2.

Today, Technical Specifications for Interoperability (TSI) are compulsory in Europe for both infrastructure and rolling stock. Elsewhere, norms also apply. For historical and understandable reasons, these sets of norms differ from one region to another in the world but they are beginning to converge as the international industrial rail market becomes more and more competitive.





Rail gauges



ROLLING STOCK

Rolling stock maintenance

There are roughly three models for the maintenance of high speed rolling stock :

1 – Maintenance is ensured by the manufacturer. A good example is provided by NTV (Italy), who have entrusted the maintenance of the AGV trainset to Alstom, the manufacturer



2 – Maintenance is ensured by the railway undertaking.This is the most common model in both Asia and Europe.



3 – Maintenance is carried out in workshops bringing together the manufacturer and the train operator. This model has been experienced by RENFE in Spain, who have bought rolling stock from various manufacturers.



Whatever the selected model, maintenance is generally organized as a 4 to 5-level process. These levels of maintenance are planned to fit with both the commercial schedule of the train and the life cycle of the rolling stock. The life cycle varies from 20 to 40 years ac cording to the operators. Some operators wih to replace the trainsets after 20 year to fit better with the technological progress and the customers's uses or requests. Other operators try to make the most with their investment but ac cepting a quite expensive overhaul and adaptation after 20 year's operations.

In Japan, for example, JR East, one of a high-speed railway companies operating about 1500 km of lines and 1350 cars for "Shinkansen".

JR East is not only a train operator but also the design authority of their trains, since they design and develop, and they also maintain their wtrains by themselves through a 4-level process :

Level 1 (Daily inspection) : Replenishing and replacing consumables such as oil and externally inspecting the state of pantographs, brakes and other parts and their performances. This will be done within 48 hours.

LEVEL 2 (MONTHLY INSPECTION) : Conduction in-situ inspection of pantographs, brakes and electric equipment, their workings and functions. This will be done within 30 days or 30,000 km.

LEVEL 3 (BOGIE OVERHAUL) : Inspecting major parts such as motors, gears, wheels and brakes. This will be done within 18 months or 600,000 km.

LEVEL 4 (GENERAL OVERHAUL) : Train cars are meticulously inspected by disassembling each of their parts and reassembling them to conditions identical to brand-new cars. This is completed in 36 months or 1,200,000 km.

The rolling stock fleet

One of the specific features of high speed rail trains is that, unlike conventional trains which have a variable number of carriages pulled by a locomotive, the trainsets cannot be changed during operation.

While building their high speed networks, rail operators have had to acquire appropriate rolling stock fleets. More specifically, the infrastructure and the rolling stock have been designed to complement one another in order to optimise their interfaces.

Two options have been considered in this perspective: either to create and manufacture the rolling stock or to buy it from abroad. Japan, France, Germany and Italy chose the first option because they already had a manufacturing company able to design and build the required trainsets. Spain, Turkey, South Korea and China started by importing trainsets from abroad before setting up the industrial tools and factories to engineer and construct their own rolling stock.



Split by country of the world Rolling stock fleet (2017)



OPERATIONS

Optimum speed

A constant feature in the world of transport is the desire of passengers to arrive earlier (in accordance with the idea of the increased value of time). From the point of view of operators, going faster and faster means being more competitive and sometimes more productive.

This process of ever increasing speed eventually leads, in each transport mode, to a stabilisation at a permanent or long-term maximum speed level – at least until a trend-breaking technological leap forward occurs. The level around which the speed stabilises for all operators is the optimum speed for each transport mode.

For several reasons, all long-distance passenger transport modes have maximum operating speeds stabilised over years that correspond to the optimum speed of each system (120 km/h for roads and around 900 km/h for aviation). However, railway proves the exception as the maximum operating speed is continuing to increase as technological improvements arise. The maximum operating speed for high speed rail has increased steadily since the 1960s and continues to increase today. While the "the optimum speed of the system" has not yet been reached, some limits have been imposed by physical phenomena, technological barriers or social criteria. Expert opinion and analysis of the various phenomena surrounding train operation at increasing speeds indicate that the main factors limiting speed increases relate to aerodynamics, the associated noise component, and the electric contact with the catenary.

Factors relating to line geometry requirements, rolling stock restrictions, the growing need for acoustic attenuation measures and aerodynamic phenomena, point to the optimum speed in the high speed system as ultimately being in the 500-550 km/h range. This optimum speed is close to the record speeds achieved to date by the two main railway technologies – wheel-rail running and magnetic levitation – which have reached 570 km/h and 603 km/h respectively.



Speed record and commercial speed

Physical operation facts and figures

Operating at 300 km/h: 1 km is run in 12 s and 5 km in 1 min

Headway: 5 minutes between 2 trains running at 300 km/h means the distance separating them is 25 km. This distance is reduced to 4 km with a 4-minute headway.

Distance to accelerate from 0 to 300 km/h : between 10 and 20 km





Capacity optimisation of high speed lines

As it is very expensive to build high speed lines, the optimisation of their use is of the utmost importance. The capacity of the infrastructure depends heavily on the signalling and traffic management system and the corresponding distance or time between two consecutive trains (headway). At very high speeds (greater than 250 km/h), a headway of about 4 minutes is a good approximation of the highest capacity performances. This is equivalent to a maximum of 15/16 trains per hour and per direction on a 2-track line. However, this level of capacity cannot be maintained for long periods because it would make it impossible to recover from any incident. As a result, the practical average capacity is fewer than 15 trains per hour and direction.

The heaviest traffic density on high speed lines in the world is found between Tokyo and Osaka (Japan) and between Paris and Lyon (France).

The maximum flow of trains is obtained when all trains operate under the same conditions, at the same speed and with the same stopping pattern. When this homogeneity is not fulfilled, operators are forced to compromise between speed and the stability of operation (i.e. facility to recover the transport plan after an incident) and between the number of trains and the diversity of their speeds. Operational studies and research have shown that the perimeter of the quadrangle pointing toward these four indicators is constant,



meaning that pushing in one direction (higher speeds for example) will affect the other three dimensions.

As the maximum speed when a train deviates at a turnout is 220 km/h, any bifurcation on a high speed line causes deceleration of the train. Similarly, any intermediate stop of a train along a high speed line reduces the line capacity because the stopping train needs to decelerate to deviate towards the station platform and, after the stop, to accelerate to reach normal cruising speed. In both cases (bifurcation and intermediate stop), the line capacity is reduced. This is the reason why there are fewer stations along a high speed line than along a conventional line.



HIGH-SPEED DEDICATED LINE
HIGH-SPEED MIXED TRAFFIC LINE

The reasons above explain why most mixed-traffic high speed lines do not ultimately mix the different categories of traffic, even if they have been designed for this purpose. More often, passenger traffic runs during the day and freight traffic runs at night, thus operating the traffic types separately.

UIC is benchmarking such mixed-traffic lines after having identified them :

- France: Tours bypass + Nîmes & Montpellier bypass
 +Montpellier
- Germany: Hanover-Würzburg + Frankfurt-Mannheim
- ► Italy: Direttissima Roma-Firenze
- Portugal: Lisbon-Porto
- Spain: Bask Y + Mediterranean Corridor
- ► The Netherlands: Betuwe line
- ► UK: HS1
- USA: North-East corridor
- ► France/Italy: Lyon-Turin
- ► France/Spain: Perpignan-Figueras
- ► France/UK: Eurotunnel
- Switzerland: Gotthard tunnel

Just to give some examples, on HS1, between the Channel Tunnel and London in the UK, no freight trains run during daytime. In Germany, on the Hanover-Würzburg line, the situation is similar.

The situation of the North-East corridor in the USA is quite different. Part of the infrastructure belongs to freight operators who consider that passenger traffic, even carried by Acela trains, cannot hog "prime time" slots and consequently, on some sections of track, this is less frequent than other passenger and freight traffic.

It is worth noting that the first Shinkansen high speed line, operated in 1964, between Tokyo and Osaka, was planned long ago at a time when there were only conventional mixed-traffic lines. The main idea supporting the project was to build standard gauge infrastructure despite the fact that the existing network was narrow gauge. Standard gauge (width between rails of 1.435 m) was used to allow for mixed traffic, with freight trains carrying transversally loaded containers. This is the reason why the width between the tracks is broader than in Europe. It was only afterwards that, in view of the volume of passengers, it was decided to dedicate the line to Shinkansen high speed passenger trains. So the first stretch of the Shinkansen network was a mixed-traffic line, used as a passenger-dedicated line.





Traffic flows on North East Corridor





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Signalling and management systems

As a guided system, rail is well-suited for speed since the direction of the vehicle is controlled by the rails. The downside of this is that trains cannot avoid obstacles by swerving right of left, like a car, or by changing altitude, like an airplane. Therefore, the track in front of the train must be totally clear of any obstacle. The specific role of the signalling and management systems is to prevent collisions and/or accidents between trains or between a train and an obstacle. In principle, a train can proceed only when the track ahead is free of other trains/vehicles/obstacles over a distance equal to or longer than its braking distance.

On conventional lines, this role is currently undertaken by signalling posts spread along the side of the track. However, this solution does not suit high speed operation because drivers would not be able to see the signals in due time because of the speed. Instead, all the required information, once delivered by light signals, must be transmitted to the driver's cab by on-board command and signalling equipment.

In the past, almost every country operating high speed trains developed its own signalling and traffic control system.

Now some universal norms and standards are enforced, focusing on :

- Interoperability
- Safety
- Capacity
- Availability
- Cost-effectiveness
- Less on-board equipment
- Open market



Classical line

High Speed Line

In Europe, the following are now enforced and compulsory for all new infrastructure and rolling stock :

► TSI (Technical Specifications for Interoperability)

► ERTMS (European Rail Traffic Management System), a system encompassing

- ETCS (European Train Control System)
- GSM-R (Global System for Mobile Communications
- Railways)

ETCS currently operates at Levels 1 and 2. Level 3 (each train knows exactly where it is and can relay this information to other trains) is not yet in operation.

In Asia, Japan has the ATC (Automatic Train Control) and ATC Digital systems, China the CTCS (Chinese Train Control System), also in three levels, and South Korea ...



Furthermore, the optimisation of a whole line or even a whole network needs a control-command centre to supervise the traffic in real time. The mission of controlcommand centres is broad :

- Operational timetable
- Real-time calculation of difference between scheduled/ actual times
- ► Display as distance/time graph or station survey
- Automatic intrusion detection
- Computer-aided conflict resolution with dynamic train running time calculations
- Preventative measures
- ► Power supply control
- Passenger information
- Station equipment control
- ► Video security



As high speed rail is being spread worldwide, new operators are facing the start-up phase. In order to help them, a UIC handbook describes the various phases and procedures to fulfil before beginning operation.



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Operation under extreme natural conditions

A catalogue of difficult natural conditions has been established by UIC to identify the risks for train operation, bearing in mind that the higher the speed, the greater the potential damage.The following items correspond to the circumstances when train operations may require special attention:

- ► High temperatures
- ► Low temperatures, frost
- Snow
- Change of humidity, high humidity
- Strong crosswind
- ► Sand, dust
- Heavy rain
- ► Flood, tsunami
- ► Fallen rocks
- Seismic events
- Surrounding fires
- ► Fallen leaves

So far, strong crosswinds, floods and seismic events have been investigated through the exchange of best practices, and the other items are planned to be analysed over the next few years.

For each risk, the work programme consists of defining the risk by means of a measurable physical threshold, under or above which the risk is considered to occur. Then the various practices are compared to recommend actions and measures at the design, construction and operation phases. Where possible, the research goes further and endeavours to predict the occurrence of the event and to model its effects.











ECONOMICS OF HIGH SPEED RAIL

On a market, whatever its nature, economic sustainability is based on both the average production costs and the marginal cost. The average production costs should decrease as the producer invests to increase his productivity. The marginal cost is essential, as on a market the price is driven by the marginal cost of the last producer. For HSR, the passenger transport market also encompasses air carriers and the various types of car actors (private cars, car-pooling and car-sharing). The technology of both these transport modes is in a phase of rapid innovation, and new business models are emerging which have a significant effect on the average production costs and the marginal cost. So, in order to keep up with competition, HSR must work on both economic aspects.

High speed rail marginal cost

The marginal cost for high speed systems is mainly composed of:

 maintenance of the track and the electric distribution system,

- maintenance of the rolling stock,
- train running,
- energy consumption,
- on-board services and on-board ticket inspection (if any).

With the liberalisation of infrastructure and operation, the marginal cost of operators now encompasses track access charges. Therefore, the track access charges policy is vital when it comes to the appeal HSR appeal, which is why a special page in this brochure has been dedicated to it. At this stage, it is essential to remember the economic principle, according to which competition is fair only if the track access charges of each transport mode are adjusted for the social marginal cost.

High speed rail productivity

Rail is well known as an economic tool with a growing return. In other words, the railway system has many fixed costs and a low marginal cost. **High speed rail has inherited this economic feature and its productivity is driven by three main parameters :**

- ▶ the intensity of the infrastructure use,
- the distance run by a trainset in each time period,
- ▶ train capacity and the average load factor.

This is why building a high speed line only makes economic sense on corridors supported by a healthy market in order to justify the investment costs, high frequency services requiring the intensive use of rolling stock and a good reservation system backed by efficient yield management to optimise the load factor.

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Principles of socio-economic balance

The following table summarises the cost/benefit balance of a high speed line project. The items in bold are those which carry more significance. Broadly speaking, the bulk of the costs correspond to the investments made and the main benefits are derived from traffic diversions from air and road, but also from the traffic induced by the enhanced transport offer. The bigger the corresponding volumes, the higher the benefits and the better the balance as a whole.

	Costs	Benefits
Before commissioning	Design studies Administrative procedures Land acquisitions Construction of stations Construction of the infrastructure Tests and certification Maintenances facilities for the line Protection of the environment CO2 emissions for fixed installations Rolling cost purchase Construction of mainte- nance facilities CO2 emissions for construction of rolling stock and facilities Training of staff	Development of employ- ment (jobs created for the construction of the infrastructure) Development of employ- ment (jobs created for the manufacture of the rolling stock) Development of employ- ment (jobs created for operation)
After commissioning	Marketing and ticket distribution Energy Driving On-board services Maintenance of infrastructure Maintenance of rolling stock CO2 emissions for the operations	Better security of trans- port (value of human life) Reduction of costs of the other transport modes for traffic diversions Reduction of CO2 emissions of the other transport modes for traffic diversions Time saved by passengers Value of induced traffic
At the end of the period spannedby the balance	Costs and CO2 emissions for recycling the investments	Costs and CO2 emissions for recycling the other modes of trans- port for traffic diversions

Magnitude of costs of high speed systems :

Average costs in Europe

- ► Construction of 1 km of new high speed line: €15 40 million
- ▶ Maintenance of 1 km of new high speed line: €90 000 per year
- Cost of a high speed train (350 places): €30 35 million
- Maintenance of a high speed train: €1 million per year (on the basis of €2/km and an average of 500 000 km / train & year)

HIGH SPEED RAIL FINANCES

Financing sources

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As a principle, the socio-economic marginal cost of operations should be covered by the revenues from the traffic. If not, the rail mode is either running into debt or subsidised to a level which does not place transport competitors on an equal footing.

For the construction of an HS line, and the fixed costs of operations, there are only two financial sources:

- the taxpayer
- the passenger

The taxpayer may be a local, regional, national or even European taxpayer, or all of these at the same time.

Public ownership versus PPPs and concessions

It needs to be clearly stated: PPPs and concessions (BOMT or BOT) are not financing schemes, because the two main financial sources (taxpayer and passenger) are still the same as for public ownership.

The only differences concern:

The moment the taxpayer is mobilised, as private partners and concessionaires invest money at the beginning of the project but only do so in the expectation of being (at least) refunded;

The amount of money coming from the two identified financial sources (taxpayer and passenger) may be increased or reduced according to the success of the PPP or the concession, depending on good risk sharing and assessment. The definition of the passenger should be broad, as some people go into stations to buy things or services and do not travel, but nonetheless contribute to the station financing. This also applies to revenue from advertising in trains and stations. However, these revenue sources are much smaller and considered ancillary when compared to the ticket farebox.

Once it is clearly understood that there is no point looking for another financing source, the financing of any HS project is always a balance between the taxpayer and the passenger.

The higher the contribution of the taxpayer:

- ► the lower the fares,
- ▶ the greater the appeal of the HS line,
- ► the greater the traffic volume,
- and finally, the higher the socio-economic return for the community.

Concessions are rarely profitable. There are many examples of bankruptcies or huge economic difficulties, including the Eurotunnel, the Perpignan-Figueras line in Europe, and Taiwan HS Rail in Asia. The reason is that private partners and banks can only bear the commercial risk if there is a very high expectation of rate of return, something that cannot be achieved on the transport market compared to other markets.

PPPs are more suitable for HSR. In this context, the private partner usually takes on the risk of the construction costs and deadline and the risk of asset maintenance. Taking on these two risks is consistent, because private partners will optimise construction as they themselves will be responsible for the subsequent maintenance.

PPPs are justified only under two conditions :

► The PPP is chosen at the very beginning of the project (before the detailed design phase) so as to provide the private partner with enough leeway in the construction method to promote innovation and economics of scale;

► When the PPP is selected, the demand for civil works, on the national market, is quite low.

TRACK ACCESS CHARGES

Enforcing competition within a transport mode necessarily entails separating (unbundling) the infrastructure from operation.

Infrastructure is very expensive, disruptive and not profitable as a stand-alone business. Creating competition within the infrastructure sector would involve the creation of competing parallel infrastructure. Almost no market is large enough to justify doubling the routes between two cities. Exceptions to this rule are extremely rare, but it is worth noting that Tokyo-Osaka could be one of the few legitimate cases. As a result, the outcome of the unbundling is that infrastructure becomes a monopoly. In response, the relevant EU White Paper recommends that infrastructure managers should be regulated and that charges for the use of the capacity should be equal to the social marginal cost. This recommendation is aimed at enforcing fair competition between modes and preventing monopolism. However, if infrastructure managers only charge the marginal cost, subsidies will be required to cover the fixed costs and this may prove too great a burden on the taxpayer. Ultimately, EU regulations are in favour of track access charges that are equal to the marginal cost plus a mark-up, without exceeding the full cost.





Track access charges represent a source of revenue for infrastructure managers but an expense for railway undertakings. As this expenditure is linked to each train-km, it is part of the train operator's marginal cost. So, there is a direct link between the infrastructure manager's fare policy and the railway undertaking's appeal.

Knowing that track access charges are crucial for the appeal of high speed services, UIC has carried out a process to benchmark track access charges across Europe, including some reference to several non-European countries, such as South Korea and North America. This benchmark is very simple and consists of calculating the average charge per km for a high speed train accommodating 500 seats and running on the most important high speed lines during the same timeslot. This benchmarking process was conducted in 2005, 2007, 2012 and 2017.

The conclusions have not changed :

these charges;

There is no stability in the track access charge policy: the calculation rules are constantly changing. The accompanying map illustrates the modifications;
 The calculation formulas and the parameters used are very different from one country to another;
 There are huge difference between the level of

4. HSR infrastructure charges are quite expensive when compared to those of other transport modes.



System changes in Europe (2017)

Charges formulas in Europe (2016 - 2017)



It is worth remembering that in North America the rail network is mainly owned by freight companies, which have private contracts with passenger companies for long-distance trips (Amtrak). As a result, track access charges, as well as the rules according to which capacity is assigned to operators, are governed by these contracts.



Infrastructure Charges

A 777-200 flying from JFK to LHR (5700 km)

Item	Charge	
JFK Takeoff	4 216,51 €	
LHR Noise charge	2 503,06 €	
FIR London EGTT	830,76 €	
FIR Shanwick	815,59€	
Others	3 560,82 €	
Total	11 926,74 €	
Total per passenger	53,01€	

Panama Canal (Norvegian Pearl)

Charge	Amount	
Total tolls (138\$ per berth)	\$ 330 372	
Tug assistance	\$ 13 005	
Linehandlers	\$ 5 825	
Locomotive Wires	\$ 4 800	
Others	\$ 3 434	
Grand Total USD	\$ 357 436	
Total per passenger	\$ 149,30	

TGV Paris-Lyon (427 km)



Eurostar



Typical Road Tolls in Europe



€ per vehicle-km for class / vehicle

COMPREHENSIVE PROTECTION

Customers and business partners are confident in the way the railway is run and in what is being done to secure operation, hence the concept of "comprehensive protection" for high speed rail systems. This concept encompasses safety, security, civil defence and protection against natural risks. Even if there is no difference between the words in certain languages, "safety" and "security" represent two very different aspects. Safety is the protection against "technical" failures and is related to certain system components (signalling, electrical energy supply and distribution, operation, maintenance quality, training, etc.) and their interfaces. This protection is almost exclusively the responsibility of railway companies and is independent of any human desire (even when it comes to the most negligent behaviour, nobody wants a train to derail). Long-range established statistic time series have shown that safety risks are correctly managed, and consider rail transport to be "safe".

Safety in railways is a particularly hard quality to maintain because rail is a guided and low grip system. This means that a train cannot, by itself, deviate to avoid an obstacle. In addition, as it is a low grip system, the breaking distance is quite long. To overcome these two problems, every measure must be taken to eliminate obstacles on the track (HS lines are fenced to prevent intrusion, level crossings are replaced by overpasses or underpasses, etc.), and the signalling and train control system must be equipped so as to maintain a sufficient breaking distance between trains and to avoid the convergence of trains.

As safety is inherent in the railway system and depends solely on railway actors, the safety target is zero accidents and there is a strong obligation to achieve this.

In contrast, security is the protection against any kind of malevolent attack or incidents of malicious intent. It covers crimes ranging from graffiti, robbery and vandalism to terrorist attacks. Such acts are committed intentionally by people. As these acts are unpredictable, protection against them must be coordinated (or even directly undertaken) by authorities. The target is to minimise consequences by drawing lessons from previous attacks and adapting the relevant legislation. Security management must go beyond the most obvious scenarios and encompass a real understanding of the cultural, social and economic environment in which the railway network is implemented and operated. UIC has issued recommendations and actions aimed at improving railway security. Understandably, such documents cannot be made public, as there would be no sense in giving terrorists information on rail weaknesses or an idea of possible responses.

Safety, Availability and Maintainability, along with Security, compose what is commonly called RAMS. Availability and Maintainability are the responsibility of the rail management in charge of the renewal of assets, investment, the implementation of redundancies, the design of modular rolling stock, and operation. Failures in these domains do not normally result in victims but can cause delays. Railways are now asked to compensate their customers for any inconvenience caused and to help them in the event of difficult conditions, for example by providing water or coffee if required. A charter on passenger rights has been enforced in Europe and each railway company has to comply with it and even go beyond the minimum requirements.

To ensure civil defence and the resilience of railway systems, the role of the emergency services and crisis management staff is essential for the mitigation of any consequences. To complete the protection concepts outlined above, it is necessary to consider that rail transport is vulnerable in the face of natural disasters, extreme climate conditions and particular geographic situations. A significant proportion of high speed lines around the world are subject to strong weather conditions and the impact of these on railway systems and operation can be extensive. Advanced technologies allow some situations to be anticipated and can offer tools to eliminate, or simply limit, the risks posed by the environment. The protection implemented against earthquakes and tsunamis has proven very effective.

STANDARDS FOR HIGH SPEED RAIL SYSTEMS

High speed rail standards are aimed at improving the system integration of railway services and also contribute to the attainment of interoperability.

International Railway Solutions

International Railway Solutions (IRS) are structured in a General Part and in some Application Parts. The General Part is valid worldwide, while the Application Parts are valid for a specific railway application, based on a geographical or service implementation. Application Parts may thus be added according to the current needs of the Railway Operating Community. International Railway Standards are now available for:

- Implementation of a high speed railway Features and definition (IRS 70100)
- ► Implementation of a high speed railway Emerging phase (IRS 70101)
- Implementation of a high speed railway Feasibility phase (IRS 70102)
- Implementation of a high speed railway Design phase (IRS 70103)
- mplementation of a high speed railway Construction phase (IRS 70104)
- Implementation of a high speed railway Operations phase (IRS 70105)

UIC high speed clusters

The UIC high speed clusters are focused on coordinating sets of documents aimed at standardising the precompetitive items of a railway application. For a given railway application (high speed rail, for example), the clusters consider the required level of service, the boundary conditions, the expected functionalities and the KPIs. They help to compile sets of standards enabling immediately applicable solutions to be worked out on a competitive market.

In accordance with the European Technical Specifications for Interoperability (TSI), the HSR system is divided into five subsystems:

- ► Infrastructure
- Track
- Energy
- Control-command and signalling
- Rolling stock

In view of the importance of considering the entire life cycle of HS system components, the HS clusters analyse the interface between these subsystems through operation, maintenance and data management processes. A preliminary list of interfaces is presently under scrutiny :

1. Track, fastening system / Bridges and viaducts (operation and maintenance)

2. Infrastructure, line gradients / Track (operation and maintenance)

3. Track formation, embankments / Bridges and viaducts (operation and maintenance)

- 4. Track resistance to applied loads/ Track geometry
- Infrastructure, tunnels sections / Rolling stock car body, aerodynamic system

6. Rolling stock propulsion and braking / Energy, traction electric line, contact wire and messenger wire parameter

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For example, transition wedges are a typical component of interface no. 3. These relate to meeting points between geotechnical aspects (involving the foundation of earthworks and structures), structure behaviour and track response. For newly designed infrastructure elements, especially those intended for HS lines, UIC Leaflet 719 recommends proven transition zones (transition wedges) ensuring gradual track stiffness and a reduction in differential settlement.

Another interesting example relates to interface no. 4 above: applied loads on the track can cause permanent deformations of several elements of the railway infrastructure which then create defects on the track geometry. **The wavelength of the defect depends on the source of the degradation :**

Track superstructure degradation due to a defect in the rail profile and, in the case of ballasted track degradation, in the ballast with variations in thickness (short wavelength defects);

► Infrastructure degradation due to differential settlements of the line through rheological settlement or degradation of the embankments or foundations of the line (long wavelength defects). To avoid or limit such defects, there are recommendations to reduce the unsprung mass to less than 15% of the total mass of vehicles. In addition, a certain flexibility of the track is required, within boundaries, in order to :

► Distribute loads, reduce dynamic overloads and insulate against vibrations from the environment;

► Limit stress in certain track components, ensure track stability, promote riding stability and comfort, and prevent rail tilting.

This has led to an ac ceptable range of values for rail vertical displacement of between 1 and 2 mm for normal 20 t axle loads. A third and final example illustrates interface no. 5 above. This relates to the minimum value of the mean gauge (mm) over 100 m in service, on straight track and over curves with radii greater than 10 000 m :

Speed (km/h)	Minimum value mean gauge (mm)
V ≤160	1 430
160 < V ≤ 200	1430
200 < V ≤ 230	1 432
230 < V ≤ 250	1 433
250 < V ≤ 280	1 434
280 < V ≤ 300	1 434
V > 300	1 434

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RESEARCH AND DEVELOPMENT

HSR is now a mature system of transport. It has not yet voiced its last words. The network is still rapidely expanding worldwide. Therefore, innovation remains essential for the railway and it is particularly important for high speed rail to innovate in the face of competition from other transport modes. Innovation in the railway can be driven by internal research or can be appropriated from other transport fields, or even other domains, and applied to rail transport.

Classification of highspeed lines according to the speed

Compared to the road and air industries, the rail industry is small. In terms of size, the global high speed trainset fleet consists of around 5 000 units. As a trainset life cycle lasts about 25 years, the annual renewal requirement is 200. This equates to one tenth of the annual aeroplane production of the four main airplane manufacturers worldwide. And this is itself still much less than what the car industry can produce. So, with much less investment, the rail industry can keep pace with road and air by focusing on the critical issues, by enhancing internal competition between manufacturers through continued standardisation, and by taking advantage of innovations from other fields. UIC has launched a benchmark study to better understand the way innovation takes place in the rail field and the means to encourage it. UIC is also being proactive and each year organises a competition for innovative rail industry start-ups. One of the award categories is high speed rail.

Up until now, rail has been considered the safest and most environmentally friendly transport mode. However, driverless electric cars will completely transform how we view road transport. Similar leaps forward are anticipated in the air industry, towards the production of much quieter, more fuel efficient and even electric airplanes. The rail industry cannot sit back and simply watch all of these breakthroughs happen. Even where rail transport is head and shoulders ahead, improvements and innovations are of the utmost necessity.

For rolling stock, future requirements concern :

Business and technical management issues (development-procurement-approval deployment, LCC*, RAMS*, standardisation and modularity);

Basic dimensions and performance (capacity, loading gauge, axle load, train and car length, configuration of trainset, compatibility with infrastructure, maximum speed, acceleration and deceleration);

 Safety and security (stability, crash resistance, fire safety, crosswinds);

- Environment (CO2 and energy, EMC*, noise, vibrations, LCA*, extreme climate conditions);
- Energy (braking energy recuperation);
- Aerodynamics (aerodynamic resistance, tunnel micro-pressure wave, flying ballast);

 Comfort (ride comfort, noise abatement, tilting system, airtight structure, air conditioning, on-board passenger service);

► Human factors (ergonomics, accessibility for PRM*, cab design, cabin design, i.e. seating, toilet, luggage space);

► Technology (body and bogie structure, power and braking systems, on-board train control and information system, new auxiliary power units, coupling systems).

LCC = Life Cycle Cost

RAMS = Reliability, Availability, Maintainability, Safety EMC = ElectroMagnetic Compatibility LCA = Life Cycle Assessment PRM = People with Reduced Mobility

For the infrastructure, future requirements concern :

- Earthworks (optimisation of earth movements);
- Materials (new materials for the platform);
- Environment (reduction of CO₂ emissions);
- Track bed (intermediate solution between ballasted track and slab track);
- Signalling and train management (ERTMS level 3);
- Maintenance monitoring.

One of the paradoxes of the rail system is that although it is a guided system, it does not take full advantage of this feature. In contrast, air and road, which are not guided, are evolving towards autonomous mobility which will lead to attractive new business models. This issue is significant when it comes to the economic balance of rail because the infrastructure is by far the most expensive component of the rail system. As a result, it is essential to increase track capacity. The biggest step forward that rail could achieve would be to eliminate the physical coupling of trainsets and replace it with a virtual one. If this could be achieved, trainsets would be able to "merge" and "separate" while running. The number of trainsets per train would no longer be limited to two, thus considerably increasing line capacity.

HIGH SPEED RAIL AT UIC

UIC aims to support its members in a variety of ways. More specifically, its High Speed Committee regularly conducts studies and research when requested by one or several members. All of these are posted on the UIC extranet and are freely ac cessible. All such works cannot be exhaustively listed here, however a selection of them clearly illustrates their typology.

Defining I&HSR scope

Defining the perimeter of Intercity and HSR business (actors, assets, technologies, traffic, statistics, etc.) helps with an understanding of their specificities and therefore serves to focus action on their core elements.

Regarding the actors, a typical benchmark, anonymously carried out, relates to the "Key Performance Indicators (KPIs)" of companies operating high speed trains.

Regarding assets, a study compares mixed-traffic high speed lines in order to better understand why this choice was made and what its consequences were.

Regarding technology, a report on the "optimal speed" for rail concludes that rail commercial speed is still increasing, while the commercial speeds of air and road transport have now remained constant for many years. Recently China has re-started trains running at 350 km/h and HS2 has a target of 400 km/h.

Promoting I&HSR

UIC has conducted a very broad 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, characterised by the purpose of the trip, the group size, the booking anticipation, the OD pair, etc., transport by train is significantly cheaper. The savings made by the customer when choosing high speed trains are calculated. This survey also covers buses as a third transport mode in competition with rail and air. This last mode proves cheaper than the train, but the travel times are much longer. This survey has been extended in order to provide examples of how air companies react to the creation of a high speed line in terms of fare policy.

Another survey has been conducted in Europe on the level of track access charges on both domestic and international routes. This survey has been carried out four times over a 12year period. The adopted methodology has been established to provide an objective comparison by considering the same train running on the 100 selected routes at the same times.

Most of the statistics illustrating this brochure come from UIC databases. Two of these databases are worth mentioning because they are unique worldwide:

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.
 List of high speed rolling stock owned by high speed operators around the world.

The conclusion is that HSR suffers from a lack of consistent infrastructure fare policy throughout Europe, for five main reasons :

 There is no common philosophy for settling track access charges between the European Member States;

There is no consistency across the various calculation methods: the marginal costs of one country may be higher than the full cost in another country;

 Over the years, most countries change their access rules, and generally increase their levels;

- Over the years, the gap between countries is widening;
- It is impossible to predict the level of track access charges two years in advance for trains on both domestic and international routes.

The report also gives an insight into track access charge policies in countries outside Europe, together with the levels of the equivalent charges in other transport modes.
Each year, UIC organises a 2-level training programme for rail managers. This training starts with Level 1 in Paris and is followed by Level 2 in Madrid. Level 1 consists of presentations covering all aspects of HSR. It is a unique opportunity for attendees to get a synthetic view of all the technical, commercial, economical and financial aspects of HSR. Level 2 is based on a study case, 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 any given subject at the request of its members. These workshops are held in the location of the requesting member:

- Daejeon City (Korea) 2009: 1st UIC World High Speed Interaction Workshop
- Marrakech (Morocco) 2009: Safety and Security Requirements of High Speed Rail
- Paris (France) 2010: 1st Workshop on Global Standards for High Speed Rail Systems
- Mumbai (India) 2010: Security Challenges and High Speed Development
- ► Etc.

Identifying and exchanging best practices

Handbooks on the construction of a high speed line and on upgrading a conventional line are now available: both documents are organised in a very pedagogic way, taking the reader step by step from the first idea to the commissioning of the construction or modernisation works. At each stage, the stakeholders are identified, as well as what is at stake for them, to show how to best orient a project.

A thorough comparison of slab track and ballasted track aids understanding of the contexts in which one technology can be preferred to the other.

A benchmark of high speed and conventional train operation under difficult natural conditions is being progressively extended to cover various natural disasters. Difficult conditions are identified and listed. For each natural event, a threshold to define it is given, prediction capabilities are assessed, and measures for the design and operation stages are proposed.

Approximately every two years, 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)







Understanding the future world

UIC is constantly observing changes in the technology not only of rail but also of other transport modes. History provides many examples of transport modes that have disappeared because they have been outclassed by nascent technologies. This is why a review of transport technologies has recently been completed.

Similarly, an analysis of new competition has been carried out. Competing actors now include the bus (while this is not new competition per se, buses have only recently been permitted to compete over long distances in several European countries), car-pooling and car-sharing.

Developing I&HSR

The UIC I&HSR Committee is in the process of setting up an

- alliance with a group of universities spread across the world. The main objectives of this alliance are to:
- Develop training on rail disciplines;
- Attract new talent to the rail sector;
- Cooperate with university laboratories to carry out research.

Credits

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