SAPIENZA
UNIVERSITÀ DI ROMA

UNIVERSITÀ DEGLI STUDI DI ROMA "LA SAPIENZA"

TRAFFIC CONCEPTS ON HIGH SPEED RAILWAY SERVICES

THESIS

Submitted for the degree of Master in Transport System Engineering

For the Faculty of

Civil and Industrial Engineering

Sapienza University of Rome

Candidate: Eyad Sherif

Number: 1690335

Adviser: Prof. Stefano Ricci

Academic year 2016/2017

Abstract

The European railway industry continues to undergo reform and liberalization due to European law incentives. Recent events in Italy give the country a special place in this process: a new competitor has commenced operations in the High-Speed Rail (HSR) market based on a private initiative. This Thesis aims to investigate these rail transport innovations, looking for the driving forces and obstacles and to identify the main impacts for the Italian consumers. We also try to provide with some interesting results helpful for other countries regarding passenger rail reforms. Basing on the Italian case, open access competition in the HSR market seems to be capable to produce significant improvements in favor of passengers and a *win-win* game between all railway actors. This is a comprehensive Study of Rail Networks in the largest European countries, with specific focus on Italy, where the utilization of high-speed rail system operates in integration and combination with regional services. The aim is to define the most fruitful solution for optimizing the use of mixed traffic operated networks, according to solutions replicable in other countries. Concerned issues are the choice of the maximum speed for both high-speed and regional services, the accessibility of the services by called stations along the lines, the travel cost for passengers, as well as the increase of line capacity.

Acknowledgements

This project would not have been possible without the help of my adviser, so many thanks to prof. Stefano Ricci for the effort and the time you gave to me.

Then the most important person in my life, my wife, thank you Sara Nusseir for standing by me all the time, and for giving me the force during the whole Master Degree, without you this would have never happened.

Thanks to my University Sapienza University of Rome , and for each prof. who taught me , Guido Gentile, Mattia Giovanni Crespi, Antonio Musso, Paolo De Girolamo, Paola Di Mascio, Gaetano Fusco, Massimo Guarascio, Gabriele Malavasi, Luca Persia, and Liana Ricci.

I was one of the lucky students who had the honour of being taught under such professors.

Table of Contents

Chapter 1 6

1.1 Introduction 6

1.2 Overview 7

Chapter 2 12

2.1 High-Speed Rail in Italy 12

2.2 High-Speed Rail in France 16

2.3 High-speed rail in Germany 20

2.4 High-speed rail in Spain 23

2.5 Integration of European HSR network 26

Chapter 3 27

3.1 Overview of services 27

3.2 Scope 28

3.3 Signalling systems 28

Chapter 4 35

4.1 International High-Speed Lines 35

4.2 High-speed network and citizens 35

4.3 Integration with Trans-European Transport Network policy 37

4.4 Growing demand 41

4.5 Intra-modality and co-modality 43

4.6 Making transport more ecological 46

Chapter 5 49

5.1 The Future 49

5.2 Conclusions 51

Bibliography 52

Table of Figures

Figure 1 Fastest trains in the world (1) 8
Figure 2 List of HSTs speeds (1) 9
Figure 3 Italian Rail network table 12
Figure 4 Italian Rail Network map 13
Figure 5 LGV under construction 17
Figure 6 French Rail Network table 18
Figure 7 German HSR network 22
Figure 8 German Rail Network map 22
Figure 9 Spain Rail Network Table 23
Figure 10 Spain Rail Network map 24
Figure 11 Features of regional services Rome-Florence-Bologna 27
Figure 12 LZB German signalling system: equipment 30
Figure 13 LZB German signalling system: speed control 30
Figure 14 TVM French signalling system: equipment 31
Figure 15 French signalling system: speed control 31
Figure 16 High Speed Trains Crossing borders (8) 35
Figure 17 Journey times between stations 38
Figure 18 Number of trains per 100 km on HSL in the world (10) 38
Figure 19 TEN-T axes and priority projects (10) 39
Figure 20 HSL development [km] 1985-2017 (11) 40
Figure 21 HSL extension [billion passengers' km] 41
Figure 22 Journey times v. distance for rail (HS and conventional lines) and air transport 43
Figure 23 breakdown by origin of energy used by the railways 47
Figure 24 CO2 emissions by mode of transport (10) 47

Chapter 1

1.1 Introduction

High-speed rail is emerging in Europe as an increasingly popular and efficient means of transport.

The first HSR lines in Europe, built in the 1980s and 1990s, improved travel times on intra-national corridors.

Since then, several countries have built extensive high-speed networks, and there are now several cross-border high-speed rail links.

Railway operators frequently run international services, and high-speed tracks building and upgrading is today in compliance with international standards.

In 2007, a consortium of European railway operators, *Rail team*, emerged to co-ordinate and boost cross-border high-speed rail travel.

Moreover, developing a Trans-European high-speed rail network is a stated goal of the European Union and most cross-border railway lines receive EU funding.

Several countries like France, Spain, Italy, Germany, Austria, Sweden, Belgium, the Netherlands, Russia and the United Kingdom have cross-border HSR network in operation.

More and more it will be in the coming years, as Europe invests heavily in tunnels, bridges and other infrastructure and development projects across the continent, many of which are under construction.

Governments look for new dynamics in railway transport to cater for the rising need of high-speed travel demand and railways are revitalizing themselves to be able to compete better with other transport modes.

An important focus is on the development of new high-speed networks in order to facilitate growth in mobility and to limit air travel.

Nevertheless, the HSR development requires substantial investments in infrastructure and the efficient use of these capital-intensive assets will justify them.
In addition, identification of areas of improvement in production and marketing is important to optimize operational performance and productivity.
National governments decide on the development of HSR systems basing on the expected future demand for high-speed travel and the social benefits for the country. Long-term performance forecasts for high-speed rail are a basic input for the decision-making process, performance.
The goal of this Thesis is to identify the best high-speed rail practices starting from the operational performances and the efficiency of the world's major high-speed rail systems currently in operation.

1.2 Overview

We will consider High Speed Trains (HST) from all over the world as a reference, so we start the analysis from the maximum recorded and operating speeds (figures 1 and 2).

Maximum-recorded speed

For a specific HST on a specific line, the train's maximum speed in safe conditions is the maximum-recorded speed.

Maximum operating speed

For a specific HST on a specific line, the train's speed achieved under safety conditions to achieve the highest capacity and efficiency we can achieve is the maximum operating speed.

World's Fastest High-Speed Trains

Below is a comparison of trains' top speed records with their maximum operating speed

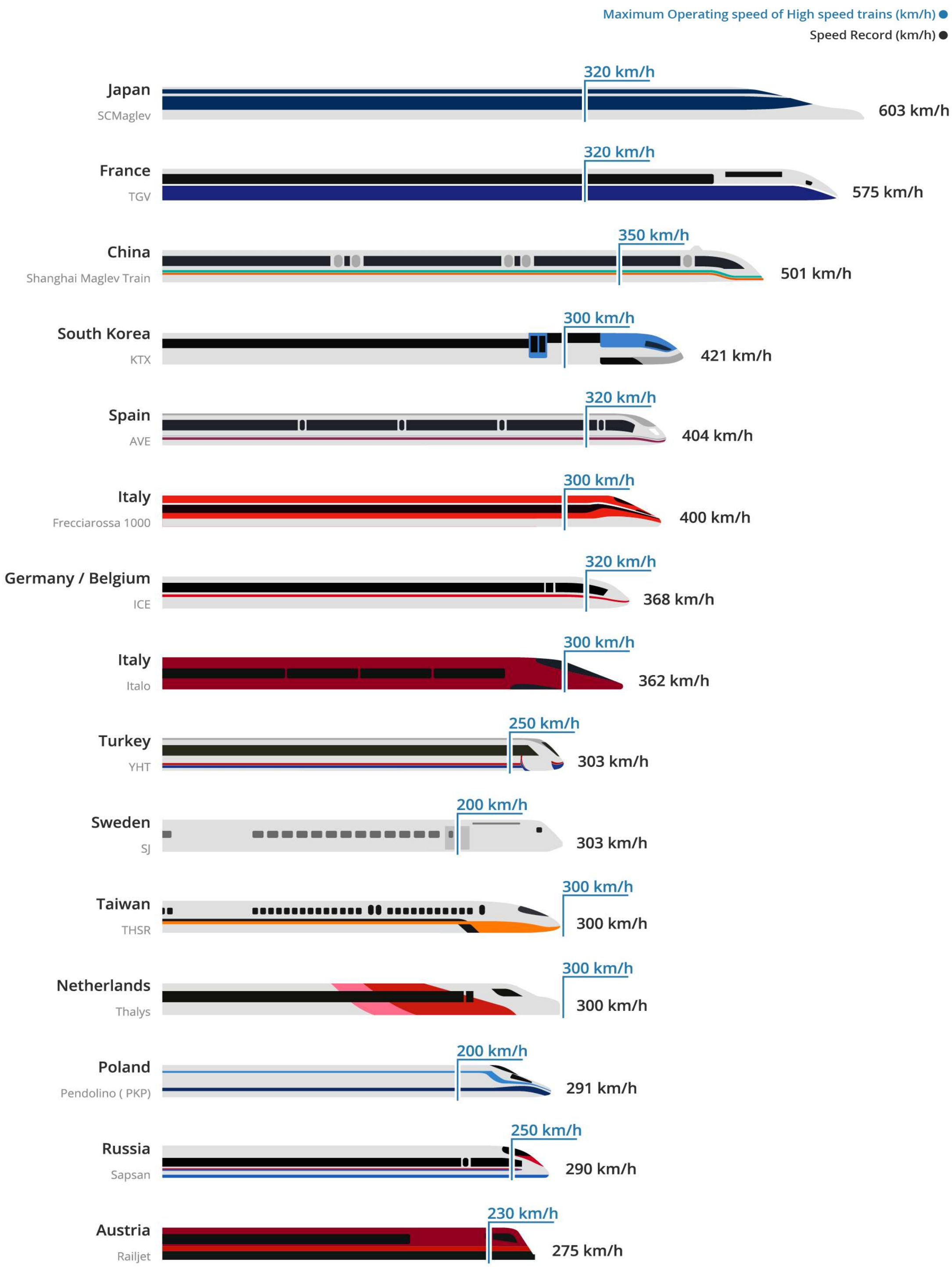


Figure 1 Fastest trains in the world (1 s.d.)

	Country	Record Speed	Operating Speed	Line Coverage	Population Coverage	€/km	Score
1	Japan	603	320	13.23%	36.55%	0.2	100
2	South Korea	421	300	1.62%	44.67%	0.14	83.79
3	China	501	350	29.22%	10.7%	0.22	69.25
4	France	575	320	6.79%	12.69%	0.19	49.39
5	Spain	404	320	20.05%	20.51%	0.12	41.99
6	Taiwan	300	300	21.84%	36.25%	0.12	37.81
7	Germany	368	320	4.75%	18.28%	0.19	32.9
8	Italy	400	300	7.91%	18.47%	0.15	25.55
9	Austria	275	230	7.06%	27.55%	0.18	23.85
10	Turkey	303	250	8.08%	7%	0.03	22.15
11	Sweden	303	200	2.01%	21.41%	0.17	21.92
12	Belgium	368	300	5.98%	7.83%	0.31	17.91
13	Netherlands	300	300	3.98%	11.99%	0.12	17.9
14	Portugal	237	220	24.56%	10.21%	0.18	17.65
15	Russia	290	250	0.91%	12.22%	0.03	16.61
16	Poland	291	200	0.51%	12.57%	0.08	15.33
17	Uzbekistan	255	250	8.21%	9.01%	0.18	13.17
18	Norway	210	210	1.54%	12.44%	0.19	11.6
19	USA	265	240	0.32%	3.73%	0.45	9.88
20	Finland	242	220	1.01%	1.89%	0.33	9.26

Figure 2 List of HSTs speeds (1)

The ranking shows that countries in Asia are the runaway leaders for high-speed trains.

Japan, with its incredible top speed record, high placing for population coverage, and operating speed dominates the competition.

In comparison, only 1.6% of tracks in South Korea are HSR, but they cover more than 44% of the country's population.

It is also noteworthy that China, with more than 66,298 km of railways, have covered 29.2% of them with high-speed tracks, serving 10.7% of their population.

France and Spain are in the top 5 ranking; nevertheless, some European countries manage to surpass Asian ones in certain aspects of HST travel:

The operating speed in France, Germany and Spain is equivalent with Japan, just behind China, but above South Korea.

More than 20% of population of Austria and Spain have direct access to high-speed lines, followed closely by Italy and Germany with around 18% and the Netherlands with 12% of population access to HST.

What criteria and factors were used for the ranking?

The criteria used to weigh and classify trains and high-speed lines in each country are as follows in order of importance:

- *Population coverage:*
  Population covered by high-speed train. The most important factor of the study - it measures the total population with access to high-speed trains in their city in each country. To calculate takes into account the registered inhabitants in absolute terms from each of the cities which have high-speed lines passing through (according to official census data and equivalents). The numbers for residents of the metropolitan areas and surrounding cities are not considered. Furthermore, only rail lines that pass through at least two cities in each of the countries have been considered.
- *Record Speed:*
  For this score, all speed records of every model of high-speed train belonging to each train operating company was examined. For countries which use the same type of train, the record speed was considered to be the same.
- *Operating speed:*
  This factor focuses on the regular operating speed of the trains. Sheer power on its own wins you nothing here, rather the technical characteristics of the tracks and rolling stock and the type of terrain that their routes cover, for example.

- *Line Coverage:*
  Percentage of high-speed railway versus regular tracks.
- *Cost per kilometer:*
  This factor indicates the cost of tickets for high-speed train per kilometer. A mean cost of tickets per kilometer using the distance between different routes was calculated.
- *Score:*
  This indicates the total score reached by using the formula, relative to the highest score achieved, which is always 100.
- *The formula used to calculate the ranking by countries is as follows:*

$$\sum_{i:1}^{5} \frac{n}{Factor's\ Ranking i} * Wi$$

(Key: n: number of countries used for the study. Factor Ranking: ranking scored by country for each ranking factor. W: the weight given to each of the factors, ranging between 0.5 and 4 points, to arrive at an overall score).

What are the sources for this ranking?

All data in this ranking was checked against official sources such as European Union directives, the railway companies, our internal database and official government population census data (1 s.d.)

Chapter 2

The largest countries in Europe at a glance

2.1 High-Speed Rail in Italy

High-speed rail in Italy consists of two lines connecting most of the country's major cities (figures 3 and 4):

- From Turin to Salerno via Milan, Bologna, Florence, Rome and Naples;
- From Turin to Venice via Milan, partially under construction.

Line	Length [km]	Opening	Travel time [h:min]	Top speed [km/h]	Voltage
Turin-Milan	125	February 2006 (Turin-Novara) December 2009 (Novara-Milan)	0:44	300	25 kV 50 Hz
Rome–Naples	205	December 2005 December 2009	1:08	300	25 kV 50 Hz
Padua-Venice (Mestre) [10]	25	March 2007	0:14	220	3 kV DC
Naples-Salerno "Linea Monte Vesuvio"	29	June 2008	0:30	250	3 kV DC
Milan–Brescia[10]	67	June 2007 (Milano-Treviglio) December 2016 (Treviglio-Brescia)	0:36	180 (Milano-Treviglio) 300 (Treviglio-Brescia)	25 kV 50 Hz
Milan–Bologna	215	2008-12-13	0:53	300	25 kV 50 Hz
Florence–Rome "Direttissima"	254	February 1978 May 1992	1:18	250	3 kV DC
Bologna–Florence	79	December 2009	0:35	300	25 kV 50 Hz
Total	**926**				

Figure 3 Italian Rail network table

Figure 4 Italian Rail Network map

Trains are operating with a top speed of 300 km/h.

Trenitalia operates passengers' services and, since April 2012, NTV-Italo, the world's first private open-access HSR operator is operating in competition with a state-owned company. 25 million passengers traveled on the network in 2011, progressively increasing to 64 million passengers in 2015 (about 55 million with Trenitalia and about 9 million with NTV) (2 s.d.).

A glance at the History

The first HSR route in Italy, the Direttissima, opened in 1977, connecting Rome with Florence.

The top speed on the line was 250 km/h, giving an end-to-end journey time of about 90 minutes with an average speed of 200 km/h.

This line used a 3 kV DC supply.

In 1988-89, a high-speed service on the Rome-Milan operated with the ETR 450 Pendolino train, with a top speed of 250 km/h cut the travel times approximately from 5 to 4 hours.

The prototype train ETR X 500 was the first Italian train to reach 300 km/h on the Direttissima on 25 May 1989.

The Italian high-speed rail projects suffered from a number of cost overruns and delays.

Corruption and unethical behavior played also a key role.

Rolling stock

Services on the high-speed lines by Trenitalia and NTV used several types of high-speed trains:

- ETR 500: non-tilting, speeds up to 300 km/h, operated by Trenitalia as the Frecciarossa;
- ETR 600, ETR 610: tilting, speeds up to 250 km/h, operated by Trenitalia as the Frecciargento, also on main traditional lines.
- AGV575: speeds up to 360 km/h, operated by NTV as Italo.
- ETR 1000: operated by Trenitalia, capable to reach 400 km/h and with operational speed of 360 km/h.

The maximum speed of these trainsets is currently anyway limited at 300 km/h, while tracks are pending certification for 360 km/h operations.

Secondary stock

Other rolling stock, anyway capable to reach high-speed are:

- ETR 460, ETR 485: tilting, speeds up to 250 km/h, operated by Trenitalia for non-high-speed services
- ETR 470: tilting, speeds up to 250 km/h, operated by Trenitalia on services between Italy and Switzerland.
- New Pendolino ETR 610: entering into service on Italy-Switzerland services;
- TGV: running on the Paris-Turin-Milan service, but not using high-speed line in Italy.

2.2 High-Speed Rail in France

Europe entered into HSR when the *Ligne Grand Vitesse* (LGV) Sud-Est from Paris to Lyon opened in 1981 and TGV started passenger service.

Since then, France has continued to build an extensive network, with lines extending in every direction from Paris.

France has the second largest high-speed network in Europe, with 2,647 km of operative HSR lines in July 2017, only behind Spain's 2,665 km.

The TGV network gradually spread out to other cities and into other countries such as Switzerland, Belgium, the Netherlands, Germany, and the United Kingdom.

Due to the early adoption of HSR and the important location of France (between the Iberian Peninsula, the British Isles and Central Europe), most other dedicated HSR lines in Europe have been built to the same speed, voltage and signalling standards.

The most obvious exception are the high-speed lines in Germany, built to existing German railway standards.

Moreover, many high-speed services, including TGV and ICE utilize existing rail lines in addition to those designed for HSR.

For that reason and due to differing national standards, trains that cross national boundaries need to have special characteristics, such as the ability to handle different power supplies and signaling systems.

This means that not all TGVs are the same, and there are loading gauge and signalling differentiations.

As of July 2017, the French high-speed rail network comprises 2,647 km of LGV and 670 km are under construction.

The present network includes:

- LGV *Atlantique* (LN2) to Tours/Le Mans (construction start: 1985, in operation: 1989);
- LGV *Nord-Europe* (LN3) to Calais and the Belgian border (construction start: 1989, in operation: 1993);
- LGV *Rhône-Alpes* (LN4), extending the TGV Sud-Est to Valence (construction start: 1990, in operation: 1992);
- LGV *Méditerranée* (LN5) to Marseille (construction start : 1996, in operation : 2001);
- LGV *Est* (LN6) from Paris to Strasbourg (in operation: 2007);
- LGV *Perpignan–Figueras* (in operation: 2010);
- LGV *Rhin-Rhône* (LN7) (first phase in operation: 2011) (3 s.d.).

The further lines under construction are in figures 5 and 6.

Line	Speed [km/h]	Length [km]	Construction start	Expected start of operation
LGV Sud Europe Atlantique	300	302	2011	2017
LGV Bretagne-Pays de la Loire	350	182	2012	2017
Nimes – Montpellier Bypass	350	80	2013	2017
Lyon-Turin	300	72	2007	2025–2030

Figure 5 LGV under construction

Traffic limitations

The operation of LGVs is specialized for TGVs.

One reason for this is that line capacity is sharply reduced when trains of various speeds are mixed, as the interval between two trains needs to be large enough to allow over-taking between two passing loops.

Moreover, passing freight and passenger trains also constitute a safety risk, as cargo on freight cars can suffer the air turbulence caused by the TGV.

Figure 6 French Rail Network table

The permitted axle load on LGV lines is 17 t, imposed to prevent heavy rolling stock from prematurely damaging the accurate track alignment required for high-speed operation.

Conventional trains hauled by locomotives are not running on these lines, since the axle load of a typical European electric locomotive exceeds 20 t.

The only freight trains that are generally permitted except are mail trains run by the French postal service, using specially adapted TGV rolling stock.

TGV power cars as well as the lightweight streamlined locomotives at both ends of TGV trainsets are within the 17th limit, but special design efforts were necessary to keep the mass of the double-deck Duplex trains within the 17 t when they started their operation in the 1990s.

The steep gradients common on LGVs would limit the weight of slow freight trains.

Slower trains would also mean that the maximum track cant on curves would be limited, so for the same maximum speed a mixed-traffic LGV would need larger radius on curves.

Such track would be much more expensive to build and maintain.

Some stretches of less-used LGV are routinely mixed-traffic, such as the Tours branch of the LGV *Atlantique* and the Nimes/Montpellier (under construction) branch of the LGV *Mediterranée*.

The British High Speed 1 from the Channel Tunnel to London with passing loops to support freight use, though the use of this facility is infrequent.

Maintenance on LGVs is normally at night, when no TGVs are running.

Outside France, LGV-type lines often carry non-TGV intercity traffic as a requirement of the initial funding commitments.

The Belgian LGV from Brussels to Liège carries 200 km/h loco-hauled trains, with both the Dutch HSL-Zuid and British High Speed 1 planned to carry 225 km/h domestic intercity services and 300 km/h international services.

The Channel Tunnel is not a LGV, but it uses LGV-type TVM signalling for mixed freight, shuttle and Eurostar traffic between 100 and 160 km/h.

2.3 High-speed rail in Germany

Construction on first German high-speed lines began shortly after the French LGVs.

Legal battles caused significant delays, so that the InterCity Express (ICE) trains deployed ten years after the TGV network.

The ICE network is tightly integrating the pre-existing lines and trains, because of the different settlement structure in Germany, with a population more numerous by a third than that of France, on a territory smaller by a third, resulting in more than twice the population density of France.

ICE trains reached destinations in Austria and Switzerland soon after they entered service, taking advantage of the same voltage used in these countries.

Starting in 2000, multisystem third-generation ICE trains entered the Netherlands and Belgium.

The third generation of the ICE reached a speed of 363 km/h during trial runs in accordance with European rules requiring maximum speed +10% (certification for 330 km/h in regular service).

In the south-west, a new line between Offenburg and Basel will allow speeds of 250 km/h and a new line between Frankfurt and Mannheim for speeds of 300 km/h is in advanced planning stages.

In the east, a 230 km long line between Nuremberg and Leipzig is under construction for speeds up to 300 km/h.

Together with the fast lines from Berlin to Leipzig and from Nuremberg to Munich, which were completed in the s, it will allow journey times of about 4 hours from Berlin to Munich, compared to nearly 8 hours for the same distance a few years ago (4 s.d.).

List of high-speed lines

Upgraded Line

- Cologne–Aachen (250 km/h)

Partially New Line

Part of these routes are new constructions that run along or close to the existing, or previous, route:

- Hanover–Berlin (partially new line, 250 km/h on the new section, 160 and 200 km/h on the existing sections);
- Nuremberg–Munich (partially new line, 300 km/h on the new part, 160 and 200 km/h on the existing section)

Fully New Line

Completely new construction projects:

- Cologne–Frankfurt (300 km/h);
- Hanover–Wurzburg (280 km/h);
- Mannheim–Stuttgart (280 km/h);
- Erfurt–Leipzig/Halle (300 km/h, opened in December 2015).

Lines not yet completed (figure 7)

- Frankfurt–Mannheim (300 km/h, in planning).
- Nuremberg–Erfurt (300 km/h, partially new, under construction).
- Karlsruhe–Basel (250 km/h, incomplete).
- Hanau-Gelnhausen (300 km/h, in planning).
- Stuttgart–Wendlingen (250 km/h, under construction).
- Wendlingen–Ulm (250 km/h, under construction).

Line	Speed [km/h]	Length [km]	Construction start	Expected start of operation
Nuremberg–Erfurt	300	190	1996	2017
Karlsruhe–Basel	250	182	1987	1993-2030
Stuttgart–Wendlingen	250	25	2012	2021
Wendlingen–Ulm	250	60	2012	2021

Figure 7 German HSR network

Figure 8 German Rail Network map

2.4 High-speed rail in Spain

The *Alta Velocidad Española* (AVE) HSR system in Spain has been in service since 1992, when the Madrid-Seville route started the operation (figure 9).

Line	Speed [km/h]	Length [km]	Start of construction	Construction completion or expected start of operation
Madrid-Seville	300	472	1989	1992
Córdoba-Malaga	300	155	2001	2007
Madrid-Valladolid	350	179.6	2001	2007
Madrid-Barcelona	350	621	1995	2008
Madrid-Valencia	350	391	2004	2010
Albacete-Alicante	350	171.5	-	2013
Barcelona-French border	350	150.8	2004	2013
Atlantic Axis	250	155.6	2001	2015
Valladolid-León	350	162.7	2009	2015
Valladolid-Burgos	350	134.8	2009	2016-2017
Seville-Cádiz	250	157	2001	2015
Antequera-Granada	300	125.7	2006	2016
León-Gijon	350	-	2009	2017
Olmedo-Zamora-Galicia	350	435.0	2004	2011-2018
Murcia-Almeria	300	184.3	Unknown	after 2018
Burgos-Vitoria	350	98.8	2009	2019
Basque Y	250	175	2006	2019
Mediterranean Corridor	250-350	>1300	2004	2013–2022
Madrid-Caceres-Mérida-Badajoz-Lisbon [29]	350	640	2008	after 2020
Madrid-Jaén	250-350	-	2015	-
Madrid-Santander [30]	-	-	-	-

Figure 9 Spain Rail Network Table

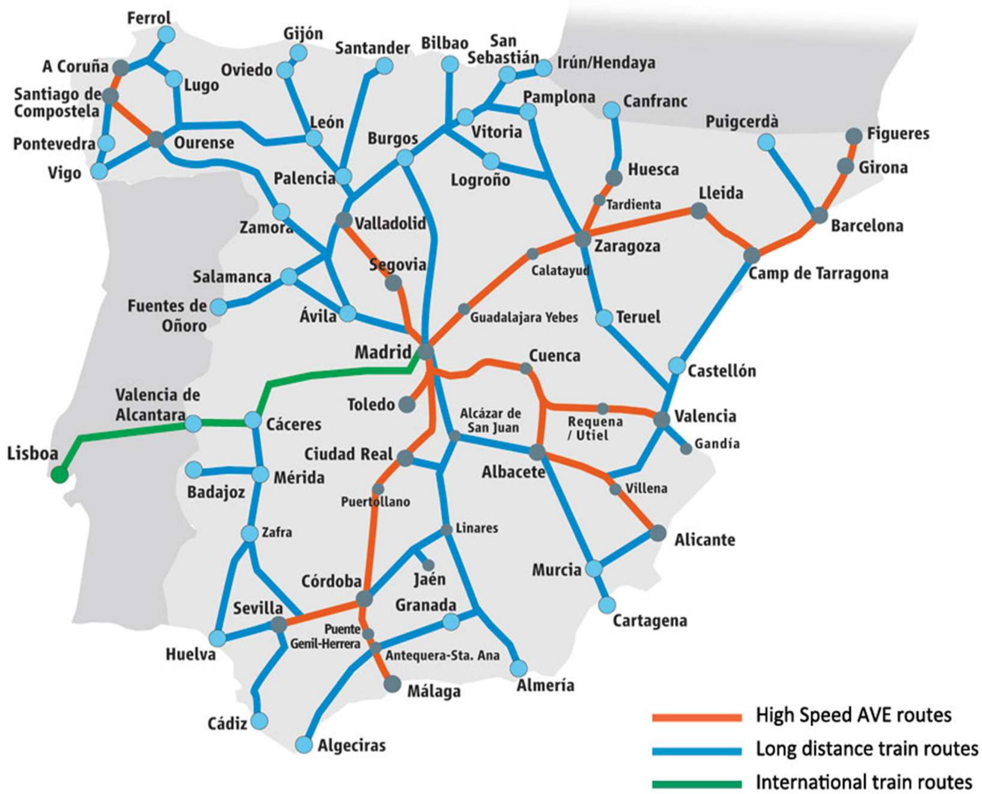


Figure 10 Spain Rail Network map

Six other lines are in operation later on, including the 621-kilometre long Madrid–Barcelona line.

The Madrid-Alicante line completed in June 2013 brings the total length of the network to 3,100 km, making it the longest in Europe and the second longest in the world after mainland China.

By 2020, Spain should have connected almost all provincial capitals to Madrid in less than 3 hours and Barcelona within 6 hours with high-speed trains.

The Spanish and Portuguese high-speed lines have European standard and UIC track gauge of 1,435 mm and electrified with 25 kV at 50 Hz from overhead wire.

The first HSL from Madrid to Seville is equipped with LZB train control system, later lines with ETCS.

Elsewhere in Europe, the success of high-speed services has been due in part to interoperability with existing normal rail lines.

Interoperability between the new AVE lines and the older Iberian gauge network presents additional challenges.

Both *Talgo* and CAF supply trains with variable gauge wheels operated by automatic gauge-changer equipment which the trains pass through without stopping (*Alvias*).

Some lines have dual gauge to allow trains with Iberian and UIC gauge on the same tracks.

Other lines have been re-equipped with sleepers for both Iberian and UIC gauge, such that the track is convertible from Iberian to UIC gauge without changing the sleepers.

The first AVE trains to link up with the French standard gauge network began running in December 2013, when direct high-speed rail services between Spain and France were launched for the first time (19).

This connection between the two countries was made possible by the construction of the Perpignan–Barcelona high-speed rail line (a follow-up of the Madrid-Barcelona line), completed in January 2013 and its international section Perpignan-Figueras, which opened on December 2010 and includes a new 8.3-kilometre tunnel under the Pyrenees.

Another high-speed rail link connecting the two countries at Irun-Hendaye is also under planning.

Several new high-speed lines are under construction with a design speed of 300÷350 km/h and several old lines are being upgraded to allow passenger trains to operate at 250 km/h (5 s.d.) (6 s.d.).

Three companies have built or will build trains for the Spanish high-speed railway network: Spanish Talgo, French Alstom and German Siemens AG.

Bombardier Transportation is a partner in both the Talgo-led and the Siemens-led consortium.

France will eventually build 25 kV TGV lines to the Spanish border (there is now a gap between Nimes and Perpignan), but multi-voltage trains will still be needed, as trains travelling to Paris need to travel the last few km on 1.5 kV lines.
To this end, RENFE decided to convert 10 existing AVE S100 trains to operate at this voltage (as well as the French signalling systems), which will cost 30 M€ instead of the previously expected 270 M€ for new trains.

2.5 Integration of European HSR network

The Trans-European HSR network is one of the European Union's Trans-European transport networks.
It was defined by the Council Directive 96/48/EC of 23 July 1996.
The aim of this EU Directive is to achieve the interoperability of the European high-speed train network at the various stages of its design, construction and operation.
The network is a system consisting of a set of infrastructures, fixed installations, logistic equipment and rolling stock.
Already on 05/06/2010, the European Commissioner for Transport signed a Memorandum Of Understanding (MOS) with France and Spain concerning a new high-speed rail line across the Pyrenees to become the first link between the high-speed lines of the two countries.
Similar promotions were setup for Helsinki-Berlin (Rail Baltica), and Lyon-Budapest axis.

Chapter 3

3.1 Overview of services

The features of present high-speed and regional services on the concerned lines are summarized in figure 11.

Line	Distance [Km]	Average travel time [h:min]	Average travel speed [km/h]	Max travel speed [km/h]	Average price one day before the trip [Euro]	Unit price one day before the trip [Euro/km]	Average price one week before the trip [Euro]	Unit price one week before the trip [Euro/km]
Rome Termini - Florence SMN	254	01:32	170	250	45	0.17	35	0.14
Rome Termini - Bologna Centrale	344	02.00	170	250	50	0.14	35	0.11
Florence SMN - Bologna Centrale	90	00:35	180	300	25	0.27	19	0.21

Line	Distance [Km]	Average travel time [h:min]	Average travel speed [km/h]	Max travel speed [km/h]	Average price one day before the trip [Euro]	Unit price one day before the trip [Euro/km]	Average price one week before the trip [Euro]	Unit price one week before the trip [Euro/km]
Rome Termini - Florence SMN	254	04:05	65	120	25	0.10	25	0.10
Rome Termini - Bologna Centrale	344	7.00	50	120	33	0.10	33	0.10
Florence SMN - Bologna Centrale	90	2.00	45	130	12	0.13	12	0.13

Figure 11 Features of regional services Rome-Florence-Bologna

3.2 Scope

The method starts from a summarized information about the average travel speeds, travel time and the price per kilometer of HSTs and regional ones and the possible transfers for a single trip between them. As shown in figure 11.

The goal is to understand the effect of mixing the traffic between HST and regional trains.

On the other side, it is interesting to investigate the possible effects in terms of ticket price and related costs for passengers, and for better understanding we need to understand the signalling systems of High Speed Trains, the actual situations of trains crossing borders, the demand, the modal share of HSTs and other services of Air transport and finally their environmental effect.

3.3 Signalling systems

Introduction

Since the birth of railways, there has always been the need to develop applications able to satisfy the railway traffic control.

For this purpose, state of art of signalling has followed a continuous improvement, starting from hand signals until to the most modern technologies for trains' separation.

Over the years, in Europe have been developed and operated a lot of different systems, with the consequent absence of interoperability among different countries.

In the modern era, where the labor market goes beyond national borders, different national ATP systems and the consequent absence of interoperability was an important limit for the European integration.

This is one of the reasons of the birth of ERTMS program.

It is composed essentially by the command and control system ETCS and the radio communication network GSM-R.

The analysis of the ERTMS main features shows how the whole architecture ensure, in addiction to interoperability, different benefits regarding safety, cost, accessibility and maintenance.

Thanks to these tangible advantages, ERTMS is currently the most used technology for railway signalling in Europe and it is on launching ramp in the rest of world (7 s.d.).

Some history about railway signalling

All railway safety systems, starting from those used since the origin of railways in Europe, to the most advanced systems used nowadays, share a basic concept: trains cannot collide each other if they are not permitted to occupy the same section of track at the same time.

For this reason, railway lines are divided into sections, known as blocks (or block sections).

In a common operative mode, only one train is permitted in each block at a time.

In the early days of railways (1850), men (train dispatchers) were standing at intervals (blocks) along the line with a stopwatch and they used hand signals to inform train drivers that a train was going to pass.

In order to help the staff, mechanical semaphores were introduced at the turn of 20^{th} century.

With the invention of telegraph and telephone, it became possible for the staff to send messages (first a certain number of rings on a bell, then a telephone call) to confirm that a train had passed and that a specific block was finally clear.

Around 1930 the first optical signals were introduced.

The whole system was called phone block system.

When fixed mechanical signals began to replace hand signals from the 1930s, the semiautomatic block was born.

Nowadays, railway signalling is based on automatic blocks, which does not require manual intervention.

A line equipped with automatic blocks is divided into sections, not shorter than the braking distance of the faster train running on the route (7 s.d.).

German signalling system for HS lines: Linienzugbeeinflussung (LZB)

It is a vital, computerized, continuous, and centralized Automatic Train Control (ATC) system for speed up to 300 km/h.

A single center manages about 100 km of double track section line.

The system may be overlapped to other national signalling system.

The safe bidirectional link train-center is realized with a cable loop laid into the track along all the whole line length (figures 12 and 13).

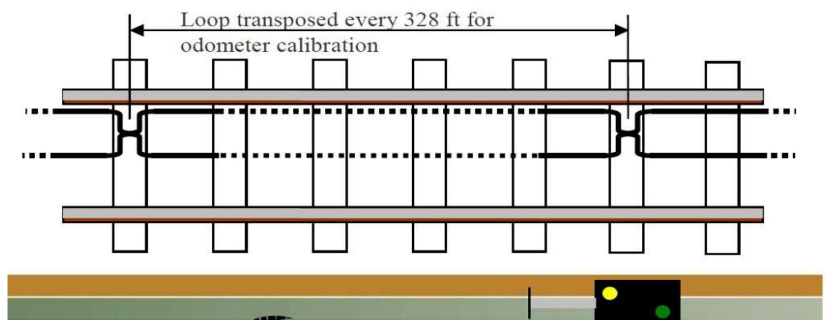


Figure 12 LZB German signalling system: equipment

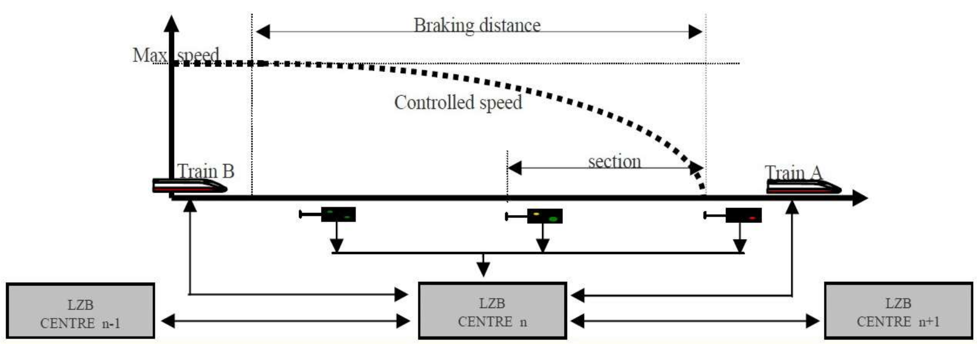


Figure 13 LZB German signalling system: speed control

Each center is permanently connected to all stations' interlocking and trains of its area, as well as to adjacent centers for in and out relationships.

The trackside vital computer sends cyclically, to every on-board computer, data concerning the length of the available braking distance and the localization of braking initiation in respect of the braking train capacity (7 s.d.).

Spanish signalling systems for HS lines

For speed up to 300 km/h, the German LZB overlapped to the national signalling system *Anuncio de Señales y Frenado Automatico* (ASFA).

The latter is a system for on board repetition of trackside signals used by conventional trains running on the HS lines.

On other lines, the ERTMS Level 1 and 2, overlapped to the national to ASFA system.

EBICAB signalling system

For speed up to 220 km/h, the EBICAB (*Électrique Bureau CABine*) is a semi-continuous system for Automatic Train Protection (ATP), based on wayside transponders, which transmit to trains information for supervision of the braking curve (7 s.d.).

French signalling system for HS lines: Transmission Voie Machine (TVM)

It is a Vital ATP system with distributed architecture for speed up to 320 km/h.

A single Trackside Control Centers (TCC) is located approximately every 15 km.

The system operates without trackside signalling, with a continuous track-to-train transmission through track circuits (figures 14 and 15).

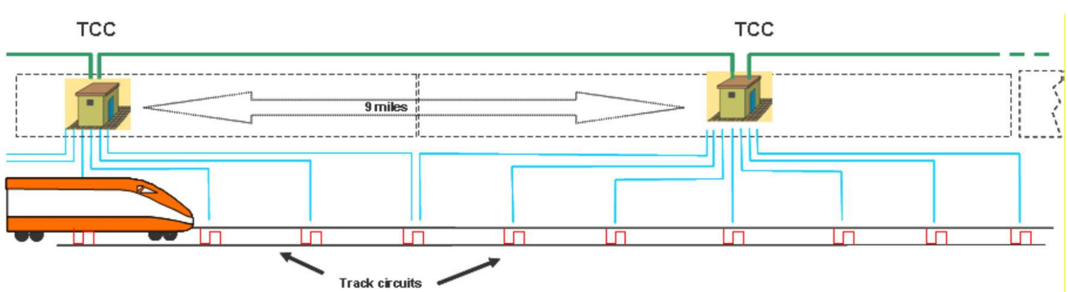


Figure 14 TVM French signalling system: equipment

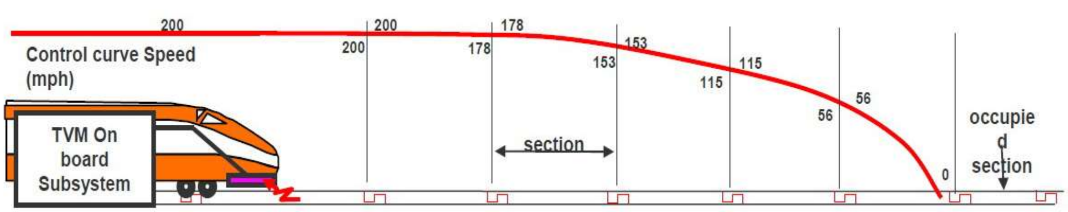


Figure 15 French signalling system: speed control

The continuous speed control is calculated on board for each block section and is based on data received from trackside: section length, speeds at the beginning and at the end of the block section, slope.

It uses audio frequency track circuits and auxiliary transmission media (balises) needed to manage track conditions (power supply, tunnels, etc.) (7 s.d.).

Italian signalling systems for HS lines

For lines with speed up to 250 km/h it is used the *Blocco Automatico a Correnti Codificate* (BACC) national signals block system, based on coded track circuits and on-board repetition of trackside light signals.

These HS lines are also used by conventional trains, to be soon upgraded to ERTMS.

For lines with speed up to 300 km/h it is used the ERTMS level 2.

In the Italian application, ERTMS operates without overlapping on other systems and without trackside signals.

Only ERTMS equipped trains can run on such HS lines.

The lack of a back-up system (ERTMS level 1 or similar) is balanced by a very high level of redundancy of subsystems involved (7 s.d.).

The motivations to use ERTMS are mainly:

1. Interoperability: European Commission supports the development of operational and technical interoperability with unified signalling equipment in order to open railway markets to all train operators;
2. Safety: ERTMS equipment is designed and produced in compliance with CENELEC standards (7 s.d.);
3. Performance: high speed can be reached using the lowest amount of time distance between the trains (in Italy only 150’ between two trains running at 300 km/h);
4. Availability/Reliability: due to ERTMS architecture, there are less equipment along the lines, reducing fault probability and improving system reliability.

The ERTMS levels are:

1) Overlay using Euro balises and track side signals;
2) Fixed block authority is communicated directly from the Radio Block Center (RBC) to the train using GSM-R; wayside track signals are optionally required;
3) Introduction of *moving block*; wayside track signals are not required (7 s.d.).

The ERTMS level 1 includes:

- Discontinuous system working underlying on already existing signalling systems, providing a continuous speed supervision;
- Movement authorities and track description data generated by electronic Lineside Equipment Unit (LEU), located trackside, based on information received from external signalling systems and track circuits;
- Movement authorities transmitted to the train via wayside balises;
- On-board sub-system calculating a dynamic speed profile taking into account train braking characteristics and commanding the brake application, if necessary;
- Lineside signals required and loop (cable or radio) used to immediately refresh information related to the clear signal aspect (infill function) (7 s.d.).

The ERTMS level 2 includes:

- Radio based Automatic Train Control (ATC) system, working on optional signalling system, which provides a continuous speed supervision toward fixed points of the line (end of block sections, speed restrictions, etc.);
- Movement Authorities, track description data, temporary speed restrictions and emergency messages generated by Radio Block Centre (RBC) based on

information received from train itself, external interlocking system and track circuit (a RBC usually manages about 100 km of double track line);

- Messages transmitted/received to/from the train via GSMR system;
- Balises used mainly for spot transmission of train location reference, to manage hand-over between RBCs and other particular situations;
- On-board sub-system calculating a dynamic speed profile taking into account the train braking characteristics and commanding the brake application if necessary;
- Optional lineside signals (7 s.d.).

The ERTMS level 3 includes:

- Main features similar to ERTMS level 2, except that the target is the end of the preceding train (moving block);
- On-board equipment to check the train integrity (RBC needs this information to calculate movement authority);
- Track Circuit for train detection not required;
- Increased line capacity (relevant for lines with intense traffic at low speed).

Chapter 4

4.1 International High-Speed Lines

The development of European high-speed network is also including various lines, existing or under construction, crossing borders (figure 16).

Countries	Line	Speed [km/h]	Lengt h [km]	Construction start	Expected start of operation
Austria/Italy	Brenner Base Tunnel	250	56	2006	2025
France/Italy	Lyon–Turin	300	72	2016	2025–2030
Germany/ Switzerland	Karlsruhe-Basel	250	182	1987	1993-2030
Portugal/Spain	Lisbon-Madrid [32]	350	640	- [103]	-
Portugal/Spain	Porto-Vigo [32]	250	125	- [103]	-

Figure 16 High Speed Trains Crossing borders (8)

4.2 High-speed network and citizens

The European HSL network is expanding constantly.

United Kingdom, Sweden and Germany have upgraded large sections of their conventional network so that they can be used by high-speed trains.

The opening in November 2007 of the second section of the Channel Tunnel to St. Pancras line is just one of many examples. HSL construction projects are proliferating elsewhere in Europe.

The Belgian HSL network has plans to expand, with the *Diabolo* line to improve rail access to Brussels National Airport.

France has plans to double the HS lines between Paris and Lyon.

Spain has plans to lay some 10,000 km of HSL between now and 2020, to ensure that 90% of its inhabitants have a HST station within 50 km of their home.

With its network saturated in the south of the country, Sweden plans to construct a completely new HS line between Stockholm and Gothenburg.

This line, which will be restricted to passenger trains, will provide better services to numerous towns between the two principal Swedish cities.

This project forms part of a global project, which is designed to improve rail capacity in Sweden by constructing new lines and renovating existing lines.

This action is being taken despite the climate and terrain in Scandinavia, which makes it very difficult to set up railway infrastructure, Europe aims to use the trans-European transport network (TEN-T) to link all HSLs on the continent into.

The liberalization of the mainline international passenger railway market on January 2010 allowed also operators to compete and offer users a wider range of transport options.

The first trans-European HSL, between Paris, Brussels, Cologne, Amsterdam and London, is already close to completion.

This network, which is used by several rail operators (*Thalys*, *Eurostar*, *Deutsche Bahn*, *NS Highspeed*) is significantly cutting journey times among major German, Belgian, French, Dutch and British cities.

The ERTMS will guarantee that the system is fully interoperable.

Already in January 2008, the International Union of Railways (UIC) had registered 1,050 HS carriages in service in Europe (9 s.d.).

Advantages for passengers

High-speed trains provide unsurpassed passenger comfort.

The layout of the compartments, the interior fittings of the carriages and even the lighting are normally designed to create a comfortable and pleasant space suitable both for work and relaxation.

Passengers have a great deal of personal space, with access to more and more services, such as Internet, power sockets for their electronic equipment, headrests and folding tables.
Moreover, they can walk around on board and restaurant cars serves food and drinks.
Unlike on aircraft, the use of mobile telephones is not prohibited, though is normally confined to dedicated spaces to avoid disturbances to other passengers.
Particular attention has also been paid to access to coaches, by reducing the gap in height between the train and the platform.
European standards are gradually being established, both to ensure increasing compatibility between trains and lines and to ensure that carriages comply with high-quality standards, especially in terms of safety and environmental impact.
Moreover, multimodal railway stations in city centers provide quick and easy access to the rail network.
The development of HSL has consistently reduced journey times between couple of cities: since 2009 London is 2 hours + 15 minutes from Paris (5 hours + 12 minutes in 1989) and 1 hour + 51 minutes from Brussels (4 hours + 52 minutes in 1989), which is 3 hours + 15 minutes from Frankfurt (5 hours in 1989) (figure 18).
The advantages of HSLs, in terms of frequent connections, which can easily be modified depending on demand and flexibility for passengers, have allowed the railways to compete more effectively against other modes of transport.
Since 1997, over 6 million passengers/year have been using the Brussels-Paris HSL. As a result, flights have been cut back on this route (9 s.d.).
The density of HS services is anyway increasing all over the world (figure 18).

4.3 Integration with Trans-European Transport Network policy

The program for the trans-European transport network (TEN-T), as introduced under the Treaty of Maastricht and defined in Decision 1692/96/EC in 1996 (2), is designed to guarantee optimum mobility and coherence between the various modes of transport in the Union.

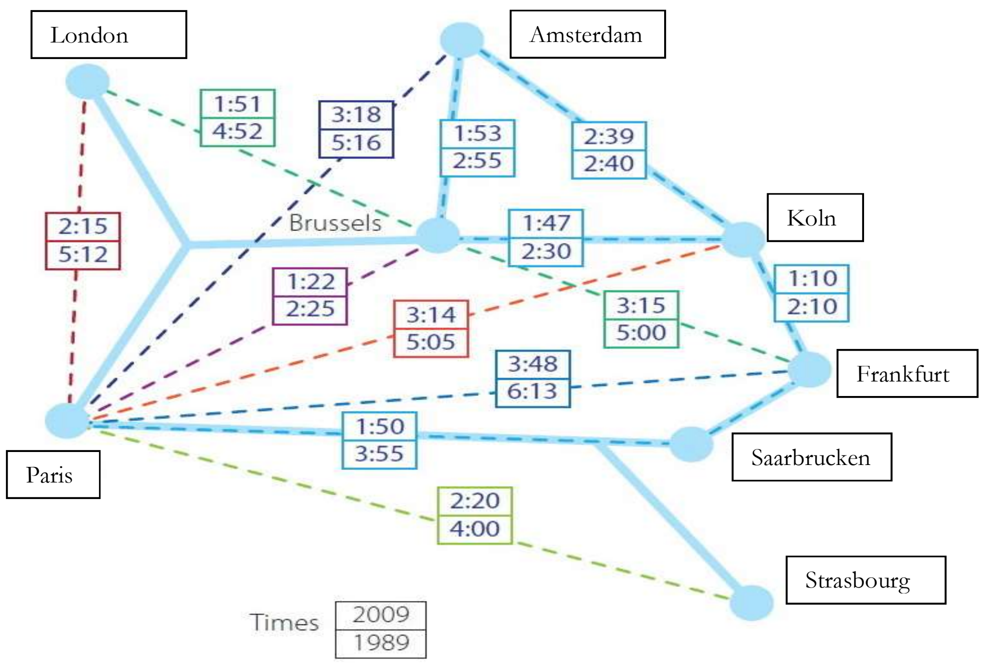


Figure 17 Journey times between stations

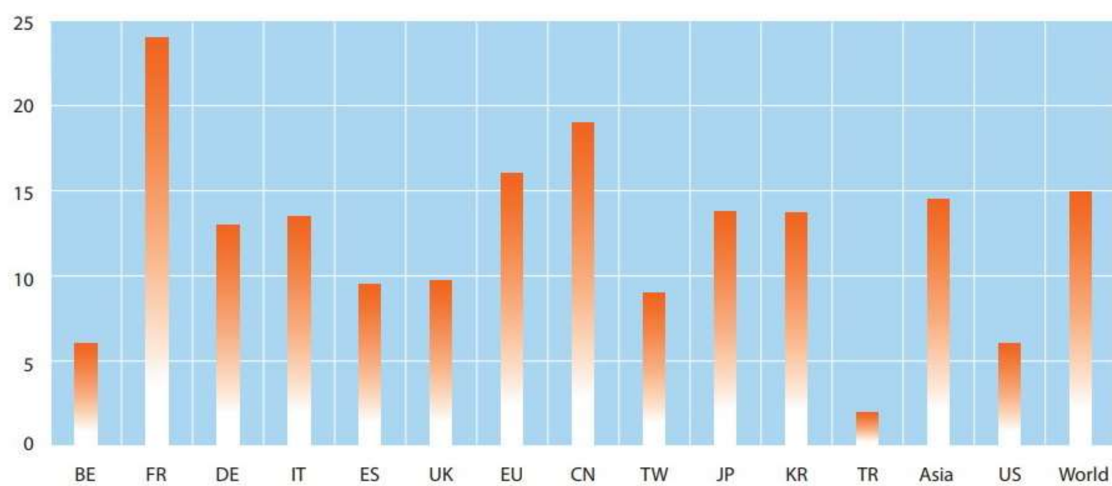


Figure 18 Number of trains per 100 km on HSL in the world (10)

The main priorities of this policy, which accounts for a large part of the White Paper on transport policy in the EU (3), are to establish the key links needed to facilitate transport, optimize the capacity of existing infrastructure, produce specifications for network interoperability and integrate the environmental dimension.

The TEN-T focuses very closely on the development of high-speed transport; of the 30 priority projects put forward under this program, no fewer than 14 concerns (Figure 19).

Axis Project N.	**Project Title**
1	Axis Berlin–Verona/Milan–Bologna–Naples–Messina–Palermo
2	HS axis Paris–Brussels–Cologne–Amsterdam–London
3	HS axis of South-West Europe
4	HS axis East
6	Axis Lyon–Trieste–Divača/Koper–Divača–Ljubljana–Budapest–Ukraine
12	Nordic Triangle railway/road axis
14	West coast main line
16	Freight axis Sines/Algeciras–Madrid–Paris
17	Axis Paris–Strasbourg–Stuttgart–Vienna–Bratislava
19	HS interoperability in the Iberian Peninsula
20	Axis Fehmarn belt
22	Axis Athens–Sofia–Budapest–Vienna–Prague–Nuremberg/Dresden
24	Axis Lyon/Genoa–Basel–Duisburg–Rotterdam/Antwerp
28	*Eurocaprail* on the Brussels–Luxembourg–Strasbourg axis

Figure 19 TEN-T axes and priority projects (10)

The new Lyon-Trieste-Divača/Koper-Ljubljana-Budapest-Ukrainian border railway axis, the new high-speed railway axis in south-west Europe and the integration of the high-speed rail network on the Iberian Peninsula into the European network are just a few examples of TEN-T projects supported by the European Union.

The development of the ERTMS is also one of the projects that receives serious funding as part of the implementation of the TEN-T (10 s.d.).

The HS lines represent a connective tissue to link citizens, which is relevantly increasing its trends (Figure 20) to almost 29,792 km in 2017.

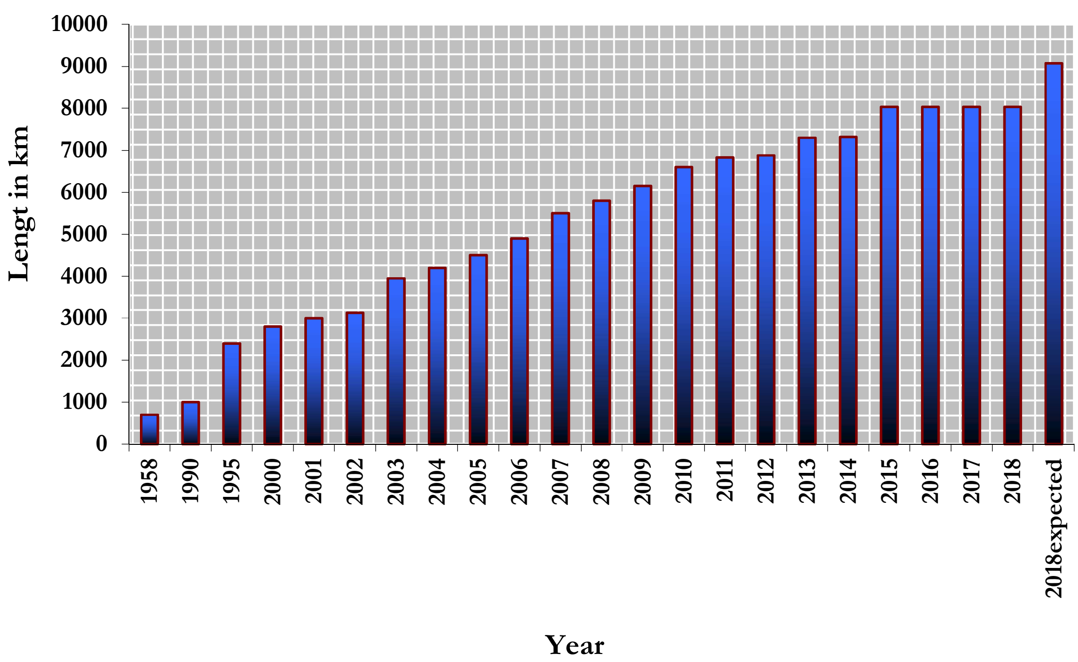


Figure 20 HSL development [km] 1985-2017 (11)

4.4 Growing demand

Since HSL starts, the number of passengers opting for this mode of transport has constantly increased.

The number of passengers on all German, Belgian, Spanish, French, Italian and British lines increased from 15.2 billion passenger-kilometers in 1990 to 92.3 billion in 2008.

The continuous development of efficient, interoperable control & management tools allows increasing infrastructure capacity, while guaranteeing high safety standards.

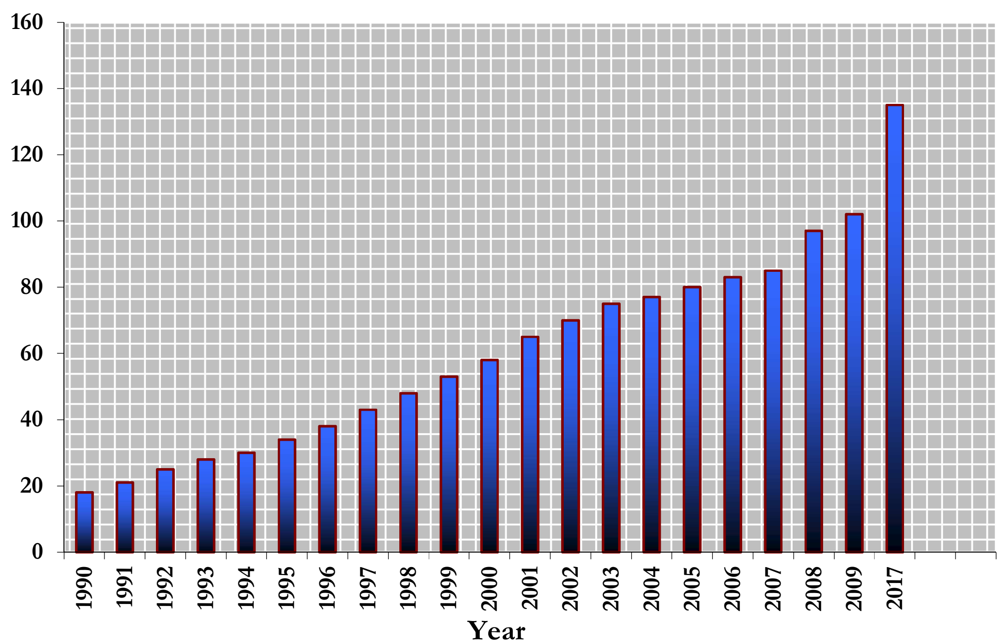


Figure 21 HSL extension [billion passengers' km]

It is possible today to route a train on an HSL every four to five minutes.

Competitiveness with other modes of transport

Expansion of the HSL network has breathed new life into rail transport in terms of competing with other modes of transport. Today, high-speed trains account for approximately 40% of traffic over medium distances and even more on certain routes, such as London-Paris, Paris-Brussels and Madrid-Seville.

It is, in fact, on journeys under three hours that HS trains are most competitive: access time is much shorter than by air and journey times are shorter than by car.

In 2007, passengers on all European rail networks travelled an average of 372 km on high-speed lines.

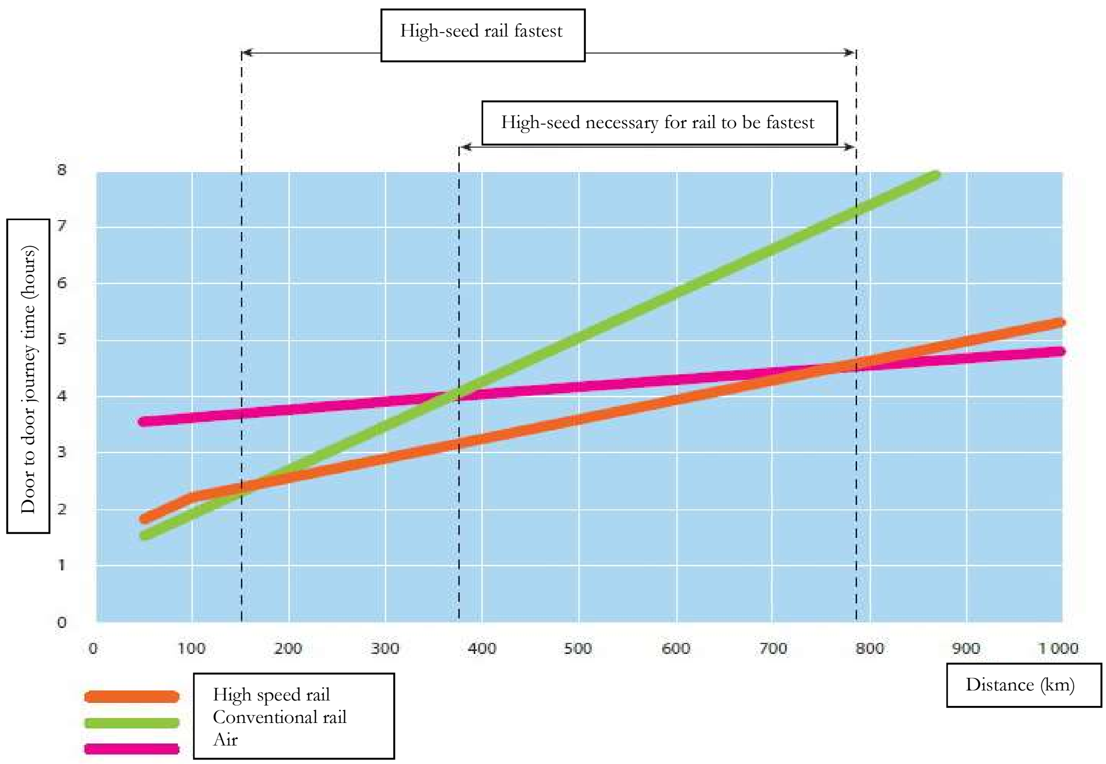
HSLs are preferred over air and road travel for journeys of between 400 and 800 km.

Under 150 km, they offer a limited bonus compared with road or conventional rail travel.

Between 150 and 400 km travel by rail (on both HS and conventional lines) is the quickest.

Above 900 km, air travel gains the upper hand, except for journeys on which rail offers specific advantages (HS snow train, overnight services, car trains, etc.).

The European Union is using the TEN-T program to encourage cooperation between rail companies, airlines and road transport operators, in order to foster synergies between these different sectors and optimize the integration of transport at European level.



This approach will improve transport energy use and generate environmental advantages.

Figure 22 Journey times v. distance for rail (HS and conventional lines) and air transport

4.5 Intra-modality and co-modality

The key role of the European Agency for Railways (EUAR) was set up in 2004 in order to support the development of a safe European rail network, the competitiveness of which would no longer suffering of technical obstacles.

The EUAR is mainly concerned with improving network safety and interoperability.

It plays a key role because, in a railway area without barriers, a decision taken unilaterally by one country might potentially prevent foreign trains from operating in it.

The existence of a European coordination body is, by definition, a key element in guaranteeing the efficiency of the European rail network of tomorrow (10 s.d.).

Intermodality means the use of several modes of transport during a single journey.

This concept applies to both passengers and freight transport.

The environmental impact of aircraft and saturation of the major European airports is leading towards limitations on air traffic within the Union.

This creates a favorable situation for fostering synergies between the rail and air networks.

Airlines can therefore make use of HS networks to channel passengers from various regions to a central airport.

The Thalys trains have already created this sort of synergy between Brussels and Paris Charles-de-Gaulle Airport.

Co-modality means the use of each mode of transport for the most suitable purpose and, where appropriate, the use of a combination of modes of transport.

Applied to the railway sector, this principle infers that the capacity freed up by HSL is available for long-distance goods traffic, which is the preferred means of transporting rail freight.

The gain in capacity translates into infrastructure availability, be it virtual (free train paths) or physical (dedicated infrastructure).

However, where train paths are available, this gives rise to a number of technical and operational challenges.

The difference in speed between a (slower) goods train and a high-speed train impacts on rail traffic management for the simple reason that freight trains spend longer on the track and therefore use up more traffic capacity (train paths).

This difference in speed may also cause safety problems when these two types of train pass.

This makes safeguarding infrastructure availability, while guaranteeing optimum capacity and security, an extremely difficult task.

Physically freeing train paths simply means dedicating HSL solely to passenger traffic and giving freight a higher priority on conventional lines.

This is an option explored by Sweden, in particular (10 s.d.).

Interoperability also concerns the synergy between HSL and conventional networks. European rolling stock manufacturers have had to call on all their know-how and technical expertise in order to design high-speed trains that can run on conventional tracks.

Some Spanish HST (Alaria, Alvia and Talgo) and all French HST are able to operate on conventional lines.

In Germany and Italy, the network is completely compatible.

All categories of trains are able to use HS and conventional lines indiscriminately (10 s.d.).

Moreover, there are some particularly remarkable examples of HS stations operating along intermodal lines with airports.

Frankfurt International Airport is a pioneer in this: opened in 1972, traffic increased considerably following the introduction of the Frankfurt-Cologne HSL in 2002.

According to Deutsche Bahn, two thirds of train passengers are either leaving or arriving by plane.

In France, the station at Paris Charles-de-Gaulle Airport is located at the interconnection between the North and the South-East HSL.

It serves 52 HST/day, linking the main towns in France, and 5 HST to northern Europe (Brussels and Amsterdam).

In Belgium, Brussels National Airport is in relationship with all main Belgian cities and to several European cities, such as Paris, Amsterdam, Cologne and Frankfurt, by 2012 (10 s.d.).

4.6 Making transport more ecological

At a time when climate change is high on the political and social agenda, the attraction of rail transport is even greater, due to its low environmental impact.

Out of 25.1% of CO_2 emissions attributable to transport in the EU-27 in 2007, only 0.6% were from rail, which carried over 6% of all passengers and nearly 11% of freight (8).

HST are electrical and their carbon footprint is therefore almost zero in their operating zones, although the CO_2 emitted during electricity generation does need to be into account.

This rate varies depending on the primary energy used to generate the electricity consumed by HSL.

If generated from solid fossil fuels (coal), as in Poland or Germany, HSL obviously have a bigger carbon footprint.

However, the development of renewable and/or nuclear energy will reduce this impact in future.

Although the environmental impact of HSL is also sensible to reduction by improving the energy efficiency of trains and working on other elements of the vehicle, the carbon footprint of rail travel is still much smaller than that of air or road travel.

In the case of a journey from Paris to Marseilles, CO_2 emissions are just 2.7 g / (passenger x km) by HST, compared with 153.0 g / (passenger x km) by air and 115.7 g / (passenger x km) by car (9).

Member State	Solid fuels	Oil	Gas	Nuclear	Renewable	Total
BELGIUM	11.8 %	1.9 %	25.3 %	58.1 %	2.9 %	100 %
GERMANY	54.0 %	0.1 %	8.3 %	26.7 %	10.9 %	100 %
SPAIN	38.0 %	3.8 %	18.3 %	21.5 %	18.4 %	100 %
FRANCE	4.5 %	1.8 %	3.2 %	85.8 %	4.7 %	100 %
ITALY	33.8 %	10.0 %	41.5 %	0.0 %	14.7 %	100 %

Figure 23 breakdown by origin of energy used by the railways

From the point of view of energy efficiency, HSTs also perform better, using 12.1 g / (passenger-kilometer) of petrol, compared with 17.6 for conventional trains, 18.3 for coaches, 29.9 for cars and 51.5 for aircrafts.

CO2 emissions by mode of transport in the EU

If the HSL network is deployed as planned, it will allow savings of the equivalent of 22 million t of CO2 until 2020 and 34 million t/year once the network has been fully deployed in 2030 (11).

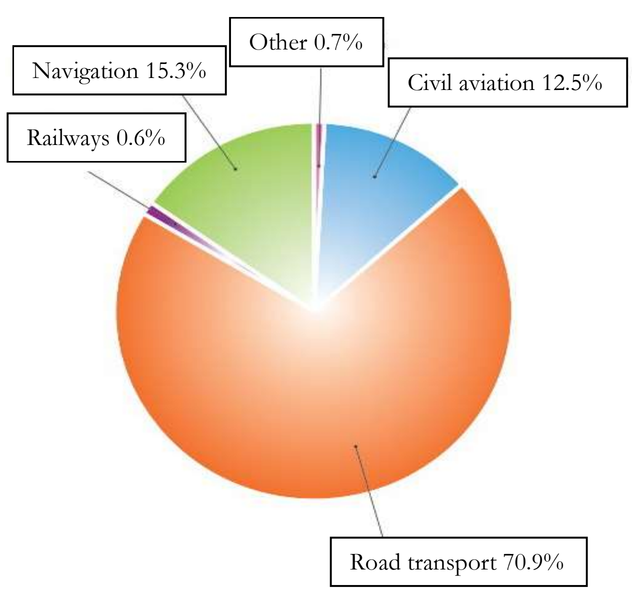


Figure 24 CO2 emissions by mode of transport (10)

Research is already under way to minimize the environmental impact of high-speed trains by reducing their dependency on fossil fuels.

Numerous projects funded by the EU focused on reducing noise pollution from HSL.

Mention should also be made of the European *Noemie* campaign, aimed at evaluating the noise impact of high-speed trains.

For its part, the European Commission issued a communication in July 2008 on rail noise abatement, which made provision for measures to halve the noise from freight trains and reduce it significantly for 16 million citizens (10 s.d.).

Chapter 5

5.1 The Future

According to forecasts in the TEN-T program, the trans-European HS network (category I and II lines) should be 22,140 km long by 2020 (they were 9,693 km in 2008).

By 2030, once the high-speed TEN-T will be complete, the network will include 30,750 km and the traffic will rise to 535 billion passengers per km / year.

In order to develop a full trans-European HS network, several priority projects are devoted to the north-south link between networks.

The South-West high-speed rail axis will link the Iberian Peninsula to the rest of Europe in a fully interoperable network.

The vital North-South corridor through the Alps (Berlin-Verona-Milan-Bologna-Naples-Messina-Palermo axis) will link major German and Italian cities.

The Lyon-Trieste-Divača/Koper-Ljubljana-Budapest-Ukrainian border axis, which crosses the North-South corridor at right angles, will be able to absorb a part of the constantly increasing traffic among the Southeast, the Centre and the Southwest of Europe.

Network extension projects will be also in Poland, Sweden and the United Kingdom.

Poland has already announced a new HSL, linked to the European network, between Warsaw, Wroclaw and Poznan.

The network will also need extensions to third countries, in order to cope with the increase in passenger and freight volumes forecast until 2020.

Thus, Russia will link to Finland by a 415 km upgraded line, which will provide the first fast rail link between Russia and the EU.

The number of passengers between Helsinki and St Petersburg are more than the double from 2007 to 2014, while speeds will increase from 160 km/h to 220 km/h, by reducing the journey time between the two cities from 5 + 30 minutes to 3 hours + 30 minutes.

To the southeast, Turkish State Railways are receiving EU support to develop their own high-speed network.

The first 200 km section linking Ankara to Eskisehir was in operation in 2009, reducing the journey time between the two cities from 3 hours to 1 hour + 20 minutes.

The extension to Istanbul (533 km), cut the journey time from Ankara to Istanbul from 6 hours + 30 minutes to 3 hours.

Three lines more lines are under construction: Ankara-Konya, Ankara-Sivas and Istanbul-Bulgarian border.

Fighting climate change, by developing a trans-European HSL network, is one of the European Union's main objectives.

High-speed passenger transport will allow maintaining high levels of mobility, while guaranteeing the sustainability of the European transport system.

5.2 Conclusions

The empirical evidences from the Italian HSR market, presented in this paper, show an outstanding increase (+45%) of passenger x km in the first two years of operation, between 2009 and 2011 of Italian HS network.

This is partly due to increased HSR modal share and partly due to the additional demand induced by the HSR.

Compared to the variation of travel time (ranging from 30% to 40% depending on the O-D), direct elasticity's values of HSR demand, significantly greater than 1 (in absolute value) were observed.

Such values are very substantial, but are comparable with those reported in the literature.

Moreover, an inverse relationship of the elasticity values with the distance is resulting: the shorter the O-D distance, the higher the elasticity's of HSR demand, suggesting for non-linear effects of induced demand, which need to be verified more in depth and possibly quantified.

Further investigations will focus on the weekend mobility and on the foreigners (occasional) demand flows.

On the other hand, the forecast framework presents a nesting structure to capture higher degrees of substitutions among specific subsets of modal alternatives, particularly the HS alternative services provided on the same route by different operators (e.g. NTV vs. Trenitalia).

Bibliography

1. *What is the fastest train in the world*

https://www.goeuro.com/trains/high-speed#footnotes. n.d.

2. *High-speed rail in Italy*

http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO/Istantanea-sulla-rete. n.d.

3. *High-speed rail in France*

https://en.wikipedia.org/wiki/High-speed_rail_in_France. n.d.

4. *High-speed rail in Germany*

https://en.wikipedia.org/wiki/High-speed_rail_in_Germany. n.d.

5. *High-speed rail in Spain*

https://www.eurail.com/en/europe-by-train/high-speed-trains/ave. n.d.

6. *High-speed rail in Spain netwok*

https://en.wikipedia.org/wiki/AVE. n.d.

7.*Signalling-systems-*

http://www.apta.com/mc/hsr/previous/2010/HighSpeed%20Rail%20Presentations/Technological-Systems-for-HSR-Lines.pdf. n.d.

8. *High Speed Trains Crossing Borders*

https://en.wikipedia.org/wiki/High-speed_rail_in_Europe. n.d.

9.*The-High-Speed-Network-and-Citizens*

https://ec.europa.eu/transport/sites/transport/files/themes/infrastructure/studies/doc/2010_high_speed_rail_en.pdf. n.d.

10.*Link-with-trans-European-transport-network*

https://ec.europa.eu/transport/themes/infrastructure/ten-t-policy/priority-projects_en. n.d.

11. *Increase in HSLs in km*

https://www.eea.europa.eu/data-and-maps/daviz/length-of-high-speed-rail-1#tab-chart_1. n.d.

12.*Increase-in-number-of-HS-passenger-kilometres*

https://www.eea.europa.eu/data-and-maps/indicators/passenger-transport-demand version2/assessment6. n.d.

13.*Journey-times-v.-distance-for-rail-(HS-and-conventional-lines)-and-air https://ec.europa.eu/transport/sites/transport/files/themes/infrastructure/studies/doc/2010_high_speed_rail_en.pdf*. n.d.

14.*Energy-used-by-the-railways https://ec.europa.eu/transport/sites/transport/files/themes/infrastructure/studies/doc/2010_high_speed_rail_en.pdf*. n.d.