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UIC 2019 PAS 614 MIXED TRAFFIC STUDY

MIXED TRAFFIC HIGH SPEED LINES OPERATIONS HANDBOOK

December 2020

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1 UNDERSTANDING

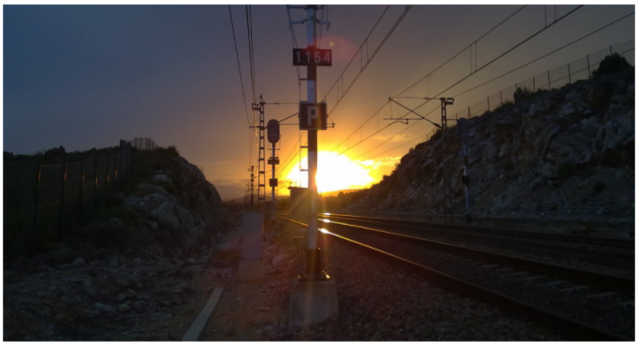
1.1 Introduction

Although currently high-speed railways are almost exclusively associated with passenger services, there is a current trend to increase the efficiency of high-speed lines incorporating certain rail freight services, in some cases with daytime integration of freight trains, and in others only with nighttime traffic.

The new sections of the European corridors, which are forecasted to complete the Core Network, expect all types of traffic with the scope of maximizing their incomes, such as those that would come from their shared use with the lines for passenger transportation at 250 km/h, goods transportation, and even, in some specific sections, with regional intercity trains operating in services over 200 km, which are considered for high speed.

In addition, these new mixed traffic lines can directly contribute to the decongestion of network sections, bottlenecks where there are saturation problems and therefore there is an under-development of rail transport.

The infrastructure managers wish to encourage both the development of new high speed freight markets and certain conventional freight trains and do not preclude the possibility that the profitability in such markets would enable them to make an increased or full contribution to all costs.



On the other hand, the hegemonic situation of the exclusive HSL for passenger traffic is being reduced by the most recent projects, as evidenced by the fact that in a large part of the European lines currently under construction or an advanced stage of planning are been designed with mixed traffic parameters.

In this change of high-speed culture as exclusive passenger lines, it is surely influenced by the fact that the existing HS network has already covered the corridors with the highest demand for passengers, and, therefore, those corridors that offered major expectations of sustainability under an exclusive passenger traffic operation.

This being so, it will be increasingly evident that the new sections that are necessary to complete the network will need to the contribution of other types of traffic for improve its sustainability, such as those that would come from its sharing use with freight transport.

Moreover, Mixed Traffic HS Lines can directly contribute to the decongestion of network sections where there are still significant saturation problems and therefore are limiting the development of rail transport.

All of the above indicates that from now on there may be a growing interest in developing new lines or new stretches of high-speed network with mixed traffic and consequently looks appropriate to study and determine what should be the most accurate conditions under they should be developed and what key requirements should characterize the implementation of these Mixed Traffic High Speed Lines.

The main expected advantages of a mixed HSL over an exclusive of passengers are the following:

- Shift freight from road to rail and therefore reduce pollution and the number of accidents.
- Enhance capacity for the entire rail network and eliminate bottlenecks.
- Improve the efficiency of high-speed lines, taking advantage of the use of its capacity available.
- Contribution to improve the cost-benefit ratio of high-speed lines.
- Improving the competitiveness of rail freight transport and opening up to new higher value markets.
- Establish operational and maintenance procedures more efficient for the rolling stock of freight trains.

1.2 High speed Lines current situation

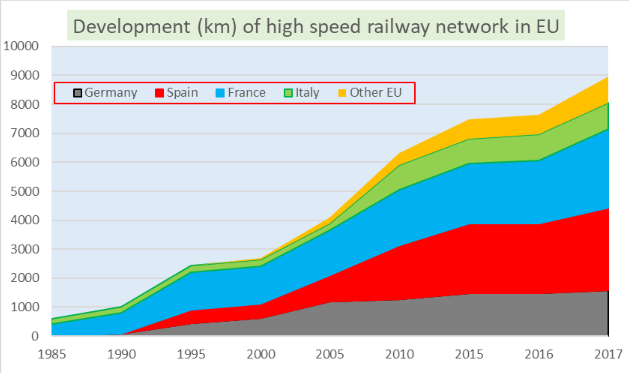
Currently, most high-speed lines in operation, understanding HS where the maximum speed is equal to or greater than 250 km/h are dedicated to passenger transport.

This situation has been revealed both since the beginning of its operation in Japan, in the second half of the last century, and in its most spectacular developments performed in China.

This conception of high speed as a service exclusively dedicated to passenger transport, has also been the main guideline in its development in Europe.

In the current European high-speed network, whose length is around 9000 km, only 15% of this network is mixed use for the transport of both passengers and goods.

This reality of high-speed prominence as an exclusive network in the service of passenger transport is a consequence of its own creation.



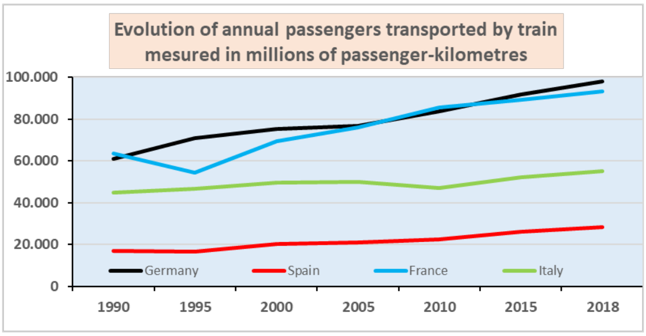
Development of high-speed railway network in the EU

Indeed, high speed emerged as a response of the rail system to its loss of competitiveness in the face of the development of other alternative modes of transport in the internal market for long-distance passenger transport.

In Europe, where the first high-speed line, Paris-Lyon, was inaugurated 1981, its triggering factor by that time was:

- The resolution of capacity problems existing in certain sections of the conventional network
- The incorporation of technological solutions that reverse the loss of competitiveness, mainly in terms of journey times, against alternative modes of transport.

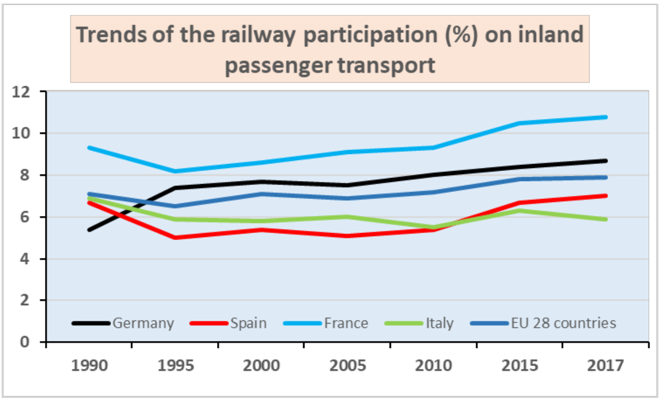
Since then, its commercial success has been unquestionable and the country where it has been implemented has contributed decisively to improve the use of the railroad and to recover its market share.



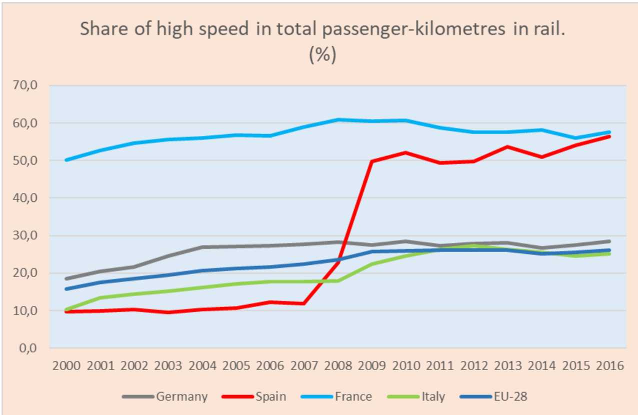
Evolution of annual passengers transported by train

With its development, the High-Speed rail has contributed to:

- Increase the total rail passenger transport by 50%
- Stop the loss of rail market share by improving it between 2 to 3 points
- Reach to transport share currently over 50% of total rail passenger

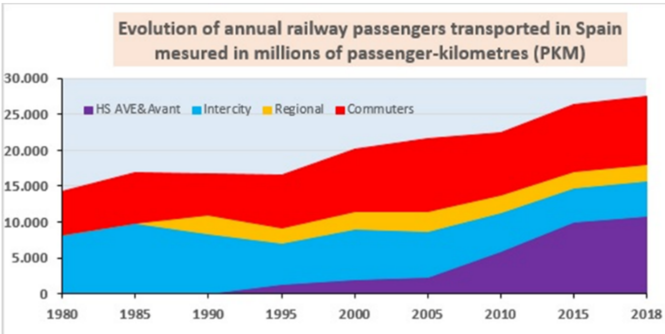


Trends of the railway participation on inland passenger transport



In Europe and so far, this century, the demand for high-speed transport has doubled, maintaining a sustained annual growth of passengers of 4.5%.

In that same period, the highest growth in high-speed demand occurred in the Spanish network, in which since 2000, the average annual passenger-kilometres growth has been 14%, and that is, the high-speed demand has multiplied by eight.



Evolution and annual railway passengers in Spain

Naturally, in this spectacular growth of the demand, the important extension of the network has been decisive, since year 2000 in Spain almost 2000 km of new high-speed lines or sections have entered into service.

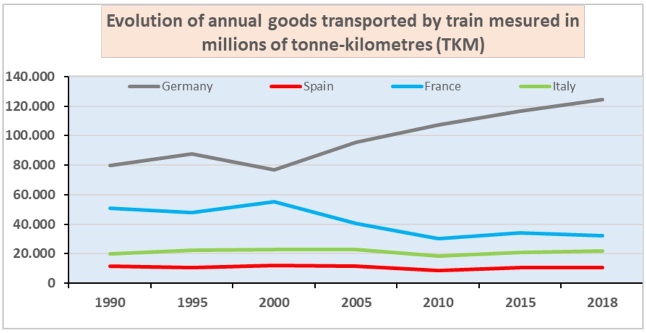
Nevertheless, without any doubt, two essential factors have contributed decisively in the success of high speed all over the world:

- The high performance of the service, basically in very competitive journey times.

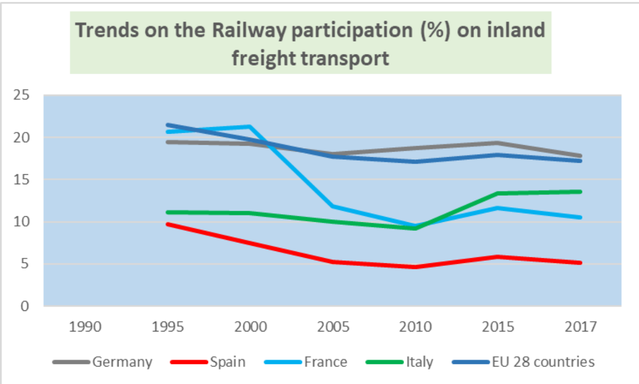
- The high quality of high-speed service, particularly in terms of reliability.

Contrary to this favourable side of the railroad, freight transport maintains an evolution of certain stagnation when it does not regress, both in absolute terms and in market share.

- In the whole the European Union, the transport of goods has been practically stagnated since 2000.
- In the last 20 years, the railroad has lost more than four (4) market share points in freight transport, and in some important networks, the loss has been even greater.



Evolution of annual goods transported by train



Trends of the railway participation on inland freight transport

For the time being, the expected recovery of the rail market share caused by the liberalization of freight transport, has not yet borne fruit.

Given this situation of stagnation and considering:

- The push of modernization and innovation associated with high-speed development, not only in terms of performance and reliability but also in service-oriented culture.
- The persistence of congestion situations in the conventional network that hinder even the natural development of freight traffic. The congestion persists particularly in the existing rail network sections located around mayor cities (densely populated areas) where the gain of capacity caused by the shifting of passenger long distance trains toward new HSL has by offset by the development of commuter services.
- The very existence of high-speed lines with spare capacity
- As well as the development of new lines or new sections of the high-speed network in which the contribution of freight transport can improve its justification and sustainability.

All this or in part is what, under certain circumstances and requirements, has led to the promotion of mixed-use high-speed line solutions, that is, with the circulation of freight trains.

1.3 Rail freight transport current situation

Freight transport by rail is economically efficient but is still confronted with an unequal playing field compared with other modalities. It is a well-known fact that competitiveness increases the greater the distance, but it has also been shown that the tipping point can be reached on shorter distances.

Road transport is much cheaper because a very large portion of the external costs are not borne by the user but by society. It is the task of policy makers to correct these distortions. This can be done by imposing additional taxes on road transport by introducing compensation for alternative modes and/or by encouraging road transport to use alternative modes. Transport policies must include environmental objectives in the development of price mechanisms.

Implementing a compensation policy is relatively easy to finance. An important part of the external costs of transport could be internalised by road charges or carbon taxation, which in turn can be used to stimulate the use of transport modes with the lowest external cost.

Here are some additional advantages of rail transport over road transport to consider:

- Rail transport can be cost effective. Shippers who convert long-haul freight from road to rail, can save 10-40%. Rail has lower fuel costs compared to road transport, especially when shipping a high volume of freight. Rail also has less costs associated with drivers and typically has better costs for drop trailer programs.
- Shipping via train is more environmentally friendly. Trains burn less fuel per ton mile than trucks. According to the Association of American

Railroads (AAR), freight railroads can move one ton of freight an average of 479 miles on a single gallon of fuel. On top of that, using rail transport over road transport can lower greenhouse gas emissions by 75%.

- Trains are capable of hauling large loads. Trains can handle high volumes of freight. In fact, one double-stacked train can hold approximately the same amount as 280 trucks. This can be very beneficial for shippers with large loads.
- Railways are reliable. Railways have standardized transit schedules and don't share their tracks with the public like trucks do with the road. For that reason, trains aren't hindered by traffic and weather the same way trucks are.
- Rail freight can be efficient. For many types of loads, the average transit time is comparable to that of road transport. While rail shouldn't be used for time-sensitive shipments, it can provide very similar transit times for longer hauls.
- Rail options provide you with access to capacity. OTR capacity is tight. The driver shortage, HOS restrictions, and current market demand can make it hard for shippers to find a truck when they need it without paying an arm and a leg. Since rail transport can be more efficient and doesn't have the same kind of limitations, this is a great way for shippers to find capacity.

Taking into account all the societal benefits of railways, authorities should provide sufficient funds for standardisation of easy-to-use infrastructure and increase of needed capacity. To-day, priority rules are used as a customary way of managing traffic, although the rationale behind the priority rules was originally to face exceptional traffic circumstances.

The systematic resort to priority rules during day-to-day operations is a symptom that the system is stretched to its limits. Public investment in rail infrastructure should come even more naturally, given that rail gives huge societal benefits for this investment compared with roads.

The same goes for spatial planning and industrial policies promoting the bundling of cargos, such as the development of freight villages / industrial parks and their connectivity with rail.

1.3.1 External costs

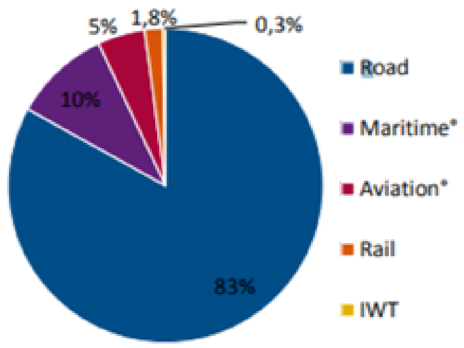
External costs have been a key issue in the last years of transport research. In Europe, this trend is in line with the political willingness to internalize externalities in transport pricing policies.

External costs are costs generated by transport users and not paid by them but by the society as a whole such as congestion, air pollution, climate change, accidents, noise but also up- and down-stream processes, costs for nature and landscape or additional costs in urban areas.

There is a market failure because transport prices are not reflecting their costs and transport users are choosing their transport mode with a wrong price signal. UIC recommends internalisation of these external costs to allow transport users to take the right decisions and the polluter pays principle to optimise the transport sector.

UIC is a pioneer in external cost study field on European scope for several transport modes: rail, road, air and also inland waterways.

External accident costs constitute a relatively large part of total external costs, in particular for road transport.



* Data for aviation and maritime: rough estimations for EU28.

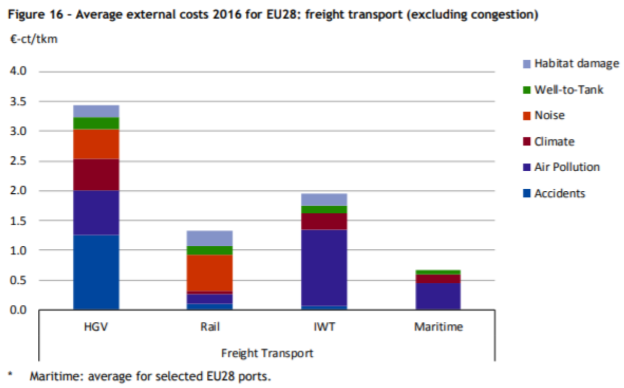
Share of the different transport modes on total external costs 2016 for EU28. Source: UIC

Accident costs in general are the result of traffic accidents. These social costs include costs for material damages, administrative costs, medical costs, production losses and immaterial costs (lifetime shortening, suffering, pain, sorrow, etc.). Material costs can be calculated using market prices as they often (but not always) can be insured against. In contrast for immaterial costs no such market prices do exist and other sources are needed to estimate these costs (e.g. risk values through stated-preference studies). The sum of material and immaterial costs builds the total social accident costs.

Air pollution caused by transport activities leads to different types of external costs. The most important external costs are health costs due to cardiovascular and respiratory diseases caused by air pollutants. Other external costs of air pollution include building and material damages, crop losses and impacts on biodiversity and ecosystems.

The greenhouse gas (GHG) emissions contribute to global warming resulting in various effects like sea level rise, agricultural impacts (due to changes in temperatures and rainfall), health impacts (increase in heat stress, reduction in cold stress, expansion of areas amenable to parasitic and vector borne disease burdens (e.g. malaria, etc.), ecosystems and biodiversity impacts, increase in extreme weather effects, etc.

Noise can be defined as the unwanted sound or sounds of duration, intensity or other quality that causes physical or psychological harm to humans. Transport noise imposes undesired social disturbances, which result in social and economic costs like any restrictions on enjoyment of desired leisure activities, discomfort or inconvenience, etc.



Average external costs 2016 for EU-27: freight transport (excluding congestion). Source: UIC*

As can be seen in the graph above, in 2008 rail freight transport is responsible for less than 2% of the total external cost.

Compared to road, rail freight has a six-time lower specific energy consumption, mainly due to its intrinsic and persisting physical advantage of the low friction of steel wheels running on steel rail. This translates into six-times lower external costs compared with road regardless of the energy source (while rail is even less polluting since it mostly operates on electric energy).

In light of accelerating climate change, this advantage must become an eligible source of compensation for the existing direct cost disadvantages of rail transport versus road transport. A higher modal share of 30% rail freight by 2030 is a better macro-economic solution for European transport growth.

The European rail freight sector is also convinced that this ambitious target is achievable, if the "*way of doing business*" is substantially changed, with more multimodal solutions, and the required prerequisites are in place.

Decisive action is required by Railway Undertakings, Infrastructure Managers and Authorities to achieve the desired modal shift. The initiative to boost rail freight traffic, which was launched by the member states with the Rotterdam Declaration and supported by the declaration of the entire railway sector (Sector Declaration) in 2016, represents a valuable basis for these actions.

Rail Freight Forward, the vision and action plan of the rail freight undertakings from across Europe, builds on the previous achievements and aims at a rapid implementation on the entire European Network going beyond the Rail Freight Corridors.

1.4 Future of freight traffic in Europe

The movement of goods in the European Union has increased by almost 25 % over the last 20 years and is predicted to increase by a further 50 % between 2015 and 2050. Total freight transport activities in the EU in 2015 amounted to an estimated 3516 billion tonne-kilometres. Almost half (49 %) of these activities were carried out by road, followed by sea (31.6 %), railway (11.9 %), inland waterway (4.2 %) and oil pipeline (3.3 %). Only 0.1 % of goods were transported by air.

All these freight transport activities are accompanied by a large amount of information, which, in 99 % of cases, still involves paper documents at one stage or another. This is mainly because many stakeholders (Member State authorities, clients and business partners) still do not always accept electronic freight transport information when provided as evidence of compliance with rules for the transport of goods. The Commission's proposal states that two main, mutually reinforcing drivers, underpin this problem:

- A fragmented legal regime setting inconsistent obligations for authorities to accept electronic information or documents.
- A fragmented information technology (IT) environment with non-interoperable systems and solutions for electronic freight transport information exchange.

Yet the digitalisation of information exchange could make the transport of goods much more efficient and reliable and generate significant savings. A cut in administrative costs could save industry between €20 and 27 billion over the 2018-2040 period, according to Commission estimates. In addition, there would be positive impacts on congestion and the environment as an electronic freight transport information would generate significant CO2 emission and natural resource savings.

In 2014, the EU established a public-private joint undertaking, Shift2Rail, to provide a platform coordinating and developing research and innovation activities to be integrated into advanced rail solutions.

Funded by Horizon 2020, it aimed to promote rail competitiveness and to pursue specific benefits such as cutting the life-cycle cost of railways by 50%, doubling its capacity and increasing its punctuality by 50%.

Although Shift2Rail does not identify digitalisation as an objective per se, it carries out several activities linked to it in some of its five innovation programmes (IP). For instance, the first programme (IP1) was designed to reinforce the digitalisation of train subsystems and equipment (traction, brakes, and doors). IP2 was geared towards maintaining the European rail traffic management system (ERTMS) as a solution for signalling and control systems across the world. IP4 introduces innovations in digital services for passengers (ticketing, trip tracker, etc.) and IP5 focuses on new digital features enhancing the punctuality of rail freight.

Originally planned for 2020 on the six corridors with the highest freight traffic, the ERTMS deployment plan was revised in 2017 with more realistic deadlines: aligned with the trans-European transport network (TEN-T) and the requirements for a European rail network for competitive freight, the ERTMS should equip 50% of nine core freight corridors by 2023 and the remainder by 2030.

The European Union Agency for Railways, the authority for ERTMS implementation and standards, and the European coordinator for the ERTMS, Karl Vinck, observed recently that deployment of this system was too slow. The EU coordinator noted that the biggest problem was the slow migration from legacy signalling to the ERTMS.

In 2015 the European Commission set up an expert group, the digital transport and logistic forum (DTLF), with a view to improving interoperability in freight transport across modes and sectors. Composed of experts from Member States, public entities and organisations, who share expertise and coordinate recommendations with regard to transport digitalisation, it provided input for the 2018 legislative proposal on electronic freight transport information and for the establishment of digital corridor information systems, which are designed to facilitate data sharing between supply chain stakeholders.

The proposal is aimed at encouraging the use and acceptance of e-freight information by state authorities and business operators in all transport modes, including rail, and to propose interoperable IT solutions to exchange this information. Digitalisation would lead to a reduction in the use of paper documents, make the transport of goods more reliable and, according to the Commission, generate savings in management costs.

In November 2017, the CER, the EIM, the European Rail Freight Association (ERFA), the International Union of Wagon Keepers (UIP), the International Association of Public Transport (UITP) and UNIFE signed a joint declaration on the digitalisation of railways. They underlined the key role of digitalisation in rail transport to adapt to customer expectations on safety, security, capacity, punctuality, and information availability. The signatories welcomed the recent open data initiatives and called for strong political and financial support from the European Commission to sustain the digitalisation process.

In the framework of commitments under the next MFF, they insisted on dedicated CEF funding, in particular to continue the rolling-out of ERTMS. Lastly, the signatories called for an increase in funding instruments for rail research, innovation and deployment in a 'Shift2Rail 2.0' programme, with digitalisation at his heart, in the framework of the proposed Horizon Europe programme.

Experts and stakeholders perceive the changes brought by digitalisation as both an opportunity and a challenge for rail transport. Rural migration to urban areas and the continuous increase in world population are reinforcing the demand for rail services, where digitalisation could have an important role to play, in particular considering the improvements in efficiency and environmental sustainability it can offer.

Rail could become the backbone of transport between and within cities, in coordination with other transport modes to provide the door-to-door services; something that is vital to remain competitive. Digitalisation is an opportunity for rail, owing to the numerous benefits it can provide improved capacity, traffic management, reliability, energy efficiency, services and lower operating costs.

Although freight rail companies are incredibly successful today, the railroad of tomorrow is going to be vastly different. They’re absolutely on the cusp of big transformational change, which is terribly exciting and creates a lot of opportunities for innovation to meet the demand.

Technology will lead the way for railroads. They’ll be successful in the future by focusing on the level of service and lowering costs; these two items are enabled and will be enabled by technology. Technology will help make railroads’ operations more resilient.

By proactively maintaining equipment and infrastructure, railroads can prevent stoppages and make the network run more smoothly. New technology will allow rail companies, shippers and customers to have much more control over their assets and use the network much more productively.

The transformation that the freight railway sector in Europe is undergoing is similar to that which must take place in other countries to increase the freight railway market.

The American Federal Highway Administration estimates that demand for freight shipments will increase 35% by 2040. Freight trains will play a crucial role in moving these goods and the American economy, ensuring raw materials and finished products move quickly, safely and efficiently.

1.5 The dilemma of mixed traffic high speed lines

When incorporating freight traffic on a high-speed line, there is a certain paradox when having to reconcile the circulation of trains with very different characteristics,- maximum axle load, train length and total weight -, but especially with very distant performances,- mainly the significant gap between their respective maximum speeds -, being that their coincidence on the same track do not always offer fully satisfactory solutions on the line design and its subsequent exploitation.

The logical process of designing and developing a mixed traffic high-speed rail line, responds to the following sequence of circumstances and correspondent decision making:

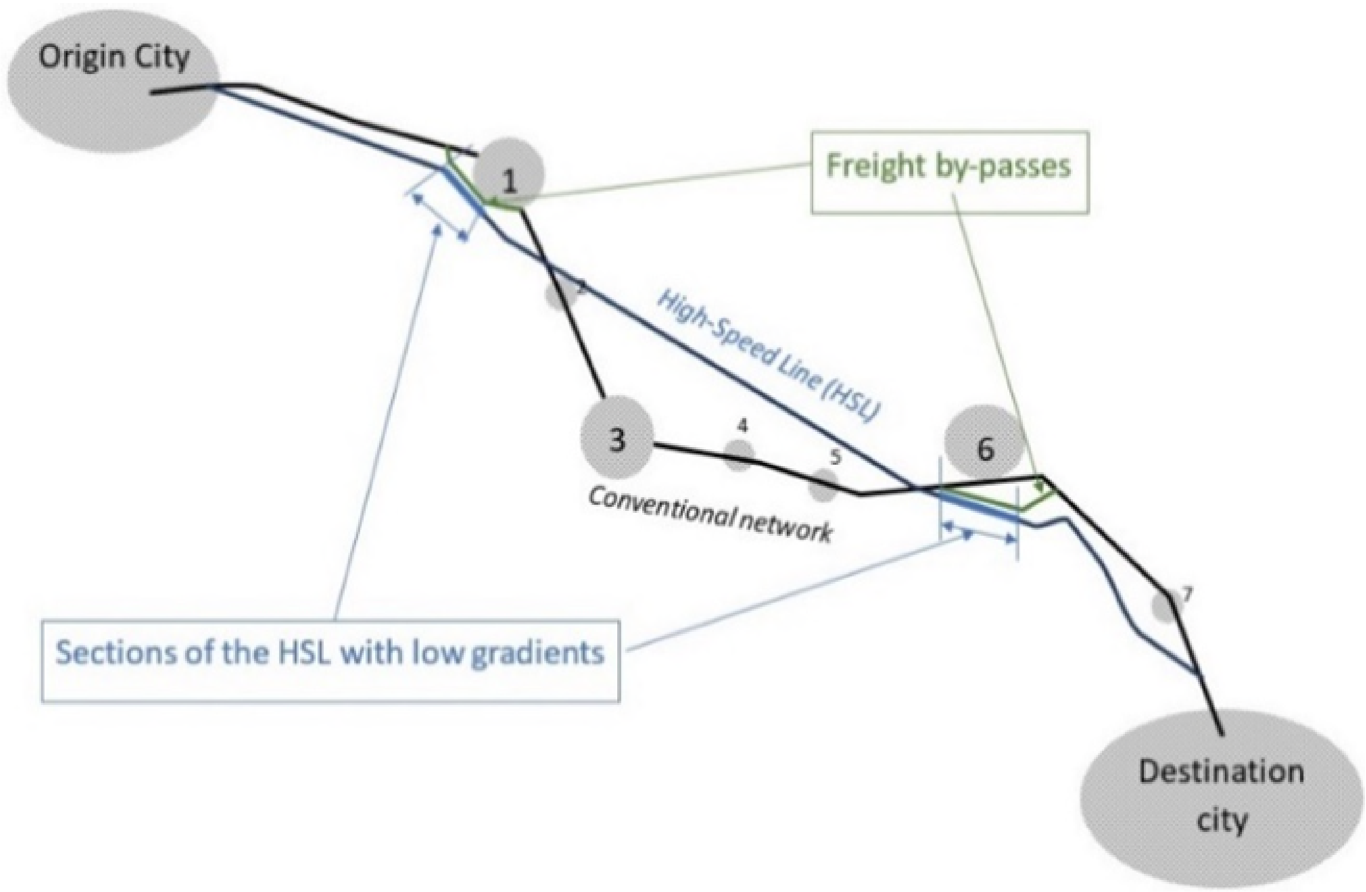
- Creating a high-speed (HS) line can only be justified if the intercity passenger traffic is high enough.
- If the traffic is huge, most likely there is already a conventional rail network line serving this market.
- Therefore, the HS line will somehow be parallel to the conventional network, depending on the physical geography.
- So, we are left with four parallel tracks (2 tracks per direction).
- It can be mathematically demonstrated that when you have 2 tracks in the same direction, the optimum capacity is reached when on one track are operated the fastest trains and, on the other track, the slowest trains.
- The fastest trains are the long-distance passenger high-speed trains running at speed equal or above 250 km/h.
- The slowest trains are the freight trains whose speed is in general around 100 – 120 km/h and also the regional passenger trains who can run up to 160 km/h but need to stop quite often leading to an average speed much lower than 160 km/h.
- So, when freight trains are operated on an HS line at daytime, the slowest and the fastest trains are mixed on the same tracks and this de-optimize the capacity of the very expensive HS line.
- Freight trains are generally relevant on the freight transport market only on very long distances, because door-to-door service is difficult to deliver by rail whereas lorries easily do it.
- If a freight train travels a long distance (say between 700 and 1000 km), the running time without any stop will be above 7 hours, since its average speed is about 100 km/h or less.
- It is impossible to drive 7 hours on a conventional network without encroaching on a passenger peak period.
- This means that if freight trains are kept on the conventional network, they will necessarily be operated during the peak hours of local and regional trains. This leads to 2 consequences:
  - Firstly, they will have to wait on a siding track for the regional trains to overtake them, since passenger trains loaded with hundreds of passengers will not be kept in a standstill to wait for freight to pass by,
  - Secondly, it means that the noisy freight trains, sometimes loaded with dangerous goods, will park in or drive at length through densely populated areas.
- Otherworldly expressed, it may not be a good idea to operate freight trains on the conventional network around cities because of the inconvenience to the daily migration of travellers and of the harm to the environment in sensitive areas.

All of the above translates into the fact that capacity is generally and primarily allocated to passenger trains for long distances on HS lines or for local and regional services on conventional lines, with which the improvement of the competitiveness of the rail freight traffic is highly conditioned by the subordination of its traffic to that of passengers.

Thus, if it is considered highly desirable that rail transport is a preponderant mode of long-distance land transport of freight, become inevitable that another way to invest in the new rail lines should be considered, incorporating in its design the provision of the infrastructures required to solve the bottle necks that impede the development of rail freight transport.

The construction of new high-speed line, or line section, also offer a great opportunity to contribute to improving the competitiveness of rail freight transport, but provided that its design is conceived with that global vision of favouring the development of rail transport as a whole.

This could be the case, for example, that the freight trains shared the line layout of the by-passes built so that high speed trains without stopping in the intermediate cities located along the line can avoid passing through the interior of that cities. This kind of design provision is shown in scheme below.



From all the above, the conclusion is that it is highly advisable to take advantage of the construction of a new high-speed line not only to improve the competitiveness of rail in intercity passenger mobility, but also that of all rail transport in the corridor. In this respect, adopting a global vision with a very long-term perspective is essential in the planning and design phases of the structural characteristics of the new railway infrastructure to be developed.

1.6 Objectives and scope of the study

The final objective of the study is to establish a set of essential guidelines in order to support the decision-making needed to allow the traffic of freight transport trains on high-speed lines whose maximum design speed for passenger trains is at least 250 km/h. Hereinafter, high speed mixed traffic lines.

In order to achieve that final objective of the study, it is necessary to identify:

- What are the types and objectives of traffic to be channelled along the line
- What functional requirements must meet the mixed traffic line to channel those objectives by type of traffic
- What should be its structural technical parameters according to the functional objectives
- What should be its operating key requirements that make its operation safe and sustainable.

The Handbook is almost finished and today we are bringing here the conclusions, organized according to the previous aspects.

In particular and without any purpose of exclusivity, the following aspects will be studied and included in the set of the implementation guidelines.

- What type of transport, -mainly freight traffic, should be the preferred target market for high-speed mixed traffic lines, for example, intermodal, automotive, rolling motorway, etc.
- What performance, for example, maximum and minimum speeds, depending on the type of traffic, reliability, safety, etc., must have the

line to ensure the quality objectives of each transport service.

- What essential requirements should be met by the different subsystems, Infrastructure, Rolling Stock, Energy, Control and Command and signalling, Telecommunications and Operation and Traffic Management to ensure the quality of service in the mixed traffic lines.
- What type of specific operational consequences incorporates the coexistence of traffic in a high-speed line, identification of causes and evaluation of their corresponding impact in the implantation and exploitation of the line, in particular in the following aspects:
  - Generation of additional costs, both Capital and Operational Costs in maintenance and operation
  - Operational constraints, such as capacity reductions, complexity on different trains scheduled due to their heterogeneity
  - Greater risks to ensure the excellent quality of service of the passenger exclusive high-speed lines, such as its high reliability and availability
  - Increase in safety risks and in particular, those produced at the crossing of trains and very especially in tunnels, which must be mitigated by taking appropriate technical, functional, operational and traffic ruling measures.
  - Effects on the environmental behaviour of the line
- As a result of all the above, how to globally evaluate the convenience of high-speed mixed traffic lines or line sections in terms of its sustainability throughout its all long large life in order to preconise a new design for future developments of the rail network

2 BENCHMARKING ON EXITING AND UNDER CONSTRUCTION MIXED TRAFFIC LINES

2.1 Some practices on existing mixed traffic high speed lines

The main goal of this chapter of the study is to analyse and consolidate the available information from existing HS mixed lines, and from that, extract new know how on the subject.

For this purpose, it has been essential to have disposed the support and collaboration of the UIC departments, particularly UIC HS Department, and the UIC members, as experience and valuable data exist among the member organizations of the UIC.

Data exist within the member organizations of the UIC the objective of the project is to consolidate the information and to develop new know-how on the subject.

The working methodology has been based on the consultation and detailed analysis on the following basic sources of reference:

- Benchmarking on existing Mixed Traffic High Speed Lines (study previously performed by DB-UIC)
- The use of SENER's own experience in the performance of comparable studies

Pertús Tunnel (HSL Figueres-Perpignan)

- New information and data obtained ad hoc by specific research performed by the study itself
  - HS1 (UK)
  - Figueres-Perpignan, whose design included piggyback-railway motorway requirements. In this case, SENER carried out the preliminary engineering and detailed design of this international section therefore is deeply aware of all mixed traffic requirements: alignment (plan and vertical design), operation, power supply, drainage in tunnel, rolling stock, sidings, etc. Just to mention that piggyback-railway motorway requires a bigger gauge to allow this kind of operation, besides particular load/unload facilities depending on the supplier.
  - Hannover – Würzburg information
  - Northeast Corridor (USA) information
  - Basque Y (Spain) discussed with ADIF and EUSKOTREN.
- Lessons learned from recent mixed traffic lines as Nîme-Montpellier.
- Finally, it has been considered for this study purposes to analyse information from the direct experience of railway undertakings, running freight traffic in a HS mixed traffic line.

To carry out the ad hoc investigation of the study, a questionnaire to obtain line information has been carried out.

This questionnaire was sent by the UIC Passenger Department to the different members of the ICHSC for completion.

In Europe, high-speed lines are concentrated in practice in 4 countries, Spain, which is the country with the longest high-speed network, Germany, France and Italy.

The main characteristics of the German lines are presented below:

Line	Operation Mode	Max Gradient	Design Speed	Length (km)			Start of Operations	Cost (m€)	Cost (m€)
		(o/oo)	(km/h)	Total (km)	Tunnels (km)	Bridges (km)	Year	Base year	2014
Köln - Rhein/Main	Dedicated	40	300	180	41,54	5,89	2002	6000	7257
Nüremberg -Ingolstadt	Mixed	20	300	77	27,37	0,51	2005	2270	2635
Mannheim - Stuttgart	Mixed	12,5	280	99	31,28	5,92	1991	2300	3604
Hannover - Würzburg	Mixed	12,5	280	327	125,21	24,8	1991	5900	9244

Line	Operation Mode	Max Gradient (o/oo)	Design Speed (km/h)	Length (km) Total (km)	Tunnels (km)	Bridges (km)	Start of Operations Year	Cost (m€) Base year	Cost (m€) 2014
Erfurt-Leipzig	Mixed	12,5	300	121	15,69	13,6	2017	2967	
Hannover - Berlin	Mixed	12,5	250	258	0,97	4,09	1998	2608	3312

Table 1 German lines main characteristics

Although in most cases the high-speed lines have been designed for passenger service, in Spain and France HSLs have had an exclusive use for passenger until recently, while in Germany and Italy the HSLs were conceived from the beginning for mixed use and in these two countries the traffic of goods by high-speed lines is maintaining some importance.

Thus, the design and construction of its first high-speed lines was carried out as mixed traffic HS lines, this was the case of HS network in Germany, where the new lines:

- Hannover - Würzburg, commissioned in 1991
- Mannheim-Stuttgart, commissioned in 1991, and
- Hannover-Berlin, commissioned in 1998

Hannover - Würzburg Line

All of them were design as mixed traffic HS lines, having:

- 280 km/h as Vmax of operation passenger trains outside tunnels and 250 km/h inside.
- Minimum radius of horizontal curves 5,000 to 7,000 m
- 4.7 m of distance between track centres.
- 82 m2 double track tunnel free section.
- 12.5 thousandths as maximum gradient were to allow freight trains traffic.
- 120 km/h of maximum speed of freight trains is in most cases.

Their main conditions of access and use as mixed traffic HS line are:

- Most of the trains that use the line are passenger trains who in practice occupy it all daytime.

- Freight trains are mainly combined traffic, using four-axle container wagons, and two-axle wagons with sliding walls.
- Services provided by both DB Cargo and freight trains private companies.
- Freight trains circulate at night-time.

However, this original vision of the high-speed network as mixed traffic lines changed in 2002, when was inaugurated the new Hs line Cologne-Frankfurt, the first German high-speed line designed for the exclusive traffic of passenger trains. This decision was based on the high expectations of passenger demand throughout this corridor as well as the fact that there is enough freight capacity on conventional lines in the corridor. So, no need for mixed traffic on this line.

This HS passenger line has:

- 300 km/h both as Vmax of design and operation of passenger train.
- 3,500 m as minimum radius in horizontal curves, exceptionally 3,250 m
- Maximum cant track admitted for exclusive HS passenger lines, 180 mm
- 4.5 m of distance between track centres.
- 40 thousandths maximum ramps, due to the difficult topography where the line runs.
- 92 m2 double track tunnel free section.

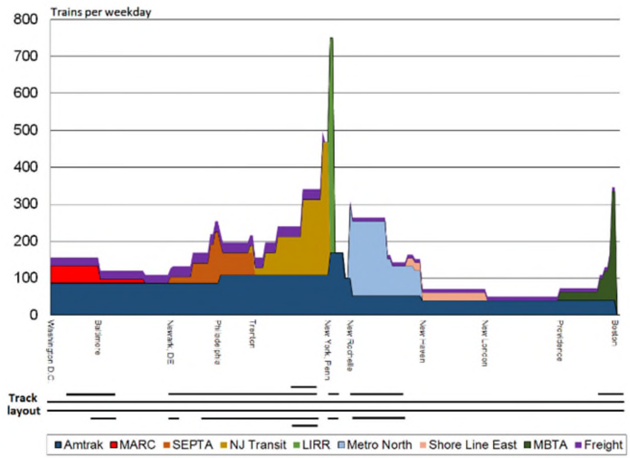
2.2 Northeast Corridor High speed line (USA)

The study corridor is the section between Boston South Station to Washington DC Union Station via New York Penn Station:

Location of the Northeast Corridor in the USA

2.2.1 *Possibility of simultaneous passenger and freight traffic*

The northeast Corridor allows freight trains at night only, however, there are some freight movements, which necessitate a movement on the Northeast corridor during daytime hours.



Split of passenger trains between Intercity, commuter and freight trains

2.2.2 *Maximum speed of passenger and freight trains*

The maximum speeds are the maximum top speed of theses trains along the whole of the Northeast corridor:

Type of train	Type of passenger	Max speed
Passenger	Acela	240 km/h (150 mph)
	Northeast regional	200 km/h (125 mph)
Freight		80 km/h (50 mph)

2.2.3 *Operating constrainsts*

There are no diesel propelled trains through the North River Tunnels (Hudson River) New York Penn station or the East River tunnels. There is an exception for track maintenance equipment with proper exhaust attachments.

2.2.4 *Lessons learned*

The responsibility for financing infrastructure must be clear and legally binding, in order to be able to increase reliability in the short term and to increase capacity in the long term.

There is no long-Term legally binding financial commitment from the Federal and State governments. This is necessary to keep the NEC in a state of good repair and to be able to have a long-term maintenance plan, which in-turn increases the reliability of the infrastructure.

2.3 Overview of European experience

The following table shows an overview of European experiences in high-speed lines with mixed traffic, in a table comparing experience and trends in HS lines of mixed traffic identified so far by the study, with respect to the lines HS dedicated exclusively to passenger traffic.

Basic design parameters and conditions of use		Mixed traffic HS line	Passenger traffic exclusive HS line	Main expected effects	Remarks
Performance parameters	Maximum line speed. P= Passenger train F= Freight trains	250 ≤ $Vmax^P$ ≤ 300 km/h. 100 ≤ $Vmax^F$ ≤ 160 km/h.(1) (1) Parcels trains	300 ≤ Vmax ≤ 350 km/h.	Reduction of the competitiveness of the passenger service	$Vmax^P$ < 250, journey time would increase on the longest O/D routes. $Vmax^P$ >350, Opex would increase (energy, maint.) unproportionally.
	Maximum Axle load.	22.5 to 25 tons per axle	17 tons per axle	improved competitiveness of freight traffic	freight traffic takes advantage of better performance and reliability of HS lines.
	Train length	850 m	400 m	Lengthen and increase the number of line sidings	But also improves the efficiency of freight trains
structural parameters	Minimum radius of horz. curve for line maximum design speed	3,800 m ≤R_{min}≤ 5,350 m.	3,800m ≤R_{min} ≥ 5,200 m. Except: 3250 m on KRM	Limit the maximum speed of passenger trains to 300 km/h.	In mixed lines the strictest minimum radius is only applied in sections with complicated alignment. Same with dedicated lines
	Distance between track centres	4.7m ≤ D_{btc} ≤ 5 m	4.2m ≤ D_{btc} ≤ 4.7m	Wider pathway, (7 to 10%)	Greater rights-way acquisition and higher construction costs
	Maximum gradients	MaxGrd. ≤ 12.5 ‰	MaxGrd. ≤ 35 - 40 ‰	greater need for civil works and therefore higher cost for the same Vmax	the lower the gradient, the lower the adaptability of the line layout to the ground
	Maximum Design Cant	90 mm ≤ Cant ≤ 120 mm. (1) (1) although up to 160 mm is ruled	Cant ≤ 180 mm	reduce the maximum speed of passenger trains in smaller radius curves	Reduction of the competitiveness of the passenger service
	Minimum tunnel free section	S_{ft} ≥ 100 m² in double track tunnel	82 ≤ S_{ft} ≤ 92 m² in double track tunnel	greater need for major works and therefore higher cost for the same Vmax	The problems of overpressures in tunnels are increased and bi-tube solutions are promoted

Table 2 Comparative synthesis of high-speed lines for mixed traffic and for passenger dedicated traffic

In accordance with this panorama of the operational reality of mixed traffic HS lines, it can be synthesized the known experience according to the following typologies of HS lines.

1. HS lines built based on a mixed traffic design but that only operate as dedicated passenger lines.
   - HS Madrid-Seville line
   - All new Italian high-speed lines, except the Rome-Florence section.
   - Ingolstadt - Nuremberg HS line (83 km). Vmax of 300 km/h inaugurated in 2006.
2. Mixed traffic HS lines with segregated schedule. Daytime passenger traffic and nighttime freight traffic.
   - HSL Hannover- Würzburg (327 km long), Vmax= 280 km/h and $Vmax^F$ = 120 km/h.
   - HSL Mannheim-Stuttgart (99 km long), $Vmax^P$= 280 km/h and $Vmax^F$ = 120 km/h.
   - Direttisima Roma-Florence (254 km long), $Vmax^P$= 250 km/h and $Vmax^F$ = 120 km/h.
3. Mixed Traffic HS lines with sharing schedule throughout all day, both passenger and freight trains rolling day and night along the HS line.

In operation:

- Mixed traffic HS cross-border line Figueres – Perpignan, (44.4 km long), $Vmax^P$= 300 km/h and $Vmax^F$ = 140 km/h.
- Mixed traffic HS line Kalrsruhe-Offenburg, (72 km), Vmax P= 250 km/h, and Vmax F=120 km/h.
- Mixed traffic HS line Berlin-Hamburg (286km of upgrading line), Vmax P = 230 km/h, train ICE, and Vmax F=120 km/h.
- Mixed traffic HS line NRLA, New Rail Link through the Alps (57km), Vmax P = 250 km/h, and Vmax F=160 km/h.
- Mixed traffic HS line "Contournement Nimes-Montpellier" (86 km), Vmax P = 220 km/h, until the ERTMS level 2 is installed, then it will be reached to 320 km/h.

Under construction:

- Mixed traffic HS line Offenburg-Basel, (100 km), Vmax P = 250 km/h, and Vmax F=120 km/h.
- Mixed traffic HS line Bilbao-Vitoria-S. Sebastián-Irún (cross-border) 180.5 km, Vmax P = 250 km/h, and Vmax F=120 km/h.

As a corollary advance, it could be concluded that:

- Classes 1 and 2 of mixed high-speed lines are basically a consequence of the high intensity of passenger train traffic, which makes unworkable to schedule significantly slower trains such as freight trains at daytime, besides, they are usually long length lines .
- Class 3, mixed high-speed lines with shared scheduling at daytime, that usually occurs in cases of relatively short length high speed, or on high speed lines with weak and / or middle passenger traffic which makes it possible to intercalate between passenger trains those paths of freight trains.

2.4 Rome - Florence HS line

In Italy, the first high-speed line built was Rome - Florence, known as the “Direttisima”, which was designed to continue the railway tradition of mixed traffic. These 254 km long line was not fully operational until 1992 and since then its intended operational design has been maintained on the same terms, consisting of a line dedicated to passenger traffic at day with possibility of use by freight trains at night, in addition to its maintenance.

This design model has been maintained in the new high-speed lines put into service in Italy, which currently totals around 900 km in length, and configuring the Turin-Milan-Florence-Rome-Naples-Salerno “great spine line”. High speed intercity corridor highlighted with a red line on the map showed below and whose current traffic is as follows:

- 332 Passenger trains scheduled on average day
- 3 Freight trains on average day the “ETR 500 Fast”
- 477 km as average route of the trains (average origin-destination distance)
- 182 as average passenger trains per km of line and day

Revealing data of the effective dedication of the line as of intensive use for the transport of passengers.

Italian High-Speed railway network

Currently the line is open to various Railway Undertaking that can apply for using its capacity in accordance with the requirements states in the RFI’s Network Statement.

The basic design parameters of the mixed traffic lines in the Italian case are the following:

- 300 km/h as Vmax of design. (Rome- Florence section, design at 250 km/h)
- GC as wagon envelope
  - 404 m as maximum length of passenger trains (ETR 1000 duplex), and 380 m for freight trains (ETR 500 Fast)
  - 17.25 tons as maximum axle load of passenger trains, as well as for freight ETR 500 Fast train
- 5,450 m as minimum radius in horizontal curves, exceptionally 3,250 m, (Rome- Florence section, 2,870 m)
- 4.5-5 m of distance between track centres. (Rome- Florence section, 4- 4.2 m)
- 105 mm as maximum cant, (Rome- Florence section, 135 mm)
  - 92 mm as maximum cat deficiency and cant excess too, (Rome- Florence section, 130 and 84 mm respectively)
- 18‰ as maximum gradient, due to the difficult orography where the line runs, (Rome- Florence section, 10‰)

- 82 m2 double track tunnel clear section.
  - 25kV AC 50Hz as traction energy supply system
  - ERTMS L2 as Control and Command and Signalling, and GSM-R as Mobile Radio-Communication System

Notwithstanding the original vocation of mixed traffic on the Rome- Florence line, the truth has been that the development of the network, which has resulted in a large Torino-Milan-Florence-Rome-Naples-Salerno spine line, which in practice is a line dedicated to intensive passenger traffic, having for the time being only one exception that is a high speed parcel service, called “Mercitalia FAST”, whose service is reflected in the attached diagram.

This freight train was originally a high-speed passenger train, ETR500, in which seats were removed and modular, mobile and anchorable shelves for carrying packages have been layout in its place. this train then, has the same operational performance than had when it run as a high speed passenger train.

2.5 Nimes-Montpellier HS line

France that has a Hs network of 2,814 km long and was the first European country putting into service a high-speed line, in 1981, It was not until 2017 that put into service the first and so far, only one French mixed traffic high-speed line. It was the case of the “Contournement Nimes-Montpellier HS line”.

The final decision about the type of use of the new high speed “Contournement Nimes-Montpellier” line, was the result of a very long public debate several options had been studied in-depth and were competing:

- Fully passenger dedicated line (initial design)
- Mixed traffic line (finally decided)
- Various intermediate solutions particularly about the implementation of the new stations which had an impact on the traffic mix.

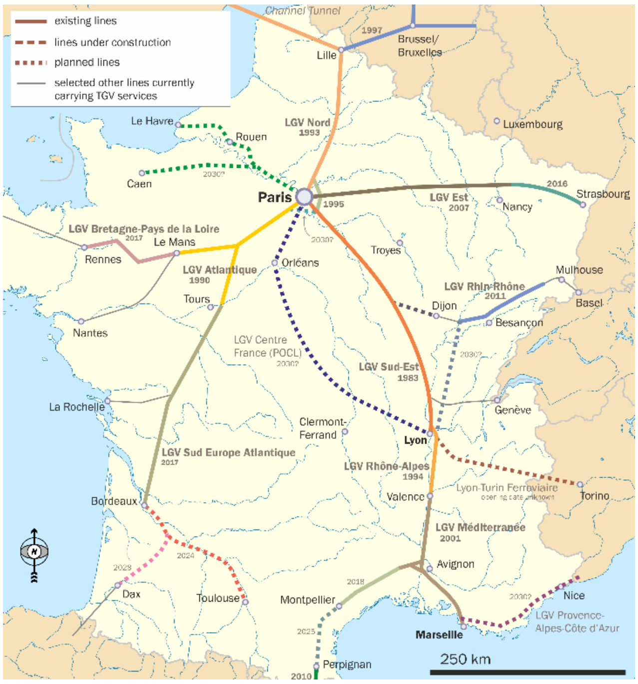
The final decision taken was to build a line for mixed traffic which could quite easily be converted into a passenger dedicated line in a later stage. This was considered in the design of the line, incorporating requirements in the basic parameters characterising the line, basically in railway systems, - track, electrification and signalling -, that make it possible easily to change the use of the line in the future.

Design vision of the line that states the concept of its convertibility or adaptability to the evolution of transport demand in its hinterland.

With its implementation as a mixed traffic high speed line it is expected that there will be a transfer of 10 Mt of goods from the road to the railroad, besides, there will be a transfer of paths from the conventional to new line to implement a regional train from Nimes-Montpellier every 15 minutes.

The basic design characteristics of the mixed traffic Nimes-Montpellier HS line case are following:

- 80 kilometres length of which 60 km are really a new mixed traffic high speed line, and the other 20 km are junction loops and various stretches of connection from its ends with the conventional network.
- 320 km/h as Vmax of design. For the time being and until ERTMS L1+BAL KVB is installed, the operation speed of passenger trains is 220 km/h.
- 5,560 m as minimum radius in horizontal curves.
- 105 mm maximum cant.
- 4.8 m of distance between track centres.
- 11 thousandths maximum ramps, exceptionally 13.
- Freight trains with a maximum load of 22.5 tons per axle are accepted.
- 2x25 kV 50 Hz as traction power electric system
- Average cost of 20.9 million euros per km of line.



French High Speed railway network

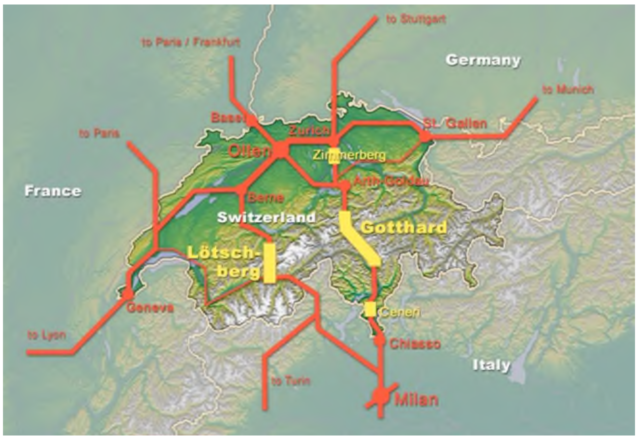
Also, in France, the projected Montpellier-Perpignan HS line, of 153 km length, it will be partially a mixed traffic HS line, because it will admit freight traffic in a 94 km stretch between Montpellier and Narbonne. The line has a design Vmax of 300 km/h, a maximum ramp of 10 thousandths and it traffic on the most loaded section of approximately will reach 180 daily trains, 120 TGV and between 50 and 70 freight trains on the Montpellier-Narbonne section. The minimum speed of freight trains will be 120 km.

Nimes-Montpellier bypass carries freight train

2.6 Swiss High speed Mixed traffic line

Outside the EU, but very much in connection with its hard core, it is of interest to mention the case of a Swiss High Speed Mixed traffic line, the New Rail Link trough the Alps, NRLA.

Given the importance of safety-related aspects, it seems interesting to consider the convenience to include a new line or section that has a very important part in tunnel as well as an intensive use.



New Rail Link through the Alps (NRLA)

This high-speed rail link, whose main section is a new base tunnel of 57 km long under the Gotthard, the world's longest railway tunnel was opened in 2015 and its main features are as follows:

- Line composed of two 57 km long single-track twin tunnel tubes, connected every 325 m by cross passages.

Gotthard Base Tunnel

- Daily capacity up to 220 trains
- Vmax of 250 km/h per passenger trains an until 160 km/ h per freight trains
- Freight trains of 750 m maximum long and a maximum of 2,000 tonne loads nonstop rolling through the link.
- Minimum gradient, just to ensure tunnel drainage through its two entrances.

2.7 High speed line Hannover-Würzburg (Germany)

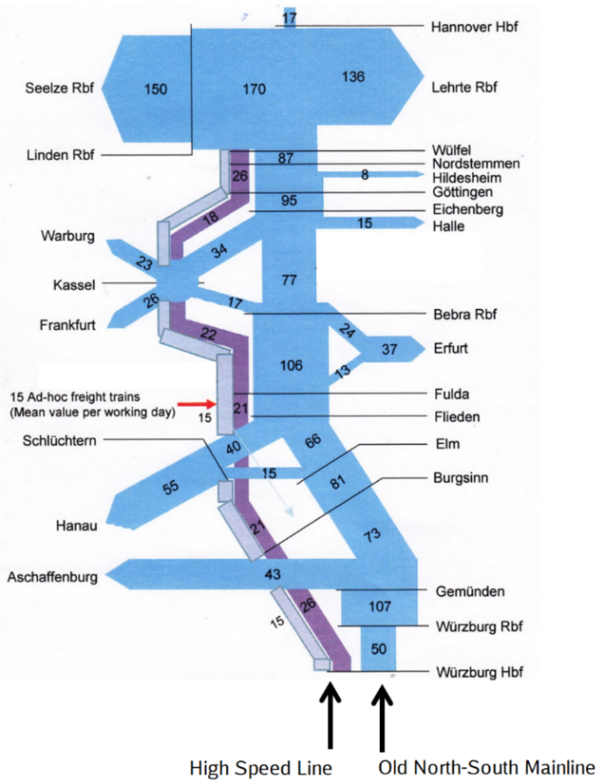
The Hannover – Würzburg high speed line is a double track mixed use (Freight and High-speed passenger) high speed line. It is 327 km long.

Situation of the High-speed Line Hannover - Würzburg Source: UIC

As the HSL Hannover Würzburg is fully integrated in the rail network of Deutsche Bahn (DB) there are many connections to the existing network, some are used by only by freight trains.

2.7.1 *Possibility of simultaneous passenger and freight traffic*

There is currently more freight traffic on the old North – South main line than on the new HSL.



Number of freight trains in the North – South corridor on a weekday; only one direction.

For the HSL the mean amount of 15 ad-hoc ordered freight trains are added (light blue colour).

2.7.2 *Maximum sepeed of passenger and freight trains*

Type of train	Type of passenger	Max speed
Passenger	ICE	280 km/h
	Intercity	200 km/h
Freight	Combined	120 km/m
	Parcel InterCity	160 km/h

2.7.3 *Operating constrains*

- Aerodynamic in tunnels. Extensive trials with freight trains passing a passenger train on the adjacent track in the 2- tunnels resulted in *restricting* the speed of the passenger train to 250 km/h, suitable for aerodynamically optimised high-speed trains. Otherwise, the wind loads on the freight train shift the containers or fright being carried.

  However mixed traffic in twin tunnels at V ≤ 160 km/h is still allowed because this is normal practice of railway operation on the conventional network.
- Safety in tunnels: It was recommended that passenger trains stopping within a tunnel should be avoided.
- Use of passing loops: very rare. No planned overtaking of freight trains by passenger trains. Use of these loops in case of train failure or by inspection vehicles or maintenance machines.

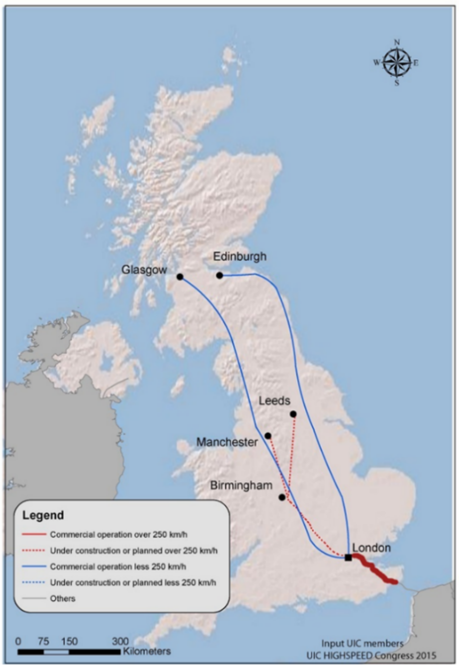
2.7.4 *Lessons learned*

The initial idea of a total mixed traffic operation on the new high-speed line proved to be unsuitable due to operational and safety constraints. Daytime and night-time segregation was the right solution. There are no current capacity issues on the old North-South main line.

Use of the HSL by freight trains at night could be more intensive if the track access charges were to be lowered.

2.8 High Speed 1 (UK)

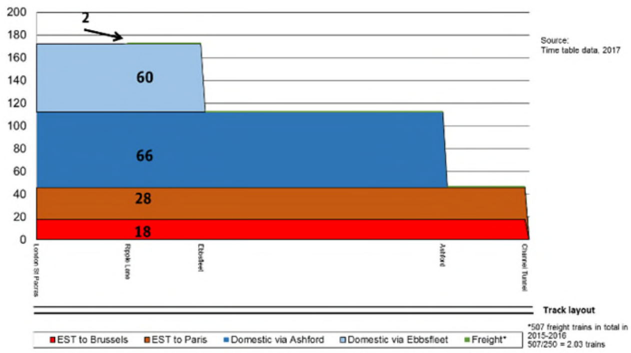
High Speed One (HS1) is the only purpose built true high-speed line in the United Kingdom. It is 109 km long and links the Channel Tunnel to London for high-speed international train services from France and Belgium to London. It also allows high speed commuter services to serve London from Kent in Southeast England.



Location of HS1 in the UK - Thick red line, (Source: UIC)

2.8.1 *Possibility of simultaneous passenger and freight trains*

There are two return services per week between London and Poland in 2020.



2.8.2 *Operating constraints*

During the Olympic Games in London celebrated in 2012 the overall traffic performance on HS1 increased by approximately 90%. Taking the maintenance regime into consideration, no freight was allowed during the Olympic period to maintain a high level of operational performance.

Due to the slower speed of freight trains, they are restricted to nighttime operations only.

However, the Network statement for HS1 does allow the operation of High Speed (300 km/h) freight trains during the day. This would most probably be some type of postal / parcel train, with a limited axle load.

To satisfy security considerations and the gauge of the trains, each station had to accommodate international TGV and commuter trains on different platforms, with separate access loops off the main line to the platforms for TGV and commuter trains.

2.8.3 *Lessons Learned*

For the relatively little current number of freight trains, the extra cost needed for the junction at Ripple Lane and the passing loops at Singlewell and Lenham Heath could have been saved.

The alignment presents a maximum vertical slope of 25‰ which could have been increased to the commonly used maximum in France and Germany of 40‰, if it were not freight services, this could have had the potential to reduce the CAPEX of the line.

The current number of freight trains using HS1 bring in approximately €1,120 per night in track access charges. This income is unlikely to off-set the extra cost needed for site safety equipment and personnel needed due to trains running in the neighbouring live track.

2.9 Basque Y (Spain)

The Basque Y is part of the Priority Project No. 3 "High-speed railway axis of south-west Europe", (Essen Summit 1994) constituting a key project that guarantees the continuity of the Trans-European Railway Network in the Iberian Peninsula.

The Trans-European Transport Network (TEN-T) is a planned set of priority transport networks designed to facilitate the communication of people and goods throughout the European Union.

The Atlantic Rail Corridor is part of one of the priority corridors of the Trans-European Transport Network RTE-T and the High speed rail project of Basque Y, integrates the Basque regions cities in the Network, this new infrastructure is an essential element that enables, among others, the connection with France by the rail and electrical adaptation of the railway network of the Iberian Peninsula and specifically of the Basque region into the European standards and networks.

The actual implementation of the Infrastructure of the Basque Y, entrusted to both the national and the regional infrastructure managers (ADIF and ETS), has the European financial support of the INEA CEF programmed, to enhance interoperability, intermodally and cross-border sections, It is planned to be completed by 2026 and connected to the French border rail infrastructure, in an initial phase by the incorporation of the third rail between San Sebastian and Irun and in a second phase by a new infrastructure connecting San Sebastian and the border (Biriatou) by 2032.

This intervention is an excellent opportunity for the Basque Country because it will enable, first of all, a new railway offers due to the commissioning of the Basque Y connecting the three Basque capitals and subsequently the development of rail connections to the North and South.

At the same time an opportunity to incorporate new rail services of intermodal goods such as the railway motorway between Júndiz and Paris/Dourges.

The commissioning of this infrastructure will reduce travel time between the capital cities of the Basque Country: Vitoria-San Sebastián by 60%, and between Bilbao-San Sebastian and Bilbao-Vitoria by 80% (the current duration of the rail transport journey between capitals such as Bilbao and San Sebastian is just over 2 hours and 45 minutes for 108 km; between Bilbao and Vitoria is 2 hours 20 minutes for 80km by train exchange in Miranda de Ebro,and finally, between Vitoria and San Sebastian it is 1 hour and 40 minutes for 104 km.

Long distance travel times to Madrid or other European capital cities like Paris, Manheim, etc. will be significantly reduced, causing healthy competition of the railway with air mode.

Basque Y is a mixed high-speed rail network being built between the three cities of the Basque Country, at the North of Spain: Bilbao, Vitoria-Gasteiz and Donostia-San Sebastián.

It will transport passengers and freight. Freight services will access directly with the standard gauge without travel disruption to the port of Bilbao, in Santurce (Bizkaia) to the port of Pasajes (Guipúzcoa), through an access from the intermodal Lezo logistic station.

Through the intermodal terminal of Júndiz, combined traffics of trucks and containers through rail motorway services are expected.

Future connections have been also planned to the future Cantabrian Axis (Cantabrian-Mediterranean Corridor) that would link it with Santander, and the Navarrese corridor that would link with Pamplona and Castejón with the Madrid – Barcelona-Figueras line.

Three major stations (Bilbao, San Sebastian and Vitoria) and two siding loops are planned, one in the Vitoria – Bilbao section and one in the Vitoria – San Sebastian section in Ezkio-Itsaso (this one will also be a passenger station). These facilities will occupy a platform of 1500 m long, with a width of between 42 and 56 m, accommodating six or eight tracks.

With a total length of about 172 km, 157 km are double track and another 15 km of single track in monorail tunnels. Due to the orography, great constructive technical complexity, being the total length of the infrastructure of 171.9 km, they are tunnelled 104.3 km (60.64%), viaduct 17.0 km (9.93%) open air embankments 50.6 km (29.43%).

The Basque Y is designed with European rail gauge (1,435 mm). It will connect Madrid via Valladolid and connect France via Irun. The network will also include a connection to the Navarre Corridor, the high speed line projected between Zaragoza and the capital of Navarre, Pamplona.

Basque Y route map

The main structural characteristics of the Basque line Y line are the following:

- 168,2 kilometres long, including San Sebastian – Irun border 15km branch.
- 63% of its total length is along tunnels, 18 % viaduct and 19 % at grade embankment.
- Double-track tunnels with a maximum length up to 20 km
- 1,435 mm of track gauge
- Minimum radius of horizontal curves 3100 m, and 120 mm of maximum track cant
- 4.5 m of distance between track centres at tunnel and viaducts and 4,7 at grade
- 270 km/h of maximum design speed
- 15 thousandths of maximum gradient

- Stations: There is one intermediate station (Ezkio) ; there are two freight terminal (Júndiz and Lezo)
- Voltage: Most section at 25kVac 50Hz 250 km/h; some sections at 3kVdc 100 km/h
- Signalling and Train Protection System: ERTMS Level 2 /BSL (ADIF)
- Train Positioning Detection system: Track circuits, axel counters/Balize / BTM -> EVC

The main conditions of access and use of the mixed traffic HS line are:

- Passenger and freight trains are admitted if they comply with the TSIs of: Rolling Stock, Energy and Tunnels.
- 250 km/h, passenger train's expected speed.
- 120 km/h, freight train's maximum speed, equipped with ERTMS.
- 400 m maximum Passenger train length.
- 750 m maximum freight's train length, including traction locomotives.
- Diesel trains are only allowed for rescue of high-speed trains.

Traffic forecasted for passenger trains is 90 trains per day and 25 for freight traffic.

2.10 Figueras –Perpignan (Spain-France)

In Spain, as in France, the first section of mixed traffic HS line did not arrive until December 2010, when the Figueras-Perpignan cross-border section was inaugurated. The line was designed, financed, built, delivered to service through under a concession regime to a private concessionaire company called TP Ferro. In December 2016, the Concession has been rescued by the states and granted to a joint public company of ADIF and SNCF, currently called LFP SA or "LFP".

Since December 2016, LFP SA is the Infrastructure Manager (IM) of the high-speed line between France and Spain, also known as "International Section".

The Figueras-Perpignan cross-border HS line, called LFP, case, it was designed to be a mixed traffic HS line and is operated as such.

This line established the connection of the Spanish network of international gauge with the French network, and through it with the rest of the European network.

Spain –France Railway connection

In 2013, this HS cross-border mixed traffic line connected with the new Barcelona-Girona-Figueres Vilafant line, which is the first Spanish fully mixed traffic HS line in operation. With this extension, the metropolitan area of Barcelona and its port were connected by rail without seams with the rest of the European rail network.

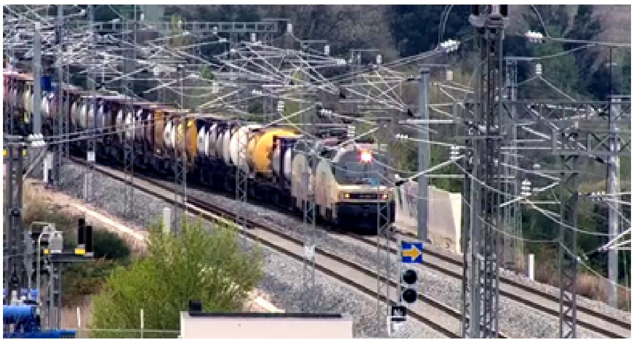
The design of the line Figueres-Perpignan complies with piggyback-railway motorway requirements. Just to mention that piggyback-railway motorway requires a bigger gauge to allow this kind of operation (which is the case with the Figueras-Perpignan HS line), among other particular load/unload facilities depending on the supplier of the piggyback wagon.

The main structural characteristics of the Figueres – Perpignan line are the following:

- 45 kilometres long of double-track HS track, of which 20 are in Spanish territory and 25 in France.
- 5 kilometres of double conventional track, connecting to the French conventional network (RFN)
- 27.6% of its total length is along tunnels or over viaducts. Longest tunnel of 8.3 km, double tube (tracks are separated).
- 1,435 mm of track gauge
- Minimum radius of horizontal curves 7,000 m, and 135 mm of maximum track cant
- 4.8 m of distance between track centrelines
- 350 km/h of maximum design speed
- 300 km/h of operation speed with ETCS L1 since December 2012
- 18‰ of maximum gradient but only implemented along short lengths

The main conditions of access and use of the LFP mixed traffic HS line are:

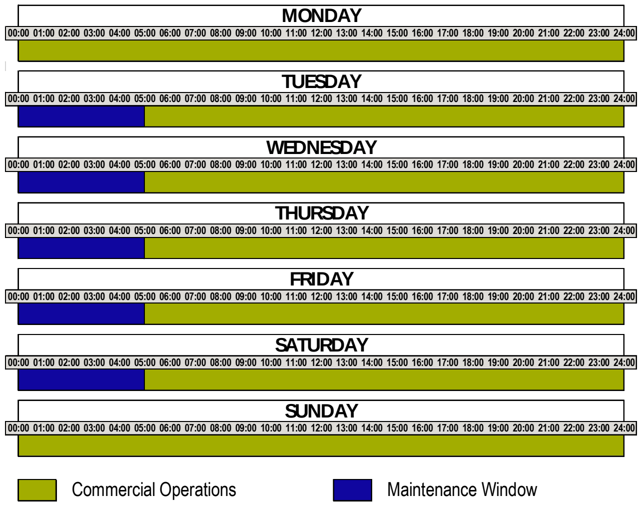
- Passenger and freight trains are admitted if they comply with the TSIs of: Rolling Stock, Energy and Safety in Tunnels.
- The static mass for each axle must always be equal to or less than 22.5 tons and the mass per unit length less than or equal to 8.0 t/m.
- 300 km/h, passenger trains' maximum operating speed, and 120 km/h its minimum speed, with ERTMS L1, if required, could be increased to 320 or 350 in the future with ETCS L2.
- 140 km/h, freight train's maximum speed with ERTMS L1, no minimum speed requirement, since 2010 freight operations are performed at 100 km/h.
- 400 m maximum passengers' train length.
- 850 m maximum freight's train length, including traction locomotives.
- 2,000 tons is the total maximum mass allowed in freight trains, for trains using normal couplers.
- For trains using reinforced couplers, there is no mass limitation.
- The operation of freight trains transporting dangerous goods is admitted provided they meet the "Regulations concerning the international Carriage of Dangerous Goods by Rail" (RID). These trains must be always clearly identified.



There are no traffic restrictions regarding traffic, excepting the so-called "tunnel condition":

- Only one train is permitted to operate in the tunnel per travel direction. The tunnel is a bi-tube (twin) tunnel, which means that simultaneous operation of two or more trains in the same direction within the same tunnel-tube is prohibited (simultaneous operation in opposite directions is allowed). This condition does not affect operating headway and capacity given that the HS trains cross the tunnel in less than 2 minutes, and freight trains in 5 minutes.
- Crossing (trains running in opposite direction) and overtaking (trains running at the same direction) is allowed with no restrictions.
- There are no traffic restrictions on bridges and viaducts.
- A passenger train at 300 km/h and another one of freight at 100 km/h can circulate in the opposite direction in the same section of the line without restriction.
- Regular maintenance window between 00h00 and 05h00 from Tuesday to Saturday on both tracs:
  - For electric traction trains: no capacity can be assigned within these hours
  - For diesel traction trains: it is possible to assign capacity within these hours except on Wednesdays and up to a maximum limit of two (2) paths per direction during this 5-hour-window

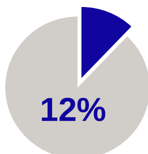
As of 2024, availability for operations and maintenance window are as follows.



Jointly with adjacent Infrastructure Managers, LFP is evaluating the possibility to open the line for commercial operations, a third night per week (e.g. Tuesday or Wednesday),

The line offers a capacity of around 60 trains/day/direction (120 trains/day both directions) with the assumption of a 50-50 breakdown between high-speed and freight trains.

As of 2024, the saturation rate of the line is 12%.



Consequently, the cross-border LFP mixed traffic HS line has a high capacity surplus and is able to absorb the significant increase o traffic expected after 2025-2026, after the UIC-gauge lines in Spain will have been delivered to service.

Due to the fact that the line was conceived and designed as a mixed traffic line, the coexistence of freight and HS passenger trains throughout the daytime does not present practical difficulties, as evidenced by the fact that the regularity index of the service of transport is at 99.7%. LFP updates the forecast of commercial services in the International Section on a weekly basis. It is available at:

https://www.lfpperthus.com/servicios-comerciales

2.11 Section Figueres Vilafant – Mollet - Barcelona Sants (Spain)

In the Spanish limit of the line, at the North of Figueres Vilafant station, the international cross-border mixed traffic HS line, LFP, connects with the HS line Figueres Vilafant – Girona – Barcelona, which is, for the time being, the only one high-speed mixed traffic line operated in Spain and by ADIF.

The Barcelona-Girona-Figueres Vilafant, case, first entirely Spanish mixed traffic HS line, has:

- 131 kilometres long, 36.6% of its total length is along tunnels or over viaducts
- 1,435 mm of track gauge
- Minimum radius of horizontal curves 7,000 m, and 135 mm of maximum track cant
- 4.7 m of distance between track centres
- 100 m2 double track tunnel free section
- 250 km/h Vmax design between Barcelona and Girona and 300 km/h from Girona to the connection with the cross-border line.
- 18 thousandths of maximum gradient
- 2 sidings along the entire line, every 30 km.

The main conditions of access and use of the LFP mixed traffic HS line are:

- Passenger and freight trains are admitted if all their vehicles comply with the TSI of: Rolling Stock, Energy and Tunnels.
- The axle load has to be equal to or less than 22.5 tons and the mass per unit length less than or equal to 8.0 t/m.
- 200 km/h, passenger train's maximum speed, AVE, with ERTMS.
- 400 m maximum passenger's train length.
- 750 m maximum freight's train length, including traction locomotives.
- The operation of freight trains transporting dangerous goods is admitted provided they meet the "Regulations concerning the international Carriage of Dangerous Goods by Rail" (RID). These trains must be always clearly identified.

Traffic throughout the Barcelona-Figueres mixed traffic HS line, 240 weekly trains:

- 32 daily passenger trains, (10 international HS trains, 18 domestic HS trains and 4 Avant- HS regional), in both directions.
- 8 dailies, (maximum), freight trains, (just trains of automobiles and containers) in both directions.
- In total, therefore, a daily average of 19 daily trains per direction,
- Current traffic is equivalent to an average interval between trains of 1 hour. There are two interval of more than 2 hours each.

Due to its medium traffic intensity and the fact that the line was conceived and designed as a mixed line, in this case the coexistence of freight and HS passenger trains throughout the daytime is also possible thanks to the existence of some intervals of more than two hours and of the existing sidings along the line.

However, it is important to underline that in this case, Barcelona-Girona-Figueres Vilafant mixed traffic HS line, the maximum speed of passenger trains has been limited to 200 km/h.

The line regularity, measured as a punctuality index of the line transport service, - % trains on time -, is 85.6% so far this year.

To conclude the Spanish experience in high-speed lines with mixed traffic, it is worth mentioning the case of the first Spanish high-speed line, the Madrid-Cordoba-Seville line, which was designed and built for mixed traffic and yet since its inauguration in 1992, a freight train has never circulated through it, due to the fact that it has been shown in Chapter 3, that is, because due to its success, the intensity of passenger train traffic in practice makes it impossible to incorporate of freight trains.

2.12 Madrid-Cordoba-Seville (Spain)

The Madrid-Cordoba-Seville, case, first Spanish Hs line, originally designed for mixed traffic, but that has never worked as such. It has:

- 470 km long, 5.2% of its total length run through tunnels or over viaducts
- 1,435 mm of track gauge
- Minimum radius of horizontal curves 3,200 to 4,000 m
- 4.3 m of distance between track centres
- Track cant 120 mm originally, but later was raised to 150 mm in order to increase Vmax
- 75 m2 double track tunnel free section
- 250 km/h Vmax originally, but later 270 km/h

- 12.5 thousandths of maximum gradient
- 9 sidings along the entire line, every 52 km

The main conditions of access and use of the HS line are:

- Only Passenger HS trains are admitted, both AVE and Avant (regional HS train).
- The static mass for each axle must always be equal to or less than 22.5 tons and the mass per unit length less than or equal to 8.0 t/m.
- 270 km/h, passenger train's maximum speed, AVE and 250 km/h Avant trains.
- 400 m maximum passenger's train length (TSI)

High Speed and Long Distance routes

Traffic throughout the Madrid- Cordoba-Seville HS line, 168 daily trains in its most loaded section and 68 daily trains in its least loaded section of the line.

- 84 daily passenger trains per direction in the most loaded section, (58 AVE and 26 Avant).
- 34 daily passenger trains per direction in the least loaded section, (27 AVE and 7 Avant).
- In total, therefore, a minimum daily average of 34 trains per direction.
- Current traffic is equivalent to an average interval between trains of 13 minutes along the most loaded section, and, 30 minutes alongside the section of the line with less traffic.

Madrid – Córdoba HS Line

Although the line was designed initially for mixed traffic, the high intensity of passenger train traffic prevented its use as a mixed line, and, consequently, in order to improve the performance of the passenger service the maximum speed of the AVE trains was raised from 250 to 270 km/h, increasing the maximum cant of the curves from the original 120 mm to 150 mm.in fact.

This increase in maximum speed gave a 9% reduction in travel time between the extreme O / D of the line, approximately 15 minutes of saving time in AVE schedule between Madrid and Seville.

The regularity measured as a punctuality index of the line transport service is 86.3%.

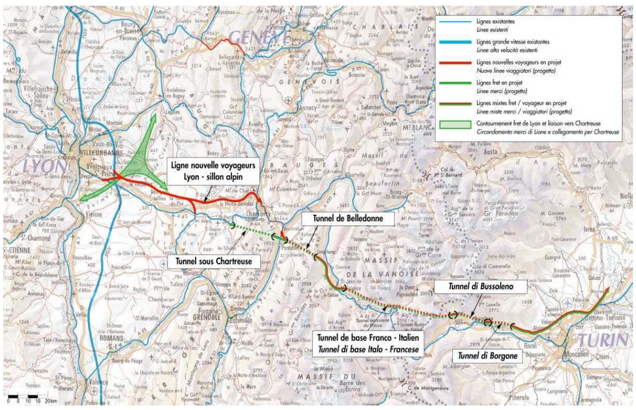
2.13 Lyon Turin High Speed Line Project

The project for the new Lyon-Turin high-speed line is a new Transalpine rail link between the French and Italian networks that is integrated into the Priority Project No. 6 Lyon-Budapest of the trans-European networks (TEN-T).

This project comes from the year 1994 with European financing to carry out the studies and preliminary work of its international section, the approximately 57 km length of a base tunnel that is part of this new infrastructure and which is the core of the project and its most decisive section.

The line, with a total length of 270 km, is made up of three sections with different characteristics and responsibilities.

- The French section, which begins at the eastern edge of Lyon and ends at St. Jane de Maurienne. The construction of this section will be the responsibility of SCNF Reseau.
- The international section between Saint-Jean-de-Maurienne in Savoie and Bussoleno includes the Base Tunnel, whose development has been in 2001 at LTF, Lyon Turin Ferroviaire, a company 50% shared by SNCF Reseau and RFI.
- The Italian section between the Bussoleno (Susa valley) and Torino whose development lies with RFI, the Italian infrastructure manager.



As can be seen in the map above, the French section is made up from the eastern contour of Lyon to

Montmelian, south of Chambery, by two independent itineraries, one consisting of a new HS line dedicated to passengers, with a maximum design speed of 300 km/h, and another that would be essentially dedicated to the freight traffic, constituted by the current line in which a new tunnel would be built to save the Chartreuse massif and connect the south of Montmelian with the new high-speed line. From Motmelian and up to the starting point of the international section in St. Jean de Maurienne, a section of mixed line with characteristics identical to those of the international section will be built.

The Italian section of the line, which begins in Bruzolo, at the eastern end of the international section, which has been and still is the most contested section of this new international connection, runs through the Susa valley to Turin along the existing line improved, through which the passenger and freight trains will circulate until the construction of the new northern contour line of Turin that is planned to connect with the international section.

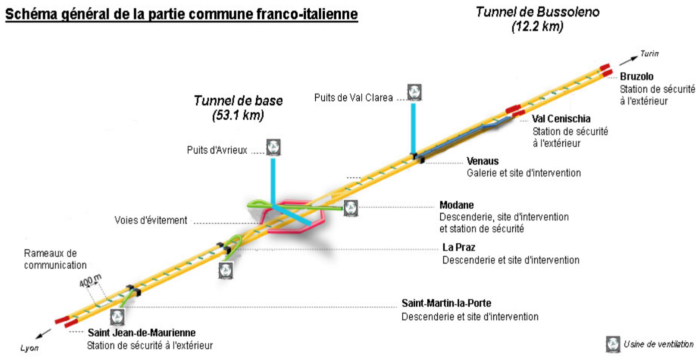
Responsibility in the new Lyon-Turin railway infrastructure program

Section / Concept	French Section	International Section	Italian Section
Ends of the Section	Lyon (surroundings Saint Exupery) St. Jean de Maurienne	St. Jean de Maurienne - Bruzolo Est	Bruzolo Est - Torino
Programme responsibility and Infrastructure owner	SNCF Reseau (IM of the French railway network)	50% shared between SNCF Reseau and RFI	RFI (IM of the Italian railway network)
Programme characterization	Two independent routes from Lyon to Montmelian, a new dedicated high-speed route and another with existing part and a new part for freight traffic. And a new common mixed section up to St.J.Maurienne.	The core of the new Lyon-Turin axis. design as mixed HS line, it includes the 57 km long international base tunnel, and a second tunnel, Bussoleno, of another 12.5 km.	Bruzolo at the Turin railway junction, consisting of the existing line and a new ring railway north of Turin

In conclusion, the future new Lyon-Turin railway corridor will be a mixed line in its most topographically complicated sections, from the French alpine groove, southwest of Chambery, to the Susa Valley in Italy, just over 100 km away. Transalpine section in which in addition to the base tunnel of approximately 57 km, there will be three more tunnels that will total almost another 40 km. all of them bi-tube, twin single-track tunnels.

The basic characteristics of the international section, Saint-Jean-de-Maurienne - Bussoleno are as follows:

- Maximum design speed 220 km / h
- Maximum speed of freight trains 100 – 120 km/h.
- Maximum length of freight trains of 750 m expandable to 1,500 m
- 72 km long, 97% in bi-tube tunnels and the rest on viaducts.
- Inner section of each tunnel 43 m^2
- Intercommunication galleries between the twin single track tunnels, each 400 m.
- Minimum radius in horizontal curves 3,200 m
- Maximum gradient of the line, 12.5‰.
- Maximum gradient within the base tunnel 6.5 and 8.4‰.



Types of trains that will run on the new line:

- High-speed passenger trains running at a maximum speed of 220 km / h.
- Conventional freight trains at speeds of 100-120 km / h.
- Transport wagons combined with lowered platform for the transport of two overlapping containers that will circulate at 100-120 km/h.
- Large gauge railway highway trains (type Modalhor). These trains will run at a speed maximum 120 km / h.

The objectives of this programme are really ambitious, in fact, once it is fully completed, there will be a total transformation in the performances, the quality of the transport service and the railway transport capacity with respect to the existing railway corridor. In other words, the competitiveness of rail transport will improve dramatically and will reverse the trend that has been occurring in the modal share of mobility generated along the corridor. So:

- The best travel time in the relation Lyon Turin would go from more than 4h at present to 1h and 45min with the program completed.
- Consequently, would be expected that the current demand for passengers will multiply by 6, exceeding 3.5 million annual passengers.
- In the case of freight traffic, and only for the effect of the entry into service of the international section, the travel time of conventional or container trains will be reduced by more than two hours.
- In addition, the considerable increase in capacity and reliability makes possible the development of new freight services, in particular the "piggy back" traffic, the railway motorway.
- Forecasts for the transport of goods will indicate that along the corridor the railroad would transport more than half of the land traffic, compared to less than a quarter today, and that the annual volume would exceed 46 million tons, compared to the least than 10 million today.

However, it is a programme as ambitious as it is complicated to execute, as well as extremely expensive, only the international section is close to 10 billion euros, and the demand forecasts will indicate that the income from all the traffic, may cover all the expenses incurred in the provision of the transport service and the operation and maintenance of the new infrastructure, but they will hardly generate surpluses to recover a small part of the important capital costs that its development requires.

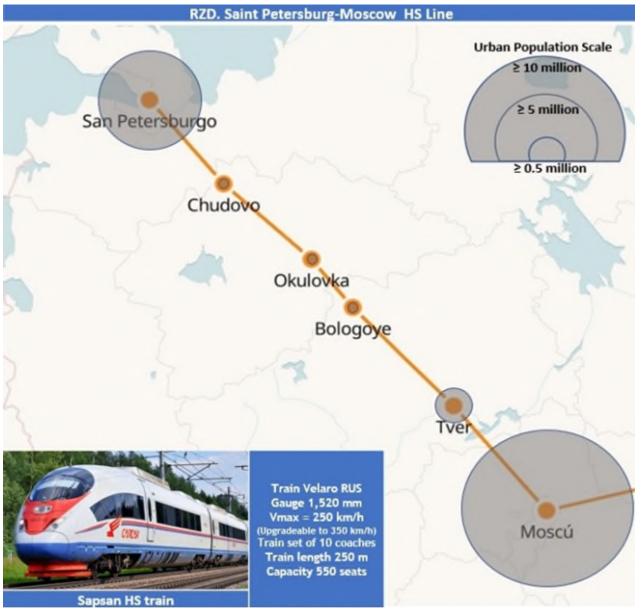
The truth is that its journey began more than 25 years ago and today it is only about to finish the works of the 9km exploration tunnel. Furthermore, it has been facing strong opposition to its construction for years, especially acute in the Italian section. All this makes it difficult to predict its commissioning horizon.

2.14 Saint Petersbug – Moscow High speed rail line (Russia)

The Russian railways, RZD, began their high-speed program in 2005, and in 2009 saw the launch of the first high-speed train in Russia to connect its two main cities, Moscow (over 12 million inhabitants) and Saint Petersburg (5.5 million inhabitants).

This first Russian high-speed service, known under the brand name "Sapsan" (which is Russian for falcon), is provided on the existing St. Petersburg-Moscow railway line (it was the first open railway line in Russia), which has been technologically improved to increase its performance, fundamentally its maximum speed up to 250 Km/h in some line sections.

Given the characteristics of the settlement of the population in the corridor, in which almost all of its more than 18 million inhabitants are located at both ends of the line, it is a clear intercity high-speed end-to-end service, where intermediate stops are fundamentally necessary for high-speed trains to overtake slower trains.



Saint Petersburg Moscow HS line

The city of Tver, with 450,000 inhabitants and located over 160 km from Moscow, it is the only large city located in halfway line, all the other cities where high-speed train stations have less than 25,000 inhabitants.

The main characteristics of the line are the following:

- 645 km of total length in double track in practically the entire route except when passing through stations and in the two extreme suburban areas where their sections with quadruple track to serve other trains such as commuter trains.
- Although the high-speed service serves 6 stations, there are a total of 47 stations along the line.
- Very straight line and also quite flat in most of the route layout.
- The line does not have tunnels, although there are some viaducts or long bridges necessary to save the rivers and water channels that the route crosses.
- 500 m as maximum passenger trains length, Sapsan with double composition.
- 250 km/h as top speed of HS trains
- 90 km/h as maximum speed of freight trains
- 24 tonnes as maximum axle load, freight trains, and 19.5 tonnes for passenger UME trains.
- 1,520 mm as nominal track gauge
- 150 mm as maximum cant

- 3 kV DC as an electrification system for traction, diesel traction is also allowed.
- Digital system for technological radio communication of the standard GSM-R 900 MHz) / LTE (1800 MHz and technological telecommunication transport network (DWDM, SDH). All the line has available radio coverage.

Mixed Traffic High-Speed Line Moscow-Saint Petersburg
View of the quadruple track section Moscow-Kriukovo

Mixed Traffic High-Speed Line Moscow-Saint Petersburg
View of the double track section Saint Petersburg- Chudovo

The St. Petersburg-Moscow line is used by all kinds of services and throughout the 24 hours of the day, currently circulating through it daily and in each direction and sharing the same track:

- 12 High-Speed "Sapsan" trains, which its best travel time is 3h 35m for the two non-stop trains. 180 km / h as the best commercial speed, and a journey time of 4h for those that make the 4 intermediate stops. 160 km / h of average commercial speed.
- 4 long-distance daytime trains with an average journey time of 9 hours. 72 km/h as average commercial speed.
- 20 long-distance night-time express trains, with sleeping coaches, presenting an average journey time of 8 hours 40 minutes. 74 km/h as average commercial speed. Some of them international connecting trains with Finland, Helsinki, and Estonia, Tallinn.
- 20 regional services, approximately one an hour during daytime, Moscow-Tver, with commercial speeds between 56 and 88 km / h, depending on the number of stops, from 8 to 30.
- An undetermined number of freight trains, but reduced, due to the high occupancy of the line by the different types of passenger trains that currently use it.

The important commuter service that exists in the metropolitan section of the line, for example in the Moscow area, Moscow-Kriukovo section, was solved through the construction and commissioning of two additional tracks deployed in parallel to the two pre-existing tracks. Currently the commuter service in this section is 130 daily trains per direction, of up to 10 trains per hour and direction at peak hours.

The merge of HS trains and commuters would have not been possible, if the tracks of that section of the line had not been quadrupled and traffic management equipped with equipment for signalling centralisation blocking, automatic rolling stock identification system, global navigation satellite system and automated operational transport management system.

As summary, it is an upgrading mixed high-speed line with great growth potential as evidenced by:

- The high volume of population concentration at both ends of the line, the two largest metropolitan areas in Russia, located at a distance, (slightly more than 600km), which is in the range of distances in which high rail speed presents its greatest competitiveness and performances.
- The very considerable number of long-distance night-time express trains, 20 daily, covering the Moscow-Sat-Petersburg relationship, that give a good clue of the significant volume of long-distance passenger demand that exist in the corridor.
- The fact that despite the current limitations of the line in terms of performance and capacity, the existing high-speed service, Sapsan trains, has an average occupancy of 85% of the seats offered and presents positive economic results.
- The favourable circumstances of the line's layout, which in a large part of its route does not present great difficulties to be able to substantially improve its performance parameters.

However, the materialization of this potential necessarily passes through the resolution of the current structural limitations of the line that restrict its capacity, performance, and reliability of the service, as evidenced by the fact:

- The line is practically saturated in important sections and prevents both the development of high-speed traffic and freight. In the current situation, many trains, especially the suburban and regional, suffer delays and important stops due to the frequent need to overtake slow trains for those of higher speed and commercial interest.
- High-speed service cannot unfold its full potential on the line. Sapsan High-speed trains,

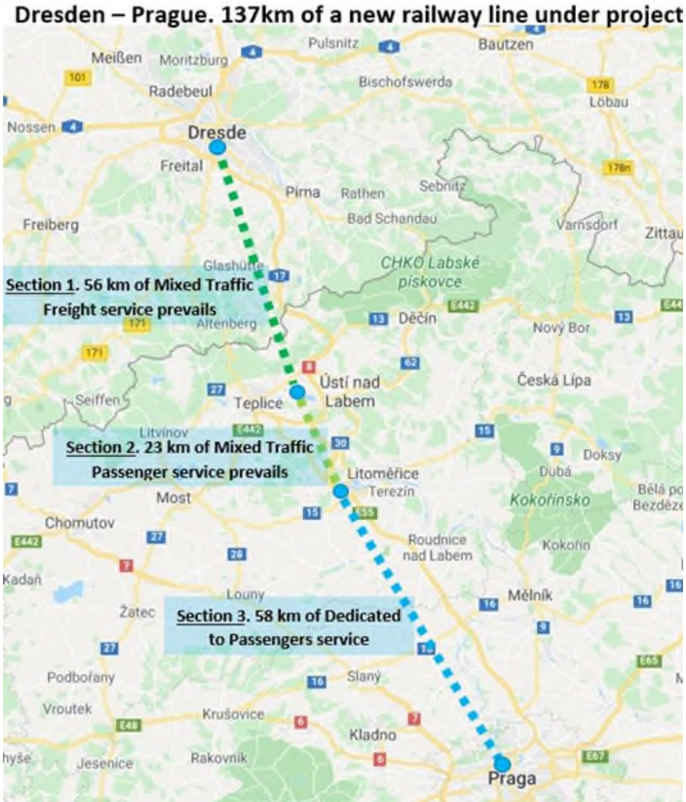
descendant of Siemens Velaro, are approved to run at maximum speeds above 300 km / h, but the line only admits maximum speeds of up to 250 km / h and only in some specific sections.

- The Russian Railways authorities are analysing the need to add new tracks to the line, at least on its Kriukovo-Tver section. But they should also opt for alternatives to improve the performance of the line, both by extending the sections with maximum high-speed and by analysing solutions to increase this maximum speed above 250km/h.

2.15 Dresden-Prague project (Czech Republic)

This is a project of a new railway line, 137 km long, between Dresden and Prague, constituted by three substantially different sections, regarding operation requirements and technical approach.

Dresden – Prague. 137km of a new railway line under project



The first stretch between Dresden and Ústí nad Labem, 56 km long, is designed with parameters for mixed traffic where prevails the number of freight trains and with a maximum speed of 200 km/h. The key construction in this stretch is Krušnohorský border tunnel with the expected length of 26 km. The expected a gradient up to 8 ‰.

The second stretch between Ústí nad Labem and Litoměřický, 23 km long, is also designed with parameters for mixed traffic but prevailing passenger services because of the high demanded domestic relation from Prague to North-Western Bohemia. In this section, the tunnel layout prevails, to save the massif of the Central Bohemian Uplands, and a new underground station will be built near the current station Ústí nad Labem západ, which is replacing.

This stretch runs through up to 18 km long tunnel. In that stretch expected gradient will be up to 17‰, due to the line passing under the river Elbe.

The following table shows the basic technical parameters corresponding to each section.

Dresden-Prague 137 km of a new high speed railway line under project

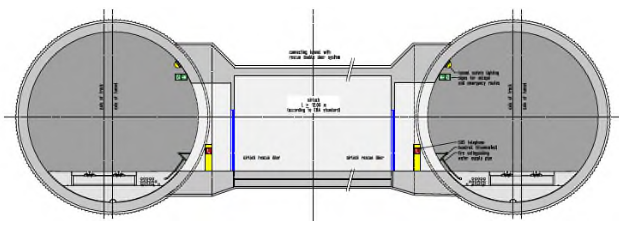
Basic Parameters \ Line Section	Dresden – Ústí nad Labem (Joint cross-border section)	Ústí nad Labem - Litoměřice	Litoměřice - Prague
Line type and daily operation time	Mixed traffic integrated daytime. 24 hours	Mixed traffic integrated daytime. 24 hours	Dedicated to Passenger transport. 18 hours
Total length	56 km	23 km	58 km
Maximum design speed	200 km/h	250 km/h	350 km/h. (320km/h operat.)
Number of tunnels and total length	1 Bitube. 26 km length cross border tunnel	1 Bitube. 18 km length	3 tunnels. 8.5 total length Longest Bitube 4.5 km
Distance between track centres	4 m	4 m	4 m
Minimum standard radius on horizontal curves	1.900m (estimated according other determining parameters)	2.950m (estimated according other determining parameters)	7.250m (estimated according to determining parameters)
Maximum design cant	100 mm	100 mm	100 mm
Maximum cant deficiency	150 mm	150 mm	150 mm
Maximum design gradient	8 ‰	17 ‰	25 ‰ some values up to 30 ‰
Maximum axle load	22.5 tons	22.5 tons	22.5 tons
Maximum passenger trains length	425 m	425 m	425 m
Maximum freight trains length and total mass	740m and 2.200 tons	740m	
Equipment in Railway Systems. Energy, Signalling & Telco.	25kV 50 Hz and 15kV 16.7 Hz AC (in German side) ERTMS level 2	25kV 50 Hz AC ERTMS level 2	25kV 50Hz AC ERTMS level 2
Number of sidings and their average spacing	3 of 1.000m length Every 14km	1 of 1.000m length Every 12km	
Average construction costs per km	Available for the Czech stretch. Total cost 1.24 B€ (89.5% Infras. plus Track)	Total cost 67.64 M€/km 62 M€/km infra. & track 5.64 M€/km Rail. System.	Total cost 32.56 M€/km 30.33M€/km infra. & track 2.23 M€/km Rail. System

Table 3 Dresden-Prague high speed railway line under project

The third stretch between Litoměřický and Prague, 58 km long, will be determined only for high-speed passenger traffic. The gradient profile reaches due to the freight train absence of some values up to 30 ‰ and the track alignment has to enable the speed up to 350 km/h.

The Cross Border Base Tunnel with a length of 26.53 km designed as twin tube tunnel according to international rescue and safety regulations. The tunnel length at the German side will be 15.10 km and 11.43 km at the Czech side. The Cross Border Base Tunnel will possess rescue connections every 500 m and an underground rescue station near the tunnel crest at Börnersdorf.

In case of emergency passengers then can reach the safe tunnel tube at the opposite side.



Regular Cross Section Connecting Tunnel

On the ground of the project schedule, there is an expectation that its proposal and ratification by parliaments of both countries have to be done by 2025.

The Operational Approach agreed jointly with DB Netz AG for the first section Dresden - Ústí nad Labem, foresees a total of 198 trains per day, according to the following structure and typology.

- 150 daily freight trains, both directions, being:
  - Weight limit up to 2,200 tonnes
  - 740 metres length
  - Operational speed up to 120 km/h
- 48 daily passenger trains, both directions, being:
  - Maximum long up to 400 metres
  - Maximum operational speed of 200 km/h

It is being taken into consideration to initiate the line construction jointly by year the 2027.

Regarding the second section, Ústí nad Labem – Litoměřický, the following operation is foreseen.

- 100 daily passenger trains, both directions, being:
  - Length up to 400 metres
  - Maximum Operational speed of 250 km/h

- About half cross-border trains and the other half domestic passenger trains

According to a traffic study performed by the Deutsche Bahn the new line will cut the travelling time between Dresden and Ústí nad Labem for freight traffic by 12 % and for passenger traffic by almost two-thirds.

- Daily freight trains have not been determined yet, being:
  - Weight limit is still under study due to the gradient problem
  - 740 metres length
  - Operational speed up to 120 km/h

Regarding the Third section, Litoměřický – Prague, stretch dedicated for high-speed passenger trains, the following operation is foreseen.

- 150 daily passenger trains, both directions, in a part of this stretch will operate up to 6 passenger train pairs per hour at rush time, being:
  - Maximum long up to 400 metres
  - Maximum operational speed of 320 km/h.

Due to some more favourable geographical conditions and including on it the pilot sections, is expected to initiate the construction already by the year 2025 and opening by the year 2030.

As conclusion, the project of the new railway line Dresden – Prague is, due to 26 kilometres long Krušnohorský tunnel, the significant international railway project in the context of entire Europe. It consists of three operational different sections, two of them that add a length of 79 km, 56% in tunnel, will be of mixed traffic with integration in daytime of the passenger and freight trains and the third section, 58 km long, which connects to Prague, will be dedicated to international and domestic passenger trains operating at daytime only.

The closest target is to finalise the feasibility study, on its basis will be determined a final corridor including the track layout.

2.16 The Eurasia Project, a future challenge for Mixed Traffic High Speed Railway lines

It is an initiative promoted by the Russian Railways, RZD, to promote the articulation of a railway corridor connecting the Chinese and European high-speed networks via the Russian federation, to configure a competitive alternative for land transport that channels the important expectations of growth in trade between both economic areas.

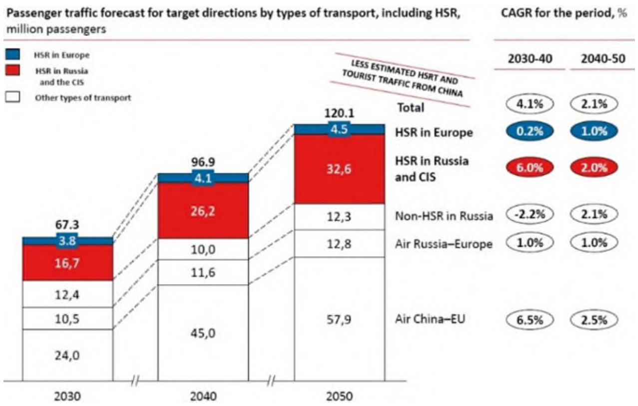
The objective is to promote a railway project with mixed-use high-speed line characteristics, which would connect Berlin with the high-speed red China, whose objective is to capture a significant part of the important growth in mobility associated with the expectations of trade development between both economic areas:

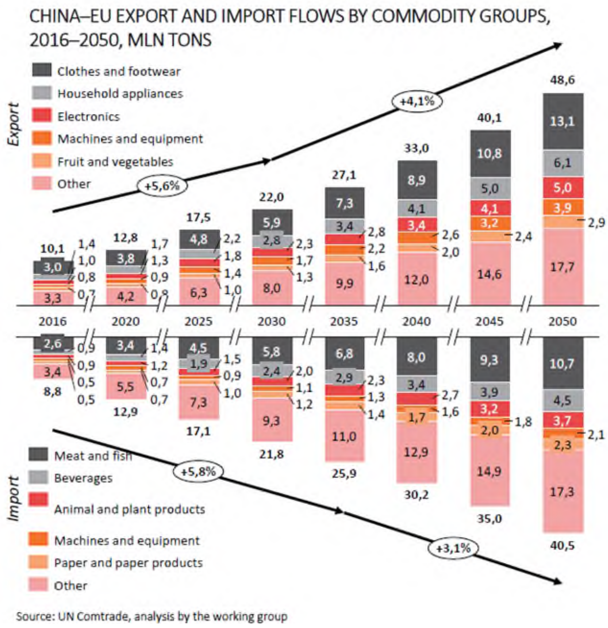
- Attract to high-speed passenger rail the intercity mobility of transnational and domestic passenger along the corridor formed mostly by businesspeople and tourists.
- Promote HSR freight trains that benefit from the advantage of higher speed and reliability compared to regular services and are similar to air transport in terms of the features they offer.

As the accompanying graphs show, the available growth forecasts, prepared within the UN Comtrade, indicate that the mobility growth dynamics throughout the corridor will maintain an average annual rate of more than 3% in passengers' mobility and more than 4.3% in freight traffic during the next 30 years.

Which means that probably in 2050 the demand for passengers will have more than doubled with respect to what exists today, but the freight traffic will have multiplied by 3.5. Thus, according to these forecasts, the traffic of goods between China and the EU in 2050 will exceed 89 million tons per year, of which about 40% will be food and beverage products and for which the transport period is very significant.

The goal of the project would be for high-speed rail freight to reach a market share of around 9% in total China-EU freight traffic flows, of the order of 8 million tons per year.





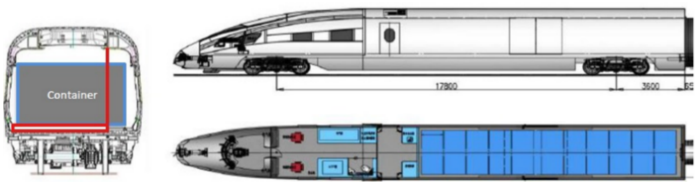
For its final determination and subsequent characterization and technological design, three alternative of deployment routes of the Corridor are being analysed, as shown in the following map.

- A first route from Berlin to Urumqi, with a total length of 6,090 km, of them 2,366 km in Russia, (Krasnoye - Zolotaya Sopka), continuing for Kazakhstan and connecting with the Chinese network in Urumqi HSR station.
- A second route from Berlin to Qiqihar, via Siberia, with a total length of 9,060 km, of them 7,013 km in Russia, (Krasnoye - Zabaykalsk), and connecting with the Chinese network in Qiqihar HSR station in north China.
- A third route from Berlin to Urumqi, with a total length of 6,272 km, of them 4,257 km in Russia, (Krasnoye - Biysk), and connecting with the Chinese network in Urumqi HSR station.

Eurasia – China's project of the century

These are the three route options that are currently under analysis and whose selection is still pending.

Regarding freight rolling stock, the project considers that its design responds to the technological base of high-speed passenger trains.



Main characteristics are as follows:

- Maximum speed up to 350 km/h
- Mean speed of cargo trains: 250 km/h
- Type composition of the train 12 carriages
- Mean speed of the passenger train 260 km/h

Incorporation into this project the new generation of NGT trains, which for the transport of freight will mean:

- Freight Transport continental and intercontinental
- Average speed of a freight car: now ~ 18 km/h => 20.000 km/year, should be ~ 150 km/h => 300.000 km/year
- Battery-electric operation for last mile service (>25 km range)
- Autonomous low speed operation of individual cars or groups of cars (25 km/h)
- Fast – automated -- marshalling
- Fast – automated -- transhipping
- Autonomous driving last mile

High-speed freight train from China to Europe has great potential to be competitive alternate solutions to problems related to existing air and sea freight transport.

High-speed rail has a shorter time than sea transport and much lower cost than air transport, what at least in theory qualifies it to be an alternate mode for freight transportation, especially for high-value and high time-sensitive goods.

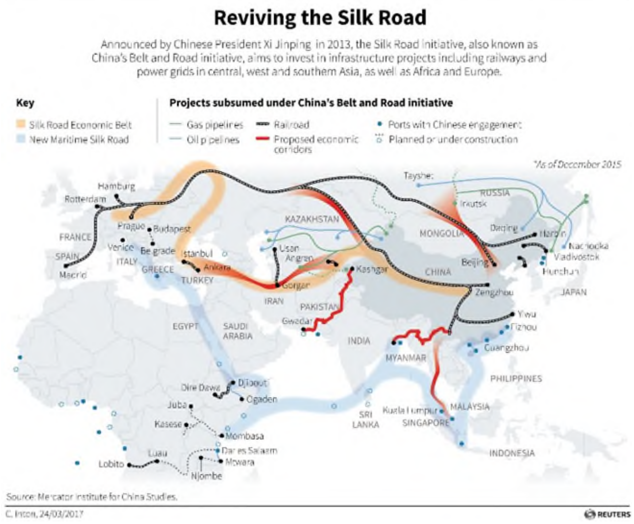
However, for this potential become a reality, it is necessary to solve important infrastructure shortcomings and notably improve the procedures and instruments for cooperation and communication between neighbouring networks.

- China's railway has played an active role in promoting the export of Chinese goods and is conducive to exchanges between China and other countries.
- Kazakhstan railway is a bottleneck in terms of quality and efficiency, this network being a very critical link for the entire Europe-China corridor. In terms of communication, for instance, running a high-speed freight train from China to Russia and Germany through Kazakhstan, is infeasible at present.
- Russian railway is the backbone of the country's transportation and is continuously expanding and upgrading the East-West and North-South international transport corridors.
- Polish railways are also a bottleneck in the corridor, with potential capacity problems.
- The Belarusian railways have a low rate of provision of double-track electrified infrastructure, although they have a major railway infrastructure upgrading program.
- In Germany, with a very powerful railway network, Deutsche Bahn is fully committed developing internationalization and logistics of the cargo market and the rapid growth of transportation of high-added-value goods. In response to several additional deficiencies load transport.

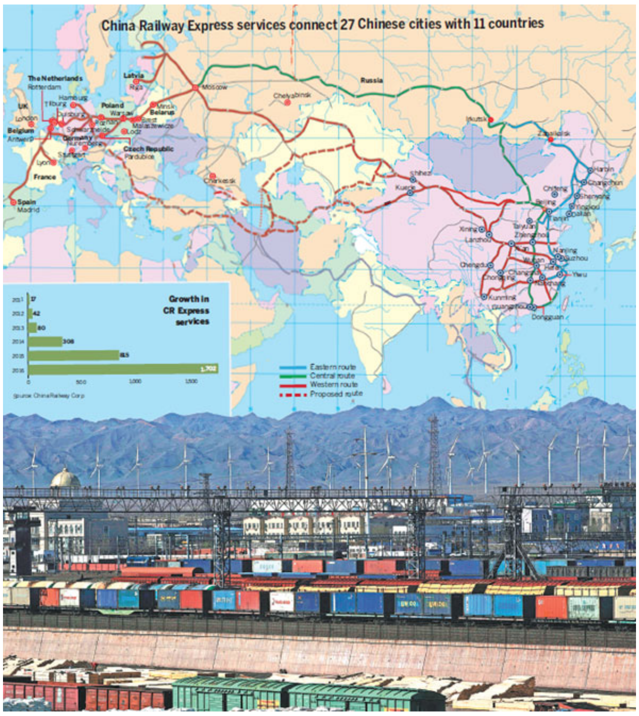
As a revealing example of the difficulties to be faced and resolved to configure a truly competitive Eurasian rail corridor, the fact that at present Because of the difference in rail gauge, 1435 mm and 1 520 mm, freight is transferred from one wagon to another twice while a freight train travels from China to Western.

In the long run, improving the infrastructure construction of railway transportation of the countries along the Europe--China corridor, is a key part of promoting the high--quality development of China--Europe Railway Freight Block trains, along with this and no less important significant progress must be made in incorporation along the corridor of the most current intercom technologies in order to know the situation and conditions of transport in real time and permanently facilitate the exchange of information, both operational and management.

Al this requires important concerted efforts and sustained commitment necessary to give coherence, consistency and continuity to the national railway programmes along the corridor, especially in matters of transport policy, its regulation, compatibility and technological harmonization and financial sustainability.



In sum, the objective of the project is none other than to promote the contribution of the new generation of rail transport in reviving the Silk Route, however, It is a project that is in a very initial pre-study phase, that requires the mobilization of important economic resources and reaching lasting commitments and agreements between networks with very different starting points, making it difficult to foresee its development and implementation program, which logically, given its extension, must progress by phases, beginning its implementation in those of greatest interest to consolidate the articulation of this complex transcontinental corridor.



China Railway Express route map, (May 2017)

2.17 Benchmark analysis summary table

Table 4 Benchmark analysis summary table

Element or Topic	Main Characteristics or Subject	Mixed traffic High Speed Line cases				
		High Speed 1	**Hannover-Wurzburg**	**North East Corridor**	**Figueres-Perpignan**	**Barcelona-Figueres Vilaf.**
General line Information	Line length	109 km	327 km	729 km	44,4 km	131,1 km
	Company responsible for line management-operation	HS1 Ltd	DB Netz AG	AMTRAK mostly (80% length) and MTA, CDoT, MDoT	LFP (owned by ADIF and SNCF)	ADIF
	Extreme O/D of the line and intermediate stations	London St. Pancras/Chanel Tunnel. Ebbsfleet. Ashford	Hannover/Wurzburg Gottingen, Kassel, Fulda	Boston/Washington New York, Philadelphia. Baltimore	Is a HS cross border link connecting with Barcelona and its port through another mixed traffic HS line	Barcelona Sants-Figueres Vilaf.-South limit of LFP. Girona Mollet (freight connection)
	Type of services, (trains) performed on the line	International HS Domestic HS Freight trains	HS Passenger (ICE) Inter City Freight trains	High Speed Inter City Local Commuter Freight trains	International HS Freight trains	International HS Domestic HS Freight trains
	Year of commissioning entire line	2012	1991	2008 with Act (PRIIA)	2010 2013 connection to Figueres-Barcelona-Madrid HS line	2010 first section 2013 the entire line
	Current Railway Undertakings using the line	Eurostar IL, London & South Easter Railway and DB cargo	DB passenger ICE, IC DB Cargo Other freight Operators	Intercity by AMTRAK, other 7 in Commuter, and freight services	RENFE and SNCF	Domestic Renfe (AVE and Avant) International Renfe and SNCF in cooperation International Renfe Freight
Line Performance Parameters	Maximum line speed, passenger,**(P)**. Freight, **(F)**, trains	Vmax ^{P}= 300 km/h Vmax ^{F}= 140 km/h	Vmax ^{P} = 280 km/h ICE trains Vmax ^{F}= 160 km/h Parcel Intercity	Vmax ^{P}= 241km/h Acela Vmax ^{F}= 80 km/h	Vmax ^{P}= 300 km/h although design speed is 350 km/h Vmax ^{F}= 140 km/h	300 km/h as design Vmax 200 km/h as operational Vmax Vmax ^{F}= 120 km/h
	Maximum axle load	Passenger trains 17ton	N/A Maximum axle mass ≤ 22.5 ton	N/A	Maximum axle mass ≤ 22.5 ton	22.5 ton
	Maximum train length	Passenger trains 400 m	N/A	N/A	Passenger 400 m. Freight 750 m	Passenger 400 m. Freight 750 m
Technical Characteristics – Infrastructure	Horizontal curve radius	10,000 m exception 8,000 m	7,000 m standard minimum. 5,000 m Exception	Minimum below 400 m	7,000	> 6,000 m standard minimum. 3,000 m Exception
	Maximum gradient	25‰	12.5‰	13‰	Standard 13.5‰, except. 18‰ (in two different sections with 2 and 3 km)	18‰ section Mollet-Figueres 30‰ section Barcelona-Mollet
	Distance between track centres	4.5 m	4.7 m	3.81m	4.8 m	4.7 m

Element or Topic	Main Characteristics or Subject	Mixed traffic High Speed Line cases				
		High Speed 1	**Hannover-Wurzburg**	**North East Corridor**	**Figueres-Perpignan**	**Barcelona-Figueres Vilaf.**
	Total km of tunnels	24.7 km, in 5 tunnels, longest 10 km, other of 7.5 km. (twin bore 1 x Track)	127 km. made up of 65 tunnels	9.2 km, the Longest 4.4km (two 1-track tubes)	8.7km, in 3 tunnels, longest 8.3km (twin bore 1 x Track) and two cut & cover tunnels 200 m long	30 tunnels totalling 34.3 km in length
	Total km of bridges and viaducts	3.4 km in 3 viaducts	33 km. made up of 268 units	8.8 km, the Longest 5.14 km	3.62 km in 10 viaducts	60 viaducts, with a total length of 13.2 km
	Percentage of line in tunnel and viaduct	25.8%	48.9%	2.5%	27.61%	36.27%
Railway Systems	Electric power supply	25kV 50 Hz	15 kV 16 2/3 Hz 1-phase AC	3 systems, but 80% 12KV 25Hz	25kV 50 Hz	2x25 kV 50 Hz. 2 substations
	Contact wire height above the head rail level	5.08 m	N/A	N/A	5.30 m	5.3 m
	Signalling System	TVM430 and ERTMS/ETCS-STM	PZB and LZB	Only one, ACSES System	ERTMS level 1	ERTMS level 1 and 2 but currently only level 1 in operation
Specific freight facilities	Connection links number	9, totalling 20.8 km length	14 connections	43 with conventional network	2, just one at each line end	3. Mollet, Girona F. and Figueres
	Number of sidings, (Passing Loops)	2 of 2.5 and 4km each	10	3rd track (not continuously)	1 (same time maintenance base)	2. Riells and Villobi D'Onyar
	Number of crossover	9	29 other than Passing loops	Approx.49		1. Llinars
Total cost of Line Construction and cost per line-km. and date		Total €6.56 billion €60.18 million/km	Total €6.40 billion. €19.50 million/km (1995 prices)	Total €3.64 billion. €5 million/km (1998 prices)	Total €950 million €21.60 million/km	Total €4.38 billion €33.44 million/km

<table>
<tr><th colspan="2" rowspan="2">Element or Topic</th><th rowspan="2">Main Characteristics or Subject</th><th colspan="5">Mixed traffic High Speed Line</th></tr>
<tr><th>High Speed 1</th><th>Hannover-Wurzburg</th><th>North East Corridor</th><th>Figueres-Perpignan</th><th>Barcelona-Figueres Vilaf.</th></tr>
<tr><td rowspan="6">Use of the line</td><td rowspan="2">Service offer</td><td>Trains per weekday (both directions)
Passenger
Freight trains</td><td>46 International HS on entire line.
126 Domestic HS trains in section 2.
66 Domestic HS trains in section 1. HS domestic trains
2 Freight trains</td><td>70-94 HS ICE trains.
2-16 IC trains
36-52 freight trains of Containers
120 km/h and Parcel Intercity 160 km/h</td><td>42 Intercity Boston-NY.
82-100 Intercity NY-Washington
Commuter above 50-200
12 to 30 freight trains</td><td>10-12 International HS (6 AVE, 6TGV)
8 freight trains (autos, combined)
A total of 120 weekly trains</td><td>10 to 14 International HS
10 Domestic HS (AVE)
7 Euromed
4 Avant City
7 freight trains</td></tr>
<tr><td>Average interval between P. trains</td><td>10 m in section 2 and 18m in 1</td><td>15 minutes</td><td>30 to 60 m to Intercity trains</td><td>2 hours</td><td>30 minutes</td></tr>
<tr><td rowspan="2">Rolling Stock</td><td>Passenger trains</td><td>Class 373 to Eurostar. 750 seats
Class 395 to domestic. 354 seats</td><td>ICE and IC</td><td>N/A</td><td>AVE S-100. 347 seats
TGV INOUI 509 seats double deck</td><td>AVE S-100. 347 seats
TGV INOUI 509 seats double deck
AVE 103 404 seats
Euromed 299 seats</td></tr>
<tr><td>Freight locos</td><td>Class 92. 5,000 kW.
140 km/h</td><td>E120 5,600 kw</td><td>N/A</td><td>Loco S 252. 5.6 MW,
220 km/h</td><td>Loco S 252. 5.6 MW,
220 km/h</td></tr>
<tr><td rowspan="2">Current demand</td><td>Annual passenger</td><td>10.5 million in Eurostar
9.0 million in domestic HS</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Freight services carried.</td><td>Containers and automotive comps.</td><td>Containers and Parcel Intercity</td><td>Multi categories of goods</td><td>Automobiles and containers mainly</td><td>Automobiles and containers mainly</td></tr>
<tr><td colspan="2" rowspan="2">Conditions of use</td><td>Operating constrains</td><td>Conventional Freight trains are restricted to nighttime operations only.
Network Statement allows operation of fast freight trains, (300 km/h), during the day, such Postal /Parcels, but so far there is not.</td><td>Freight trains operates at night-time only.
Due to aerodynamic effects, maximum speed in 2-track tunnels is limited to 250 km/h
No planned overtaking of freight trains by passenger trains. Use loops in case of train failure</td><td>Normally allows freight trains at night only, but some need some movement at daytime.
Diesel trains are not allowed on underground sections.
Maintenance is predominantly at overnight time</td><td>Freight trains operates at day and night-time.
Only one train can be present in the tunnel for each running direction.
Due to regular maintenance between 00h00 and 05h30, line is not available for traffic.
RID requirements are applied to admittance of dangerous goods.</td><td>Freight trains operates at daytime.
Overtaking of freight trains by passengers is scheduled.
For safety reasons at the train crossing and given the low incidence on journey time, Vmax =200km/h.
Due to regular maintenance between 00h00 and 05h, line is not available for traffic.</td></tr>
<tr><td>Infrastructure charging for passenger trains</td><td>An all-costs coverage charging system is applied.
€48.2 per Domestic train-km.
€44 per international train-km</td><td>Charging scheme cover: Path fee per train-km, stations per stop and energy consumption
€8.4 per ICE train-km.</td><td>There is costs share system among every operators based on train mileage
Share costs based on car miles, covering maintenance,</td><td>Flat-rate fees scheme is applied for the use of line which depends on trains type and class. An average fee is as follow:</td><td>Addition Charging model (Path allocation, access, and use)
€ 14.64 per AVE train-km
€ 11.65 per Avant train-km</td></tr>
</table>

Element or Topic	Main Characteristics or Subject	Mixed traffic High Speed Line				
		High Speed 1	Hannover-Wurzburg	North East Corridor	Figueres-Perpignan	Barcelona-Figueres Vilaf.
	Infrastructure charging for freight trains	Freight services are only charged an "avoidable" cost, (OMRC). €5.13 per conventional train-km €6.17 per fast train-km. (daytime)	€5.09 per train- km on HS line €3.17 per freight train-km on conventional north-south line	train dispatching centres, security and power consumption	HS Passenger trains €52 train-km Freight trains €44 train-km Up to 25% discounts for loyalty agreements	€ 1.74 freight train-km (Container and Automobile trains)
Other topics of interest	Legal scheme	HS1 Ltd is responsible for management and operations, and Network Rail for infrastructure maintenance and safety.	All CAPEX were paid by federal Government. Db Netz AG owns and operates the line	Track access fees system have changed many times with different operators paying through different models.	After the bankruptcy of TP Ferro, the original concessionaire of this international high-speed connection, its operation and management has been granted to LFP S.A., co-owned entity of ADIF and SNCF reseau	Adif, Spanish Railway Infrastructure, IM, owns the line and performance its operation and maintenance. Renfe is currently the only operator of domestic passenger and freight trains. International services are performed in cooperation Renfe-SNCF.
	Experience gained	The major criticisms of HS1 were that passenger demand forecast were too high.	The initial idea of a total mixed traffic operation on the new HS line proved unsuitable due to operation and safety constraints	The lack to invest in capital projects has reduced reliability and increasing repairing costs	The development of international connections must be synchronized with the development of the networks to which it is connected. It seems has not been the case	Studies and tests are being carried out to determine the maximum crossing speed between passenger and merchant trains.
	Lessons learned	Low use for freight traffic which does not cover the line over costs. If line were passenger dedicated, CAPEX, could have been reduced.	Daytime and Night-time segregation has proven to be the best solution. There is now no capacity issues on the old North-South main line.	Financial commitment from federal government is necessary to increase reliability	In addition to considering the above, improving the risk analysis, both in determining CAPEX and especially in forecasting revenues, more rigorous and prudent demand studies, both to passenger and goods, appears quite recommended.	It is necessary to validate the implantation and operation of the specific safety detectors required by the freight traffic, specifically, of vertical impact on track, of dynamic behaviour of pantograph and of dragged objects.

3 HIGH SPEED RAIL LINES CATEGORIZATION PROPOSAL. DECISION TREE FOR SELECTION

What we know today as high-speed rail emerged in the second half of the last XX century as a modal response to reverse the significant and progressive loss of competitiveness of the railway in the market for intercity passenger mobility.

With the spectacular development of the motorway network, the intercity transport of passengers by road, private car and buses, experienced a very noticeable improvement in quality, a significant reduction in journey times and equally important improvement in safety.

No less important was the spectacular development experienced by the airport network and short and medium-range passenger air transport, which culminated in the explosion of low-cost flights, generating a new interurban air offer very competitive, in journey times and prices, both in the domestic market and in the international demand of passengers generated between neighbouring countries.

Faced with this overwhelming dynamic of the other modes of transport, the reaction of the railway was to develop its system in technological terms that would allow it to reposition its interurban service offer at levels of competitiveness comparable to that of alternative modes.

China - Europe freight trains

In other words, the original concept and vocation of high-speed rail was none other than to develop a truly competitive new offer, mainly in end-to-end journey times, in the intercity passenger mobility market. Which in practice translated into the development of:

- Infrastructures and rolling stock suitable for developing high speeds services for passenger traffic. Vmax ≥ 250 km/h as structural performance parameter.
- Maximum safety operating systems and procedures.

In fact, it was with this vision of exclusive passenger traffic service that the first high-speed lines were conceived and developed, for example:

- Tokaido Shinkansen in Japan. The first high-speed railway line built in the world, it was inaugurated in 1964, its maximum speed is 270km/h and currently transports 130 million passengers annually through a daily service of 450 passenger trains in both directions, up to 12 trains/hour per direction.
- Paris-Lyon in France, the first commissioning high-speed railway line in Europe, was inaugurated in 1981/82, its maximum speed is 300km/h and its design was exclusively for passenger transport, in fact it has maximum gradients of 35 mm.

High Speed Line - Viaduct

These are clearly new rail lines whose route runs through highest population density corridors, connecting its large urban centres that are located at efficient distances for the high-speed rail offer compared to air and road transport and whose traffic volume expectations allow to obtain a clear financial return.

Therefore, the original motivation for high-speed rail had two fundamental purposes:

- Recover the competitiveness of the railroad in interurban passenger mobility in corridors with a high concentration of population, obtaining positive economic results.
- Solve along corridor possible problems of saturation of the existing line as a consequence of the diversion of the main passenger services through the new line.

Logically, in these cases, the intensive use of the new line by passenger traffic, mainly high-speed trains, made its use by other types of traffic impractical. With what originally the high-speed rail lines were of the type that today we call lines dedicated to passenger traffic.

Dedicated use condition that was maintained with the development of new high-speed lines, whenever they were deployed in interurban corridors with high population density capable of generating high demand and consequently the need for an intensive supply of intensive passenger train traffic.

However, in successive deployments of high speed, the two factors of its original motivation have not always fully met, - neither sufficient passenger demand to justify its profitability and exclusive use nor sufficient traffic deviation to solve capacity problems on the pre-existing lines. This has led to the development of high-speed lines known as mixed traffic, that depending on their main motivation and their performance parameters, they have given rise to different types or categories of high-speed lines of mixed traffic.

The purpose of this chapter of the study is none other than to include a proposal for the classification or categorization of high-speed lines, based on the knowledge obtained in the technical-operational characterization of the different lines analysed in the study and in coherence with that categorization offer a procedure to support decision-making on the type of line to be developed in a future high-speed program, which is included as a decision tree.

3.1 High speed railway lines Categorization proposal

Following the success of the first high-speed lines as a competitive and efficient land transport modality in terms of sustainability, the development of this transport system gained interest and gradually led to successive experiences in construction and operation of high-speed railway systems in a large number of countries, initially mostly Europeans but progressively also in countries of other continents.

High-speed rail is an intercity land passenger transport that competes in time with air and car for travel markets in the range of approximately 150 to 800 km, and it is in this mobility market that it finds its greatest justification because in most metropolitan regions there is not enough space available to expand the road network or airports, and there is strong environmental and political opposition when such expansion is planned.

Despite this predominant orientation of the high-speed system towards the interurban passenger market, however, the system, which has developed from the construction of independent national networks, currently presents a vast high-speed rail network with different conditions of use, from lines exclusively dedicated to high-speed passenger trains, to mixed-use lines from the modernization of existing lines, passing through high-speed lines of shared use of passengers and goods in different modalities of length and proportion of mixed use.

Logically, each type of high-speed line built intends to respond to the specific reality of each mobility market as well as the conditions of the pre-existing network.

How much greater distances and concentration of the population greater degree of dedication of the line. At the opposite end of the mobility market, the shorter the distance and less concentrated the population, the greater the possibilities for mixed use.

Based on these considerations and the experiences known and analysed by the study, a categorization of the high-speed lines has been made according to their effective use, the proposal of which is presented below with the purpose of being the object of analysis, discussion and improvement within the study management group.

The line categorization proposal starts from two basic types of HSR system:

- Exclusively dedicated high speed line to passenger trains. Named in the study as High-Speed Rail Lines Dedicated to Passenger Traffic, and
- Shared use high speed lines by both passenger and freight trains. Named in the study as Mixed Traffic High Speed Rail Lines
- The first category in turn groups two types of lines:
  - HS Lines Dedicated to Exclusive Traffic of Passenger High Speed trains, those whose Vmax ≥ 250km/h. In them, high intercity demand saturates capacity and enables profitability. This type of line is indicated in the categorization table with number 1.1
  - HS lines Dedicated to passengers in both the intercity and regional travel markets. In them, the achievable interurban demand is not enough to saturate the capacity of the Line and achieve its profitability. This type of line is indicated in the categorization table with the number 1.2

In the large category of lines that mostly concerns the study, Mixed Traffic Lines, the classification proposal frames 5 different types of lines, according to the market to which they are directed, their location and territorial scope and structural configuration. Resulting in the following types:

- Total mixed traffic high speed lines deployed along an interurban corridor and in which freight trains can runs along the entire line at operating hours that depend on the intensity of use by passenger trains. This type of line is indicated in the categorization table with the number 3
- Partial mixed traffic high speed lines, deployed along an interurban corridor and in which freight trains circulate only in some sections of the line, those that coincide with congested sections on the pre-existing network, circulating on schedules which also depend on the intensity of use of passenger trains in these sections. This type of line is indicated in the categorization table with the number 3.1

Freight trains at Washington State

- New high speed rail Infrastructures crossing natural barriers. They are mostly high-speed mixed traffic links connecting HS and/or conventional networks to improve dramatically railway competitiveness and its shorter length makes it possible that, normally, freight trains can run sharing timetables with passenger trains. This type of line is indicated in the categorization table with the number 2
- Mixed traffic conventional lines upgraded to HS lines. On these lines, the movement of freight trains can be in their entire route or only in certain sections, in which, if possible, quadruple tracks are made to segregate freight traffic as far as possible, which logically depends on the intensity and prevalence of different trains. This type of line is indicated in the categorization table with the number 4.
- HS lines dedicated to passengers in which high-speed freight trains operate, that is, freight trains whose Vmax ≥ 250 km/h. In known practices, these freight trains are actually high-speed passenger trains retrofitted internally to transport parcels and express mail safely, with what, from the operational point of view, they have the same behaviour as the passenger trains from which they come. This type of line has been included in the categorization table as type number 5, although for operational purposes it could be considered and classified as one more category of the types of dedicated high-speed line.

In the table below, its structural characterization is collected for each one of these types of high-speed lines according to its essential features in the following essential aspects:

- Territorial scope and line length range
- Target market and main HS System choice criteria
- Prevailing design parameter online performance
- Most representative examples of HS line
- Main operational features
- Main benefits and problems

Although the abstraction and synthesis need of the table prevent offering a more comprehensive and detailed explanation of the essential characteristics of each type of line, it is believed that the table does present a sufficiently illustrative overview to obtain a first vision of the possibilities offered by each type of high-speed line.

		Main characterization parameters and reference examples according to the type of high-speed lines					
Type of Traffic (Service to provide)	Types of high speed lines	Territorial scope and Line length range, km	Target market and main HS System choice criteria	Prevailing design parameter on line performance	Representative examples of HS line	Main operational features	Main benefits and problems
1. High Speed Lines Dedicated to Passenger Traffic HS lines designed to compete in the Intercity market	1.1 HS lines Dedicated to passengers exclusively to long distance InterCity mobility	Long distance Intercity Corridor 150<L<800	Maximum attract of high intensity Intercity mobility $\geq 10^7$ Annual Pax	Top Maximum speed 270≤ Vmax ≤ 380km/h	LGV Sud-Est Paris - Lyon LAV Madrid—Barcelona HS2 under construction	Best travel time Path uniformity Daytime use only Overnight maintenance	Highest competitiveness. Top service reliability. Not always reach full costs recovery.
	1.2 HS lines Dedicated to passengers both long distance InterCity and Regional mobility	Long distance Intercity Corridor 150<L<800	High intercity mobility prevails being the regional important too	Top Maximum speed 250<Vmax≤300km/h	Shinkansen HS line, JR Madrid-Seville-Málaga (*) Koln-Frankfurt	Best travel time Improved accessibility Daytime use only	Highest competition Great reliability improves cost/benefit Reliability may lessen
Mixed Traffic High Speed lines High-speed lines designed to improve the competitiveness of railway system	2. New HS rail Infrastructures crossing natural barriers (Great high-speed mixed traffic links connecting HS and/or conventional networks to improve dramatically railway competitiveness)	Great Network Connectors and/or Missing Links 40< L<100	Both passenger and freight trains balanced, strongly driving railway system competitiveness	Traffic capacity prevails. Vmax≤250 km/h. Normally are based on long tunnels.	Gotthard base tunnel Perpignan-Figueres Channel Tunnel Lyon-Turin, under construction	Mixed traffic in day and night-time freight trains may run grouped into lots 100≤ V^Fmax < 160km/h	Improve railway system competition. Capacity optimization Very high costs. Highest safety requirements
	3. Total Mixed traffic high speed lines (Purposely built for mixed traffic where Freight trains run the entire length of the new HS line)	Long distance Intercity Corridor 150<L<800	Passengers prevails freight trains improve network capacity and line economic results	balance maximum speeds passenger and freight trains 250≤Vmax≤300km/h	Hannover - Würzburg, DB HS1 Barcelona-Figueres Basque Y (under construction)	Passenger trains at day-time. Freight trains mostly at night-time 100≤ V^Fmax < 160km/h	Improve network capacity Better cost-benefit ratio May lessened passenger revenues and its reliability

	Main characterization parameters and reference examples according to the type of high-speed lines						
	3.1 Partial Mixed traffic high speed lines (Freight trains can run only on some new line sections, those that coincide with congested stretches)	Long distance Intercity corridor 150<L<800	Intercity prevails and freight partially adds better results and improves its competitiveness	balance maximum speeds passenger and freight trains 220≤Vmax≤300km/h	Nimes- Montpellier plus Montpellier-Perpignan and Dresden-Prague under project	Freight trains at day and night-time 100≤ V^Fmax < 160km/h	Improve network capacity Better cost-benefit ratio
	4. Mixed traffic conventional lines upgraded to HS lines	Long distance Intercity Corridor 150 < L > 800	Gradual improvement of line performance, with shared use	V^Pmax < 250 km/h 80≤V^Fmax ≤ 100km/h	North-East Corridor, USA Saint Petersburg-Moscow Berlin-Hamburg	Freight trains run over the entire line length, normally at night- time some also at daytime	Lower investment costs System can be improved increme ntally. Less competitiveness
	5. HS Lines Dedicated to passenger on which HS freight trains are operated (Mixed traffic HS lines limited to HS freight trains)	Long distance Intercity Corridor 150<L<800	High Intercity mobility and some HS parcel trains provided	Top Maximum speed 250≤Vmax≤300km/h	Torino-Milano-Bologna-Firenze-Roma-Napoli HS freight trains "Mer citalia"	Best travel time Path uniformity Day and night-time use 250≤ V^Fmax < 300km/h	Highest competitiven ess Top reliability Slightly Improve cost-benefit ratio

(*) Madrid-Seville line was designed as a mixed traffic HS line, but due to the high level of traffic of passenger trains and the availability of capacity on conventional line, it operates only as a dedicated line.

Table 5 High speed rail lines categorization proposal

3.2 Decision tree for choosing modality of use of HSR Lines

The selection and decision between a dedicated high-speed system, (in any of the categories indicated above), and a shared-use high-speed line system, (in any of the different types of Mixed Traffic HS lines also already indicated), is the fundamental question ever since the preliminary phase in planning and designing of a new High-Speed program.

The decision process should consider and evaluate several key factors, from the quantitative and qualitative characterization of the mobility market to be served to the specific circumstances and possibilities of the pre-existing network, passing through the particular topographical conditions of the corridor and the existing city system.

There is an effective maximum speed for each category of line. for example, the dedicated passenger line provides the fastest travel times, thus better serving the longer travel markets, (markets of more distant city pairs); meanwhile, a partially shared line provides mid-range travel times and serves mid-range markets, (the higher the proportion of dedicated line, the longer the market serve); finally, at the other extreme, a total shared use of the new line will provide the longest travel times and best serve shorter mobility markets.

For their part, the specific circumstances of use and performance of pre-existing lines on which the new program affects, must also be considered in the decision on the type of line to be developed. Aspects such as the technological level and degree of saturation of the pre-existing network and the possibilities of its resolution are also key aspects in determining the type of new line to consider.

Be that as it may, this prior decision-making process on the best type of program to develop in each specific case is key to achieving the best expectations of program success in both technical-functional and financial terms, that is, to plan a new truly sustainable high-speed program.

With the sole objective of offering a guide to the process to be followed in the selection of the type of line in a specific case, the study has prepared an initial contribution to a possible decision tree to be followed in the selection of the type of programme, high-speed line, to be developed. Naturally, the decision tree included below should be considered as a first contribution to the process of selecting the type of line, and should be the object of consideration, discussion and possible improvement within the working group that directs this study, hence that is featured as draft.

As can be seen in the proposal, the starting point to deploy the decision-making tree proposal is the clear identification of the essential motivation behind the initiative to propose a high-speed rail program. Basic aspect on which the proposal includes three possible original motivations, perfectly distinguishable from each other, supporting the development of the new program:

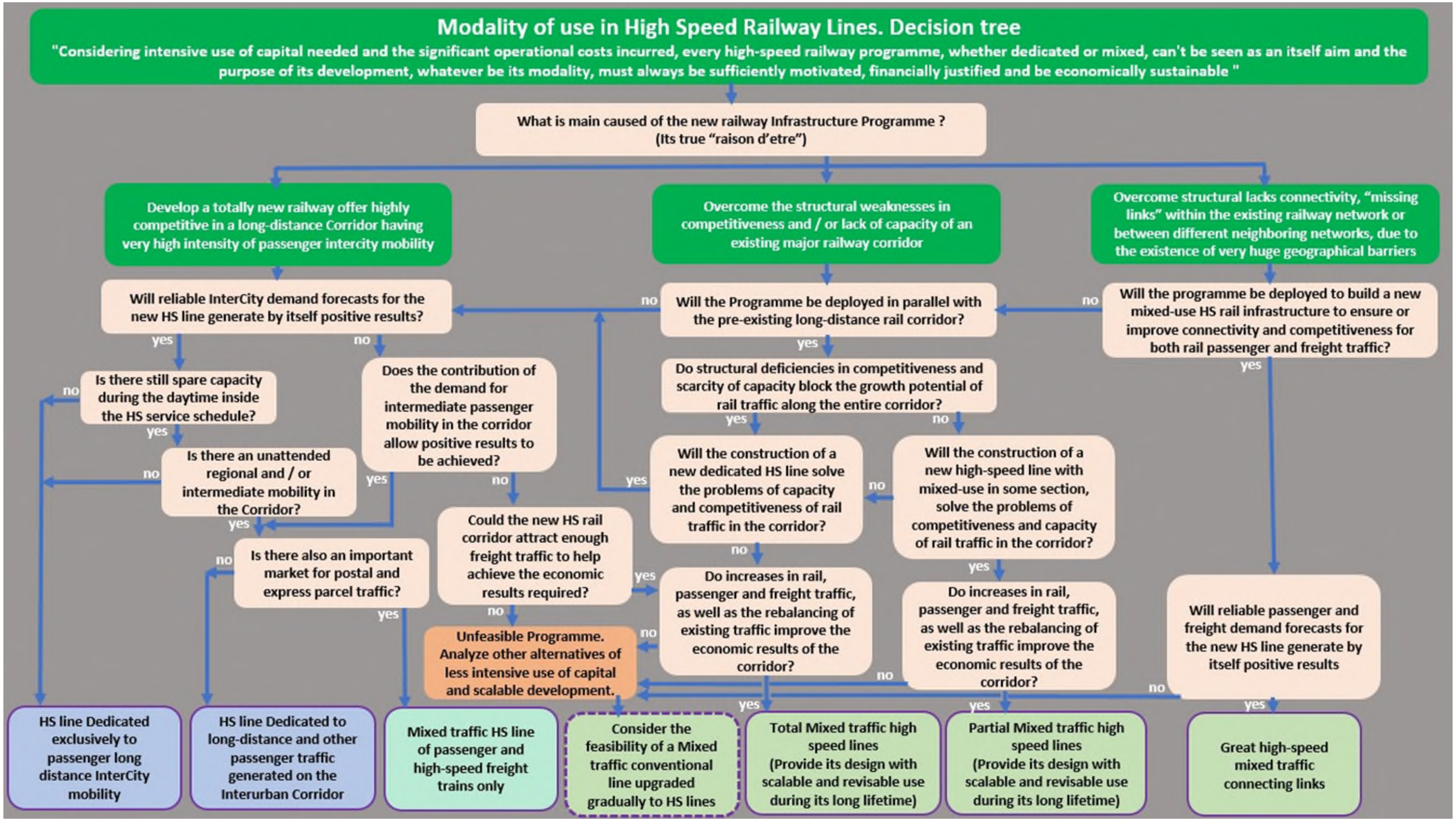
- Create a new passenger transport rail service, reference in the market, in a very high-density interurban corridor.
- Overcome structural deficiencies of competitiveness and capacity of the existing network providing most updated technological solutions.
- Overcome structural deficiencies in connectivity, missing links, essential for the development of the existing network, also with updated solutions.

In what follows, the decision tree proposal leads to the best solution for a new program, type of line according to its use, applying a selection criterion based on its sustainability. Getting to determine what type of line, of those that have been categorized in the classification table, would be the most appropriate to develop in the specific case analysed, from a completely exclusive line of high-speed passenger trains, to a mixed line resulting from a progressive modernization of an existing one, logically passing through new high-speed mixed lines of different characteristics according to their territorial scope and conditions of use, that is to say:

- Total mixed traffic high speed rail line.
- Partial mixed traffic high speed rail line.
- Great high-speed rail mixed traffic connecting links.
- Conventional mixed traffic railway line gradually upgraded to a high-speed mixed line.
- Mixed traffic HS line allowing only high-speed freight trains.

In view of the high cost of implementing a high-speed line and the fact that they are expected to last for a long time, it seems reasonable to think that major variations in the mobility of the hinterland may occur during their lifetime. For this reason, it seems highly recommendable to consider the concept of its possible convertibility to a different use than that which can be deduced from the current analysis in the decision process of each new line.

This is especially interesting for mixed traffic lines, total and partial types, hence the recommendation in the decisional scheme, including below, to formulate a scalable and reviewable design that allows the adaptability of the use of the line to possible major changes in mobility its hinterland occur throughout its life.



Modality of use of high-speed rail lines. Decision Tree

4 PHASE I. DETERMINATION OF THE TECHNICAL-FUNCTIONAL REQUIREMENTS

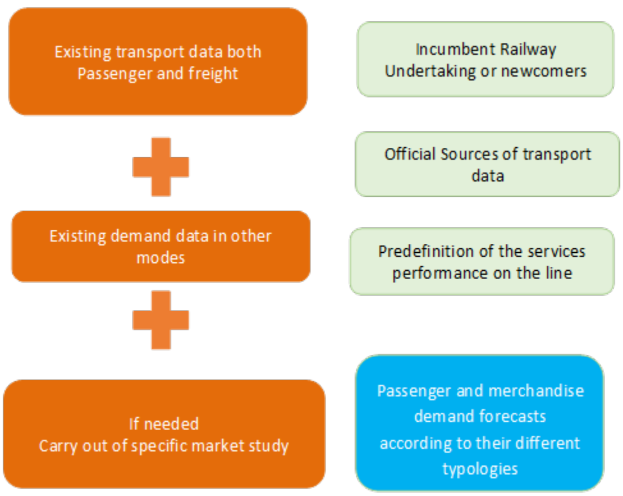
4.1 Identification and determination traffic objectives and line service

This is a previous and critical phase for appropriate decision-making in determining the technical-functional characterization of the line, according to its target market and level of demand to reach.

According to the socio-economic characteristics of the territorial area served by the line the following types of service should be identified and selected:

- What type of passenger mobility are intended to cover, just inland intercity, also cross border, even regional?
- In the same way, what type of goods and traffic are catchable and are the main objective of the freight transport by the line, bulk never, neither general non-palletized product, which preferably?

To answer those basic questions, it will be necessary to identify and forecast the traffic objectives of the line by analysing the available traffic data and studies and carrying out, if necessary, a specific market study for the case.



Traffic objectives forecast process guidelines.

In this market analysis, it will be convenient to propose different functional technical configuration alternatives of the line that, after its contrast, allow the best decision making in terms of cost benefit.

The optimal solution for the operation of a new railway infrastructure has to be evaluated individually for each case.

High speed station

Annual volume of passenger and freight traffic is one of the major factors for classifying railway grade. Railways are built to satisfy the needs of local transportation first. Annual volume of passenger and freight traffic is the basis for designing railway, the basis for evaluation of economic effectiveness, and an important factor for determination of route alternative.

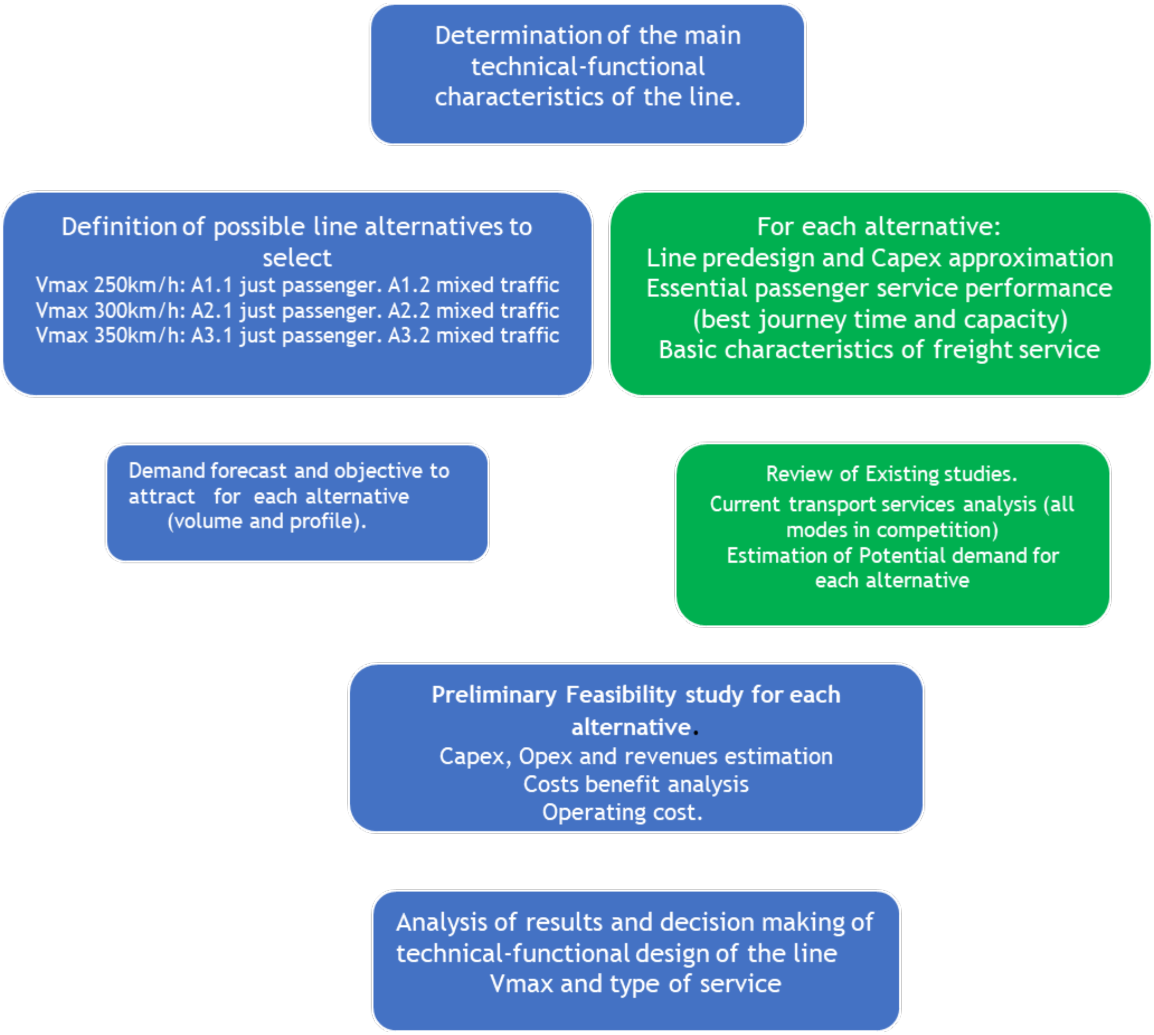
The annual volume of passenger and freight traffic may affect the track-train interaction, track distortion, even the service life of facilities. In general railway investment, cost of railway traffic and traffic revenue are decided by annual volume of passenger and freight traffic.

Moreover, the annual volume of passenger and freight traffic is the crucial for the design of railway capacity, it has significant impact on the engineering investment, transportation costs and income of design line. Therefore, to ensure that the same service life, larger capacity is necessary when using high standard technical equipment.

Therefore, it would be very convenient to consider several high-speed passenger line design options, for example, one for Vmax 250 km /h, another for Vmax 300 km/ h and a third option for a line of a Vmax 350 km/h, and then, for each option define two alternatives, first one as an exclusive passenger line and the second one as a mixed traffic line.

For each alternative, a preliminary cost benefit study should be carried out in order to identify the most appropriate technical-functional solution for the high-speed corridor in question.

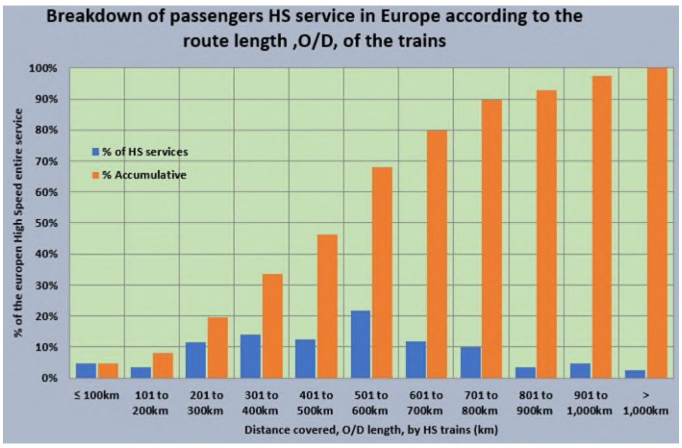
The following scheme tries to synthesize this decision process:



Selection process for the technical functional design of the high-speed line

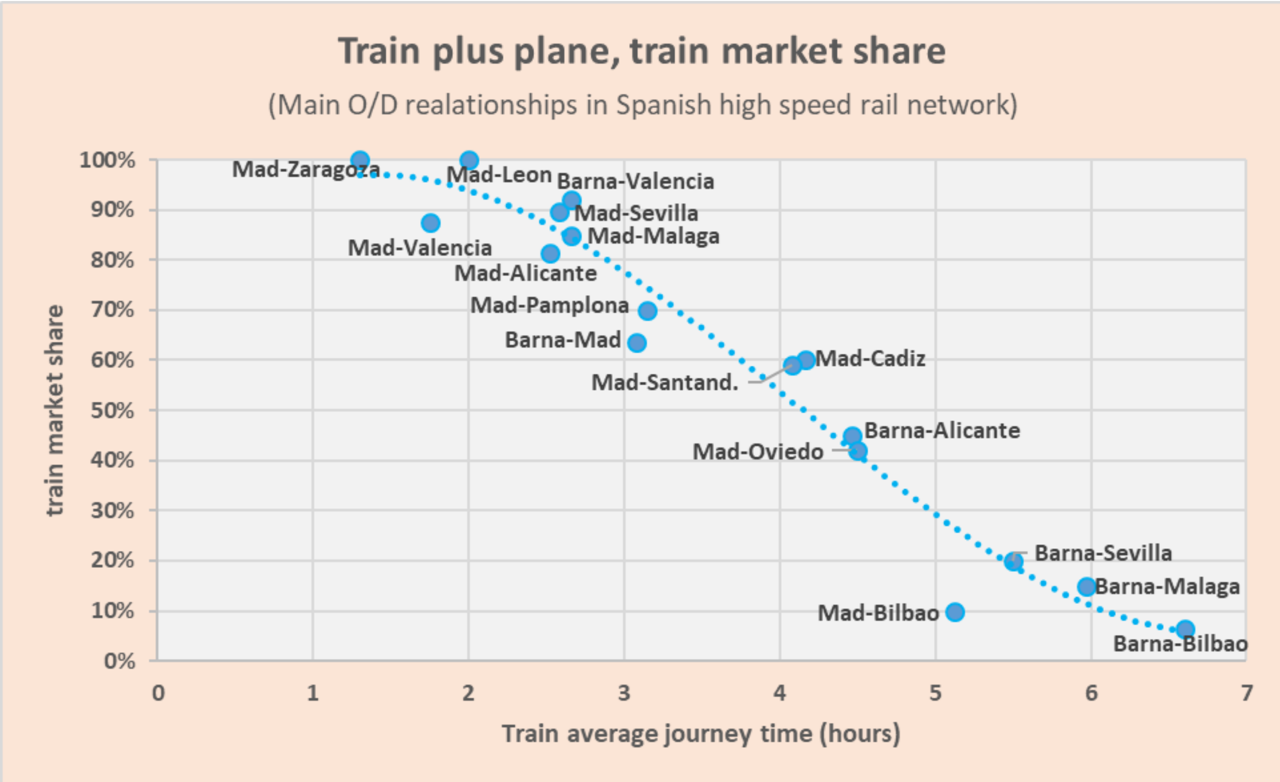
In this process, it becomes especially relevant, specifically in the case of passenger traffic objectives, to correctly identify the target market of the line.

The high-speed passenger service is mainly aimed at offering an extremely competitive alternative with air transport in the range of distances between 200 to 800 km. as evidenced by the fact that around 80% of high-speed services have a route included in that range of distances.

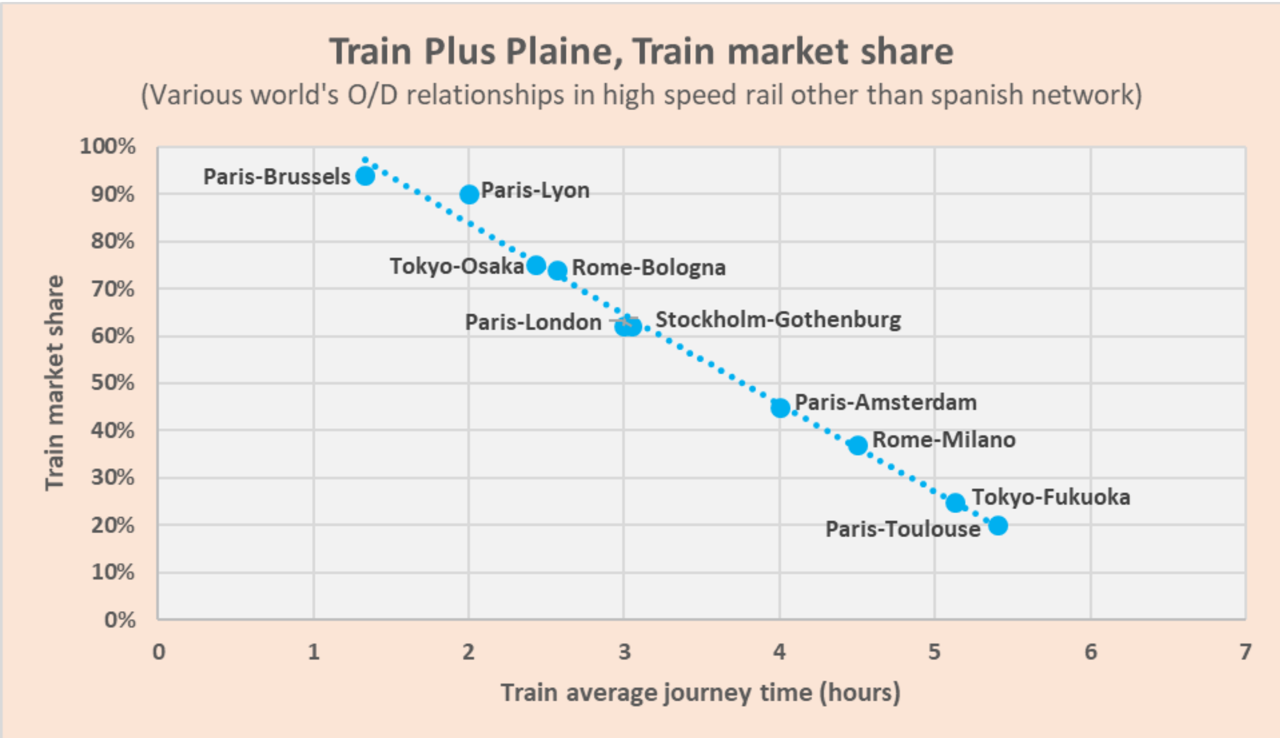


In that market, the configuration of the service in terms of journey time will be critical in the effective competitiveness of the passenger service provides on the HS line.

As proof of this, it is very illustrative and useful to refer to the results achieved by the high-speed service in the interurban mobility market, which are included in the figures below.



AVE market share versus plane in its service deploying throughout ADIF HS network



Market share of the HS Service versus plane in the interurban mobility of different O / D relations in the world

These results show the great importance of the travel time of the HS service to attract the interurban demand. In the range of distances from 300 to 700 km, the elasticity of demand with respect to travel time is around -0.5. Very interesting result for the decision on the Vmax of design of a new HS line.

Based on the determination of the market objectives, both for passenger and freight transport demand, the essential performance parameters of the line's design must be defined in order to achieve these objectives, specifically those of line infrastructure related to:

- Structure gauge
- Line speed
- Axle load
- Train length
- Usable length of platform

4.2 Analysis of infrastructure requirements and capacity assessment for different type of traffics.

The high-speed lines according to their objective performance require design parameters and operation and maintenance requirements determined by their use.

Consequently, based on the results of the previous chapter, mainly Infrastructure components must be considered, and its requirements will be defined according to the traffic to canalize as well as its operational performance. Some of them are described below.

- Basic line performance parameters
  - Maximum speed of passenger trains (km/h)
  - Maximum long of passenger trains. (m)
  - Maximum speed of slowest freight trains (km/h)
  - Maximum long of freight trains. (m)
  - Maximum axle load and total train weight (tons)

Regarding the design of the line, there is a basic key decision to take, which is the maximum speed of the passenger trains. First of all the maximum speed of passenger trains has to be consistent with the train journey time required to meet demand expectations, but at the same time, that maximum speed, which will determine the alignment and track parameters of the line, must be such that its value allows the freight trains traffic throughout the line.

That is, in the mixed lines, a reconciliation between the maximum speed of passenger trains and the maximum minimum speed of freight trains must be achieved.

Railway line layout most relevant parameters are:

- Clearance envelope
- Distance between track centres.
- Axle load
- Alignment design
  - Minimum radius of horizontal curve.
  - Cant. mm and Deficiency (PT)/Excess (FT) of Cant. mm
  - Minimum radius of vertical curve. m
  - Maximum gradients, 0/00, and its length
- Tunnels design considerations
- Drainage design considerations

The basic performance parameters of HS lines in Europe, which includes the required structural gauge, are shown in the table below.

New Line Type	Structural Gauge	Axle Load	Maximum Speed	Max. Train Length
Passengers Traffic	GC, Infrastructure gauge	17 ton	250-350 km/h	400 m
Freight Traffic	GC/recommended AF, if any market	22.5 ton	100-120 km/h	750-1050 m

Table 6 General performance parameters of HS lines in Europe

4.2.1 *Clearance envelope*

The gauge is the basis for ensuring safe train operation, limiting the cross-sectional dimension of the rolling stock and the mounting dimension of equipment along lines, and deciding valid dimensions of architectural structure.

Depending on different functional requirements, the gauge can be divided into structure gauge and rolling stock gauge.

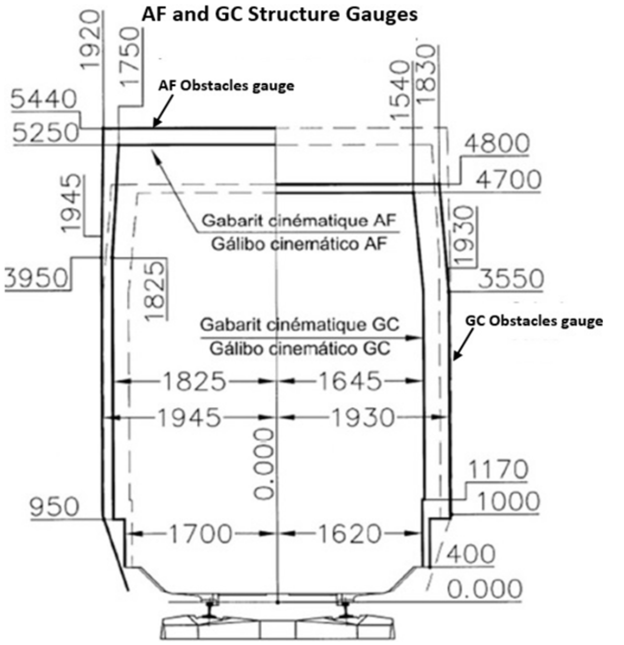
A structure gauge is a cross-section vertical to the track centre of line and defines the minimum dimension of the cross-section required to ensure safe passing of rolling stock.

Any part of the buildings and equipment close to the railway may not intrude on the structure gauge, except for equipment interacting with rolling stock.

A rolling stock gauge is the maximum dimension of the cross-section of rolling stock (passenger & freight trains).

At a minimum, the required structural gauge must be the GC, defined according to EN 15273-3, which must envelop the kinematic gauge as dimensioned in the UIC 505-1 and 506 leaflets and in the TSI 2002/735/EC, related to rolling stock.

Following diagram shows both structural gauge, GC (European/UIC Standard gauge) and AF ("rolling motorway" or piggy-back railroad gauge), overlapping for European railways:



European Structure Gauge

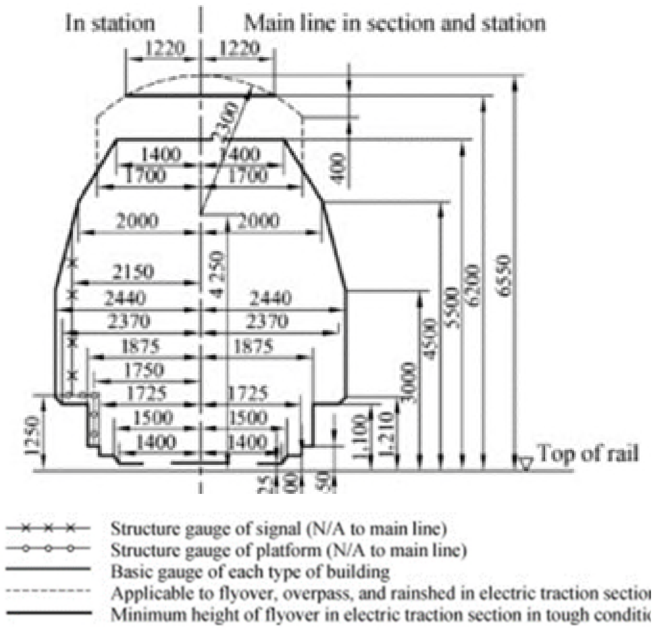
Piggyback railroad

The American loading gauge for freight cars on the North American rail network is generally based on standards set by the Association of American Railroads (AAR) (Mechanical Division). The most widespread standards are AAR Plate B and AAR Plate C, but higher loading gauges have been introduced on selected routes to accommodate rolling stock that make better economic use of the network, such as auto carriers and double-stack container loads.

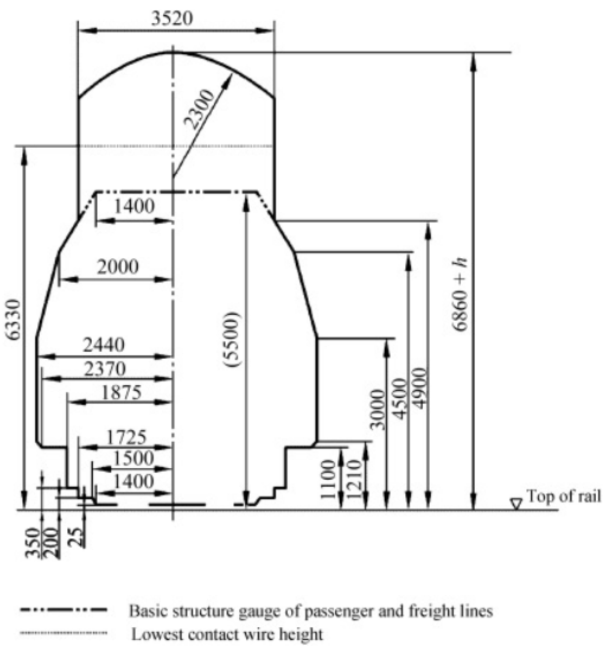
Double deck freight trains

Contact lines, as infrastructure, need to be mounted out of a rolling stock gauge and in structure gauge because it needs to interact with pantographs in operation.

For example, the following figures show the structure gauge for freight with single deck or double deck in China railways and the potential installation of the catenary:



Chinese Structure gauge of mixed passenger and freight railw*ay (unit: mm)*



Basic structure gauge of transport of double-deck container (electrified section) (unit: mm).

Consequently, with respect to gauge established for line design, the mixed traffic would mainly suppose:

- Study the convenience of establishing the freight gauge, according to piggyback transport market expectations on the corridor served.
  - In the case of Europe, the difference of gauge AF with respect to the GC is in practice only in the height free of implantation of obstacles, 640 mm higher.
  - The difference in gauge, according with American Standards (AREMA), between passenger and freight trains is about 1 m at each side. Therefore, when passing through stations, freight trains cannot run on tracks served by platforms.

Freight service platform & passenger train

- Lifting the contact wire
- Increase cross section (freight trains are wider than passenger trains)

4.2.2 Length of trains

Authorizing longer trains on certain routes with the adequate number of longer sidings and adaptations to the control command system, as long as their performance on acceleration, braking is the same as today or even better.

Extending train length may affect the safety of certain critical points to be surveyed, inducing some small investments, including the signalling, control and command system, which has to be adapted to the extra length.

Greater length of the trains will affect the design of the facilities needed for trains preparation, stabling, overtaking, length of sidings, etc.

For example, in the case of Europe, the variety of signalling systems and the timing of ERTMS deployment means that specific solutions will have to be implemented and that parameters of ERTMS will have to cope with the new future lengths.

4.2.3 Track centres distance

The distance between track centres has to be established in full compliance with the structural gauge specified for the line considering passengers trains and freight trains gauges.

Additionally, horizontal distance between track centres has to be defined considering aerodynamic effects, subject especially significant in the case of mixed traffic lines, even train crossing effects.

In any case, according to the EU Infrastructure subsystem TSI, in a new line track centres distance should not be smaller than the figures states for this parameter, being that:

- Minimum nominal horizontal distance between track centres.
  - 4.00 meters for 200 < Vmax ≤ 250 km/h.
  - 4.20 meters for 250 < Vmax ≤ 300 km/h.
  - 4.50 meters for speed >300 km/h

In the case of North America, following AREMA recommendations this track centre distance would be bigger.

The distance between track centres has to satisfy at least the requirements for the limit installation distance between track centres, defined according EN 15273-3, related to Railway applications. Gauges. Part 3: Structure gauges.

For example, in the case of Figueres-Perpignan, LFP line, this distance is 4.8m, distance that allows, under normal operation conditions, that passengers and freight trains operate and run simultaneously on adjacent tracks, respectively at 300 km/h and 100 km/h, with no speed or crossing constrains. Noting that in this mixed traffic line its sole tunnel, with more than 8 km long, is a twin tube tunnel.

4.2.4 *Axle load*

Axle load of rolling stock is important for railway construction and also for maintenance needs. It is one of major basis to determine the designed load standard.

The locomotive axle load may affect the power of locomotive, and train's axle load may affect the train's load per meter. The bridge load and track type shall also be driven by train's axle load.

The permissible axle loads front, and rear are specified by the vehicle manufacturer. Several points on which the axle loads have a direct effect must be considered:

- component strength of the body and wheel suspension or axles
- load capacity and therefore minimum size of the tyres
- configuration of the brake and brake force distribution
- springing and damping

Axle load of rolling stock in China are generally 21–23 ton. Axle loads with 25-ton, 28-ton, 30 ton are only applied for coal transportation. The axle loads of EMU in China are 14–16 t.

Axle load of interoperable rolling stock in Europe for freight trains are 22.5 ton and for passenger trains are 17 ton.

The heavier axle loads shorten track component lives, increase the rate of degradation of the track structure and may increase the risk of derailments.

Likewise, the wagon-maintenance costs may increase with increased wagon loading. There still is no common standpoint on what the 'optimum' heavy axle load would be. The various operators favour 25 or even 30 tonnes.

Essential prerequisites for any additional increases in axle load and speed:

- Utilisation of modem running-gear designs
- Ride tests using measuring wheelsets on track of different qualities
- Utilisation of matching pairs of wheel/rail profiles
- Long welded rails
- Good quality of track
- Limiting of speed in tight curve radii

Axle load will need a review of the capacity of the bridges to support such heavy trains with the new load per axel and of the capacity of the tracks to accept such load and at what speed, thus introducing some speed limits and some reinforcement investments. Special constraints in case of AREMA: COOPER 50, COOPER 80. The use for bridge dimensioning based on COOPER 80 is much more demanding that the UIC/EUROCODE recommendations.

Freight train running on a bridge

4.2.5 *Alignment design*

Design of mixed traffic railway lines is a very complex task from the aspect of horizontal and vertical alignment determination. Chosen parameters have to ensure safety for all vehicle types. In addition, it is necessary to ensure ride comfort for passenger trains.

Meeting these requirements implies restriction of minimum and maximum speeds for passenger and freight trains. European standard EN 13803 prescribe limit values for parameters of horizontal and vertical alignment.

In this case of mixed traffic, the vertical alignment design takes a special importance, as the freight trains, according to the total load and maximum slope could require one additional locomotive, or even two.

However, Infrastructure Manager has to define limit values for above-mentioned parameters in national regulations according to the adopted railway maintenance strategy.

The passenger Vmax has an impact to the minimum radius of horizontal curves to be designed, according to the cant deficiency/insufficiency. Vmax, Minimum radius of horizontal curve and cant are Vmax, determined by the following expression:

$$R = V2 \ / \ ((H \times g/s) + \gamma)$$

V = Maximum speed. m/sec

H = Cant (mm)

g= 9.8 m/s^2

s = distance in mm, between axles of each railhead = 1,503.5 in standard gauge

γ = Uncompensated centrifugal acceleration. Usually limited to 0.65 m/sec2 for reasons of passenger comfort, and in any case to a maximum value of 1 m/sec² because safety requirements.

Below are the results achieved in an exercise aimed to show the relationship between maximum design speeds of a high-speed line and minimum radius needed on its horizontal curves, according to type of line, mixed or dedicated to passenger traffic.

The exercise has been carried out for two cases:

- Case 1: adopting the limit of the unbalanced acceleration in the value of greater comfort for the passenger, 0.65 m/s², which is equivalent to limiting a value of 100 mm the cant deficiency of the horizontal curves.
- Case 2: adopting the limit value established for safety, 1m/s², which in this case is equivalent to limiting the cant deficiency in horizontal curves to a value of 153 mm.

In both cases, most common maximum design cant values have been adopted:

- 140, 160 and 180 mm, for dedicated passenger lines,
- 90, 100, 110 and 120 mm, as maximum design cant for mixed traffic lines.

In addition to all this, also the following limitations, for the maximum cant deficiency and cant excess as well as on operational conditions in terms of minimum speeds, have been taking into a count:

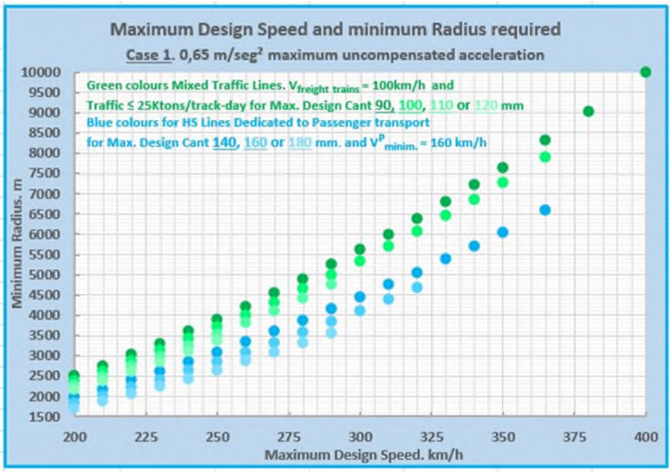
- 153 mm as long as Vmax ≤ 300 km/h.
- 100 mm as long as Vmax exceeds 300 km/h
- 100 km/h as minimum speed for freight trains hauling a total maximum of 25,000 daily tons per track, adopting, consequently, a limit of 85 mm as excess cant due to freight safety as well as affordable track maintenance criteria.
- 160 km/h as minimum speed of the slowest passenger trains, adopting for these trains a limit of 95 mm as excess cant, because these slowest passenger trains could be composed by locomotives and coaches and consequently also have maximum axle loads of up to 22.5 tons.

Cant track and tilting train

CASE 1

Results and its representation for Case 1, considering a common limit on cant deficiency of 100 mm which is equivalent to an uncompensated acceleration of 0,65 m / s², and a cant excess of 95 mm for passenger dedicated lines and 85 mm for mixed traffic lines, are as follows:

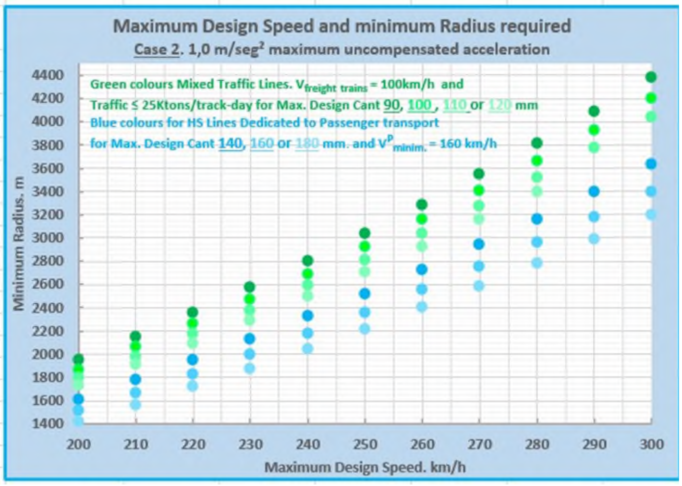
High Speed Line Maximum Design Speed. km-h	Minimum Radius requiered on horizontal curves — Case 1. HS Lines with a maximum uncompensated trasversal aceleration of 0,65 m/s² ≈ Maximum cant deficiency of 100 mm						
	Dedicated Passenger transport High Speed Lines $V^{P}_{minimum}$ = 160Km/h			Mixed Traffic High Speed Lines $V_{freight\ trains}$ = 100km/h and daily Traffic ≤ 25Ktons/track			
	Max. Design Cant 140	Max. Design Cant 160	Max. Design Cant 180	Max. Design Cant 90	Max. Design Cant 100	Max. Design Cant 110	Max. Design Cant 120
200	1975	1823	1693	2496	2371	2258	2155
210	2178	2010	1866	2752	2614	2489	2376
220	2390	2206	2048	3020	2869	2732	2608
230	2612	2411	2239	3301	3135	2986	2850
240	2844	2625	2438	3594	3414	3251	3103
250	3086	2849	2645	3900	3704	3528	3367
260	3338	3081	2861	4218	4007	3816	Cant Excess > 85 mm
270	3600	3323	3085	4549	4321	4115	Cant Excess > 85 mm
280	3872	3573	3318	4892	4647	4425	Cant Excess > 85 mm
290	4153	3833	3559	5247	4985	4747	Cant Excess > 85 mm
300	4444	4102	Cant excess > 95 mm	5616	5334	Cant Excess > 85 mm	Cant Excess > 85 mm
310	4746	4380	Cant excess > 95 mm	5996	5696	Cant Excess > 85 mm	Cant Excess > 85 mm
320	5057	4667	Cant excess > 95 mm	6389	6069	Cant Excess > 85 mm	Cant Excess > 85 mm
330	5378	Cant Excess > 95 mm	Cant excess > 95 mm	6795	6455	Cant Excess > 85 mm	Cant Excess > 85 mm
340	5709	Cant Excess > 95 mm	Cant excess > 95 mm	7213	6852	Cant Excess > 85 mm	Cant Excess > 85 mm
350	6049	Cant Excess > 95 mm	Cant excess > 95 mm	7643	7261	Cant Excess > 85 mm	Cant Excess > 85 mm
365	6579	Cant Excess > 95 mm	Cant excess > 95 mm	8313	7896	Cant Excess > 85 mm	Cant Excess > 85 mm
380	Cant Excess >95 mm	Cant Excess > 95 mm	Cant excess > 95 mm	9010	Cant Excess > 85 mm	Cant Excess > 85 mm	Cant Excess > 85 mm
400	Cant Excess >95 mm	Cant Excess > 95 mm	Cant excess > 95 mm	9983	Cant Excess > 85 mm	Cant Excess > 85 mm	Cant Excess > 85 mm



CASE 2

For Case 2, also applying a common cant deficiency limit, but in this case of 153 mm which is equivalent to an uncompensated acceleration of 1 m/s², and a cant excess of 95 mm for passenger dedicated lines and 85 mm for mixed traffic lines, the results and their representation are as follows:

	Minimum Radius requiered on horizontal curves						
	Case 2. HS Lines with a maximum uncompensated trasversal aceleration of 1 m/s² ≈ Maximum cant deficiency of 153 mm, limited on HS Lines up to 300Km/h of maximum speed						
High Speed Line Maximum Design Speed. km-h	Dedicated Passenger transport High Speed Lines $V^{P}_{minimum}$ = 160Km/h			Mixed Traffic High Speed Lines $V_{freight\ trains}$ = 100km/h and daily Traffic ≤ 25Ktons/track			
	Max. Design Cant 140	Max. Design Cant 160	Max. Design Cant 180	Max. Design Cant 90 mm	Max. Design Cant 100 mm	Max. Design Cant 110 mm	Max. Design Cant 120 mm
200	1614	1511	1420	1945	1869	1798	1732
210	1779	1666	1566	2145	2060	1982	1909
220	1953	1828	1718	2354	2261	2175	2096
230	2134	1998	1878	2573	2471	2377	2290
240	2324	2176	2045	2801	2691	2589	2494
250	2522	2361	2219	3039	2920	2809	2706
260	2727	2553	2400	3287	3158	3038	2927
270	2941	2753	2588	3545	3405	3276	3156
280	3163	2961	2784	3813	3662	3523	3394
290	3393	3176	2986	4090	3929	3779	Cant excess > 85 mm
300	3631	3399	3195	4377	4204	4045	Cant Excess > 85 mm



As a result of this exercise, the following table shows the impact of mixed traffic both on the design of the minimum radius of the horizontal curves of the line, and on its maximum design speed.

Maximum Design Speed range (km/h)	Impact of mixed traffic on the minimum radius and maximum design speed on a High Speed line			
	% increase in minimum radius regarding a dedicated line to passenger		% reduction in maximum speed regarding a dedicated line to passenger	
	Case 1. 100 mm as max. cant deficiency	Case 2. 153 mm as max. cant deficiency	Case 1. 100 mm as max. cant deficiency	Case 2. 153 mm as max. cant deficiency
V_{max}=250	9 to 47%	7 to 37%	5 to 17 %	10 to 17%
250 < V_{max} ≤ 280	14 to 47%	7 to 37%	7 to 14 %	7 to 15%
280 < V_{max} < 300	20 to 37%	11 to 37%	10 to 12 %	7%
300 ≤ V_{max} ≤ 350	20 to 37%	N/A	9 to 12%	N/A
V_{max} > 350	20 to 26%		5%	

The results presented indicate that all other parameters being equal, mixed traffic will require greater minimum radius in its horizontal curves.

The need for a greater radius increases with the maximum design speed, and its incremental value, for example additional %, will also depend, as seen in the previous table, on the limit adopted for cant deficiency, 100 mm, or 153 mm, equivalent respectively to 0.65 and 1 m/sec^2 of unbalanced transversal acceleration.

In other words, with the minimum radius necessary to reach a certain maximum design speed on a mixed traffic line, a higher maximum speed between a minimum of 5 % and a maximum of 17%, depending on the maximum design speed and the maximum allowable cant deficiency, could be reached if the line was dedicated to passenger service., increase provided by the possibility in that case of being able to raise the cant to its maximum limit commonly admitted, between 160-180 mm.

What would mean that in the sections where the line layout find topographic difficulties, crossing hilly zones, and in which the design of the line for obvious reasons of construction costs must adhere to the minimum radius that ensure its maximum design speed, mixed traffic will decrease the maximum speed that could be reached with that same radius if it were a dedicated line for the transport of passengers.

That is, for the same investment in civil works along the topographically more winding or hilly areas of the high-speed line, and depending on its length, mixed use of the line could undermine the competitiveness of the passenger service due to the reduction of the maximum speed on these sections, and at the end might damages its economic results due to revenues reduction.

This possible reduction in the competitiveness of passenger service and its economic effects has to be considered in the feasibility studies on which decision-making on the development of the line is based.

- Regarding the horizontal alignment of the line, mixed traffic will translate into a renouncement of a higher maximum speed under equal investments in civil works on those sections of the line with difficult topography, which if its length is relatively important in the whole of the line, can have an appreciable impact on the competitiveness of passenger service by lengthening travel times in those sections.
- In the mixed traffic lines, the limiting effect of the maximum speed of the fastest passenger trains in the sections with the most difficult layout, will be mainly determined by the maximum cant excess required by the slowest freight trains, so again, the higher be the speed ratio of the fastest train compared with slowest,

the greater the impact on passenger service performance in this hilly line sections.

- At equal civil works costs, the longer the line and its section with topographic difficulties the greater mixed traffic possible impact on passenger service competitiveness.

Recommendations

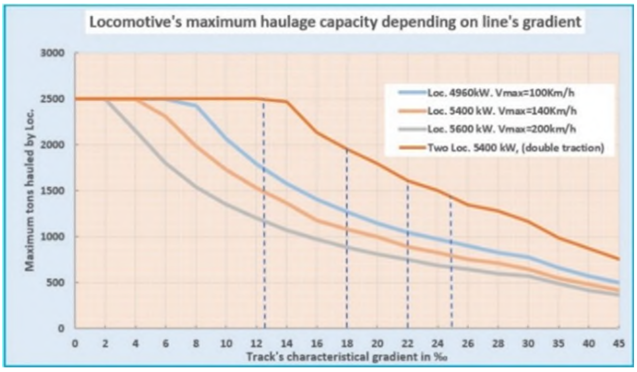
As a summary of all of the above, the following limits on cant design parameters could be recommended:

Type of HS line	Design Cant limit	Maximum Cant Deficiency		Maximum Cant Excess (mm)	Maximum Cant variation
		Vmax≤ 300	Vmax >300		
Mixed Traffic	160 mm	153 mm	100 mm	110mm (*)	0.5 mm/m
Passengers Dedicated	180 mm				0.5 mm/m

(*) Maximum cant excess can be limited to values around to 80 mm depending on the daily total gross tons towed by trains with V<160km/h.

Key vertical profile parameters are maximum gradients and its length, as well as potential low points that affect drainage of track form and high points where gas can be accumulated in underground sections.

As the bellow graph and table shows, the maximum load capacity of the freight railway traction, locomotives, and consequently the performance of freight transport, is dramatically reduced with the increase in the gradient of the line.



Gradient	Freight trains. Maximum hauled load depending on Locomotive type and traction mode			
	5,400kw Vmax=140km/h		5,600kw Vmax = 200km/h	4,960kw Vmax = 100km/h
	Single Traction	Double Traction		
12.5 ‰	1,500 t	2,500 t	1,170 t	1,735 t
15 ‰	1,250 t	2,240 t	1,020 t	1,490 t
18 ‰	1,090 t	1,950 t	880 t	1,270 t
20 ‰	1,000 t	1,800 t	810 t	1,150 t

In fact, it can be checked with high-power locomotives, around 5,000 kW and maximum speeds of around 100 km/h, on ramps of up to 12.5‰, can pull freight trains with a maximum weight, (gross tons), of 1,735 tons, which are reduced to 1,270 when the ramp reaches 18‰ and remains at 750 tons when the ramp exceeds 25‰.

It can also be seen that in the case of double traction freight trains, the maximum load carried will be 2,310 tons for a line with a maximum slope of 12.5 ‰, a maximum load that will be reduced to 1,500ton when the gradient reaches 20 ‰ and the freight train is carried by two locomotives.

Consequently, line gradient has a very important impact on freight trains performance, so the limitation of maximum ramps around of 12‰ is a key requirement in the design of mixed traffic high speed lines.

Gradient requirement that in the sections of the line with greater topographic difficulties, entails, as we will see next, notable increases in construction costs.

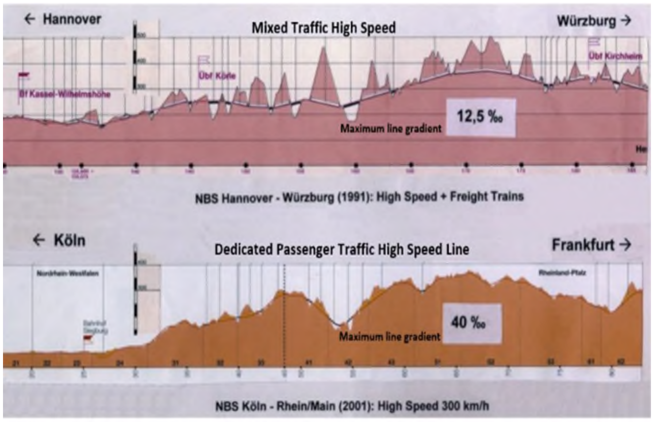
In accordance with all this, the parameters required in terms of gradient of new high-speed lines are as follows:

- Minimum gradient, normally limited due to drainage requirements
- Maximum gradient:
  - Mixed traffic: 12‰ (exceptionally 18‰)-To be discussed
  - Dedicated Passenger's traffic: 35‰, bearing in mind the following requirements:
    - Moving average gradient over 10 km is less than or equal to 25‰.
    - Maximum long of continuous 35‰ gradient does not exceed 6 km.

The maximum gradient of the line in the case of mixed traffic must be a balance of the length of the gradient, the traction power of freight trains and the speed that is considered acceptable to lose.

During the design phase, the vision of the Infrastructure Manager and the Operator comes into play.

A very illustrative example of the incidence that presents the lowest gradient required by mixed traffic lines in the insertion of its route through hilly orography is shown in the following figure below that represents the vertical alignment of two German high-speed lines, one with mixed traffic, top image, and other of dedicated passenger traffic.



Incidence of the gradient limitation on the insertion of the line layout through the natural terrain

Even being routes with comparable terrain difficulty, the result was:

- The Kassel-Kirchhein section of the Hannover-Wurzburg mixed traffic line required that about 80% of the route runs in tunnel or viaduct.
- However, in the Siegburg-Montabaur section of the Köln-Frankfurt, line dedicated to passenger traffic, 36% is the part of the route that runs through tunnels and viaducts.

This important increase in the needs of civil constructions imposed by the limited gradient of the mixed traffic lines represents significant increases in the cost of the infrastructure of the line, which in the sections like these of greatest difficulty of terrain can exceed 35%.

Another case of interest in this analysis of the impact of the greater limitation of the gradient that require the mixed traffic lines is the enlargement of the two branches of the TGV Atlantique in France, one to Bordeaux and the other to Rennes, both inaugurated in 2017.

The new high-speed line of Tours-Bordeaux of 302 km and that of Le Mans - Rennes of 182 km in length, are designed for the same maximum speed of 350 km/h and are operated at the same maximum speed of 320 km/h, but:

- The Le Mans - Rennes HS line was built with a maximum gradient of 35‰ and had a construction cost of 18.8 M€ per km.
- However, the Tours-Bordeaux line was built with a maximum gradient of 12.5‰ and its construction cost was 25.8 M€ per km, which means that for the same line performance, its unitary cost was 37% more expensive.

Finally, another example of the impact of the maximum gradient, in the cost of construction of a high-speed line, which in this case brings a new line in the project phase, the Montpellier - Perpignan high-speed line, in its section Montpellier – Narbonne, where several alternatives have been studied as a dedicated passenger line and as a mixed traffic line, being that:

- If a line dedicated to passenger traffic with a maximum speed of 320 km/h is decided, the cost could be about 24.2 M€ per km.
- But the decision that it is a mixed traffic line, with a Vmax of 300 km/h for passenger trains and 120 km/h for freight trains, will bring the cost to 34 M€ per km, this is the mixed traffic will increase its cost in 40%.

Finally, it could be noted that, with same line performance for passenger service, a high-speed mixed traffic line may present higher construction costs that can even reach 40% in the sections with more difficult terrain.

4.2.6 *Tunnels design*

In case of tunnels in a high-speed line, it is generally advisable to have separate tunnels (twin tunnels) and slab track.

Both the tunnel typology, a single tube or twin tunnel solution, and their respective cross sections and length, undoubtedly presents a major complexity for two fundamental aspects that determine its configuration and equipment to be installed in potential train crossings inside and its safety and security requirements under normal operating conditions (please refer to section 4.4 Analysis safety design requirements in mixed traffic).

In this limited space, the track is to be fit, as well as electro-mechanical devices, drainage systems and ventilation, fire protection facilities and telecommunications, as well as the space required for evacuation of passengers and workers in case of emergency.

The provision of passive fire protection to rail tunnels is not usually required, if the fire loads are low and the safety provisions within the rolling stock and rail infrastructure are specified and maintained to a high standard.

Tunnel design constraints will be different if the traffic is mixed, with passengers and freight, because additional equipment and consideration should be provided, for example: separated drainage system, fire-breaks siphons, equipment in tunnels portals, hazardous products tanks, detectors, etc.

However, the existence of imported fire risks such as vehicle shuttles and fuel tankers may imply significantly higher fire loads. In addition, there may be cases where the collapse of a tunnel may imply unacceptably high social costs. In such cases, a cost/benefit analysis, informed by a quantitative risk assessment, may demonstrate a strong case for additional fire protection measures, including passive fire protection and/or fire suppression systems.

Guadarrama tunnel section (Spain)

The diesel locomotives' exhaust fumes can pose a threat to the safety of workers as the application is classed as a confined space. Continuous gas detection is required to ensure workers safety as stipulated by the Health & Safety Regulations.

The identification of the gaseous contaminants (NOx, CO) within the diesel emissions as well as their limitation to acceptable levels in the passenger carriages is therefore an important safety requirement. Secondary considerations arising from diesel emissions included the requirement to limit the temperatures at the locomotive and air-conditioning system intakes and to provide reasonable forward visibility for train drivers.

The concentrations of diesel emissions in the tunnel will be crucially dependent on the train scheduling, particularly of diesel locomotives travelling uphill, since such locomotives are particularly polluting.

The following loss prevention and mitigation measures are therefore recommended:

- Use of non-combustible and non-toxic construction materials for the tunnel structure and pavement, in order to ensure safety for people and to prevent severe physical damage.
- Installation of fully automatic fixed water-based fire-fighting systems in tunnels where necessary. This would enable safe evacuation and facilitate control of a fire in its early stages (control mode or surface cooling mode design objectives). Final extinguishment would be achieved through manual firefighting.
- Installation of fixed gaseous clean agent type extinguishing systems in the technical rooms of tunnels, approved and adequate as per recognized international standards.
- Provision of emergency ventilation system and smoke control system designed to maximize the exhaust rate in the ventilation zone that contains the fire and to minimize the amount of outside air that is introduced. In all cases, the desired goal is to provide an evacuation path for people exiting from the tunnel and to facilitate fire-fighting operations.
- Establishment of adequate emergency response planning including all coordination / communications aspects, traffic control, emergency ventilation / de-smoke systems management and fire-fighting operations between the different entities having jurisdiction inside and possibly at both ends of the tunnel, especially for trans-border tunnels.

4.2.7 *Drainage*

In designing a drainage system, it is recommended to consider safety aspects as specified:

- Minimal longitudinal and transversal inclination to ensure efficient removal of fluids
- Protection from explosion: prevent fire/explosion spread in closed pipes and in basins/pump sumps

- Protection from fire/explosion spread in the drainage system (separated sections)
- Dimensioning of drainage system: expected water from the mountain, capacity of water mains (if installed) or other firefighting means, leaking wagons (at least 80 m³ - UIC 779-9)
- The track drainage system includes retaining basins - if dangerous goods are routed through a tunnel - to retain polluted extinguishing water or drain out dangerous substances.
- Dimensioning of retention basin: leaking wagons plus water mains for a defined time period

It is necessary to distinguish between tunnel infiltrations and poured effluents within the tunnel (from a tank or from cleaning watering, for example). In this sense, drainage systems could be considered depending on the kind of traffic: mixed or passengers.

In case of dangerous goods are allowed, it is highly recommended to dispose segregated systems. So, in case of a fuel tank (for example) breaks and the liquid is poured on the permanent way the effluent is collected in a proper system that will be equipped with firebreaks siphons to avoid flame being extended throughout the whole tunnel. This system will be required additional facilities as pits, tanks, pumping stations, etc.

The impact of the track drainage on tunnel safety is:

- An appropriate dimensioned drainage system reduces the possibility of escalation (e.g. explosion after release of dangerous goods)
- Reduction of environmental damage at portals
- Reliable drainage of water from the tunnel (risk of flooding decreases)
- In the event of release of explosive dangerous substances, retaining basins or pump sumps have a higher risk of explosion.

4.3 Crossing speed with mixed traffic

4.3.1 Analysis of aerodynamics requirements in mixed traffic

In the operation of a freight train in a mixed traffic line, trains crossing generates a complex aerodynamic field that affects both the train and its cargo. This effect is proportional to some power of the relative velocities between trains and therefore it can be an important issue when the crossing is with a passenger High Speed Train.

Train crossing occurs either in the open air or in tunnel, on flat terrain, over embankment or in viaducts, with and without crosswind; each case presents similitudes and differences that are highlighted along this section.

ADIF (Spain) already developed a study regarding these aspects whose conclusions will be helpful in this analysis.

The aerodynamic field affects many aspects, being some of them:

- Loads and moments on the rolling stocks that when considered the vehicle dynamic, operational parameters, track, etc. can produce wheel unloading
- Loads and moments on the cargo (or containers) which can produce movements or drops, mooring stressing and breaking, etc.
- Local under and over pressures on the rolling stocks, containers, cargo… making necessary sometimes the provision of pressure sealing or venting
- Axial drag forces on certain parts and components affecting their integrity or operation, such as loads on sliding doors
- An unsteady aerodynamic field which possible high impact on flexible structures such as fabric covers or curtain walls

A review and description for those phenomena generated in the crossing that should be considered in order to preserve the integrity of the cargo/vehicle and because safety issues is described below.

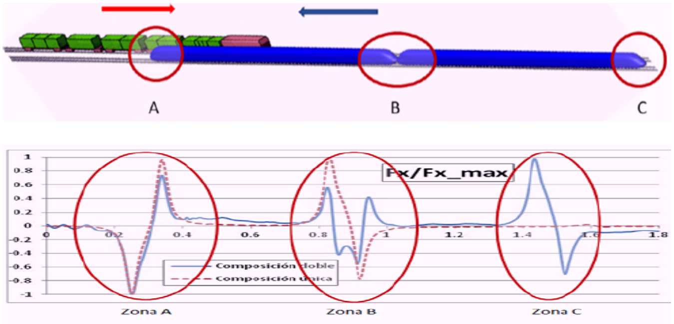
4.3.1.1 Aerodynamics considerations in mixed traffic in the open air

When a freight train runs on a conventional line without a crossing train, there can be some influence due to aerodynamic effects, mainly related with loads and pressure variations (not considering the impact of aerodynamic drag in energy consumption during operation); both are proportional to the train velocity squared and because the low circulation speeds (around 120 km/h) they are moderate. Within a tunnel, it is possible to have higher pressure fluctuations, and in both cases lateral loads or moments greater than those caused by cross wind or alignment particularities (embankments, fences, etc.) are not expected.

The scenario is different during the train crossing process. The passing train induces two pressure pulses that is translated in lateral forces and overturning moments.

These pulses are generated by the nose and tail of the passing train, and they are roughly symmetrical. Each pulse consists in an overpressure followed by an underpressure for the train head and the opposite for the tail. In the case of crossing with a passenger double composition train, there are three pulses.

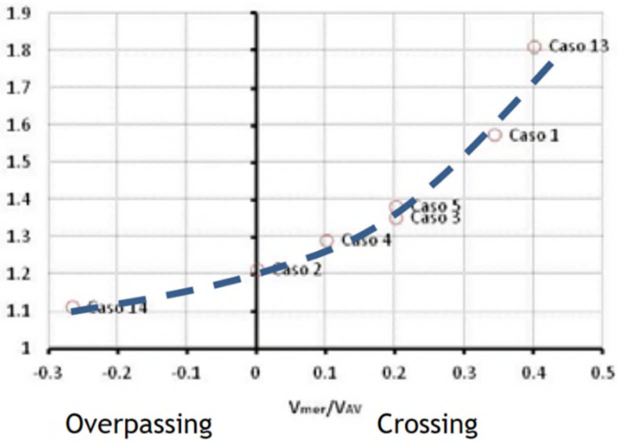
. Each pulse consists in an overpressure followed by an underpressure for the train head and the opposite for the tail. In the case of crossing with a passenger double composition, three pulses may be identified.



Lateral force on a wagon. Dotted line, caused by a single passenger composition. Solid line due to double passenger composition

When the passing train is a passenger train, usually the pressure pulse increases its intensity because the higher velocities (in the range of 200 to 300 km/h). As loads and moments are related to the pressure integral over then train surface, their behaviour is as the one of the pressures.

The scheme below shows a typical trend in the maximum lateral loads generated during a crossing on a given wagon (Source: ADIF project CRUCE).



Horizontal axis represents the ratio between freight and passenger train speeds, being 0 when the freight is stopped. To the right trains are crossing (high relative velocity), to the left the passenger train is overpassing the freight train. Vertical axis reflects maximum lateral force divided by the squared speed of the crossing train.

Typically, for a ratio between the freight train speed to the passenger train one, $\frac{V_{fr}}{V_{HS}}$, of 0.4 the force on a wagon is 40-50% greater than if the freight train were stopped.

The pulse duration is the inverse of the relative speed between trains, typically around 0.2 to 0.6 second.

Depending on train type and compositions, the characteristic value for the pressure amplitude is 10 to 15% of the high-speed train dynamic pressure on freight surfaces facing the crossing train (typically some hundreds of Pa). On the opposite side, the pressure reduces up to 15% of the one on the facing one.

Higher pressure amplitudes correspond to compact wagons or cargo (for example, containers) while low value corresponds to more diaphanous ones (such as car carriers)

The value of pressures, loads and moments are dependent of the track distance centres, decreasing is level as d^{-n} , being d the separation between tracks an n an exponent close to 2.

4.3.1.2 Aerodynamics considerations with mixed traffic in a tunnel

All the previous discussion is qualitatively applicable to the crossing inside a tunnel; but in this case, a new effect arises:

A high-speed train entering a tunnel generates a set of pressure waves of the order of several kPa which propagates and reflect on the tunnel exit or any other obstacle or discontinuity (such as the other train in a crossing event). An unsteady and complex pressure distribution of compression and rarefaction waves is generated in the tunnel and interacts with the train. Both high- and low-pressure levels maintains during a period of several seconds.

The phenomena is dependent of many parameters, being the more significant the train velocity, tunnel blockage (ratio of train frontal section to tunnel section), tunnel length and train length.

In the case of a crossing inside a tunnel, the patterns of pressure waves complexity increases because the set of waves generate by the other train, also function of the same parameters above cited, plus a new one, the time instant when each train entre the tunnel.

While the trains are moving in the tunnel but not physically crossing, the pressures waves are planes (uniform along the tunnel transversal section). Then no important lateral forces neither moment appear, and only axial forces are expected (in general these loads are of short duration, of the order of L/c being L the typical axial length for the wagon or cargo and c the sound speed in the air).

Principal effect of these pressure fluctuations are the stressing of vehicle and cargo, mainly if they are sealed because they are subject to compression/expansion loading cycles of several kPa. Vented or unsealed wagons and cargo should be less sensitive to this effect.

During the crossing, the local pressure fluctuations caused by the crossing train (mainly by the head and tail) overlaps to the pressure waves effect. The effect is very similar to the one on the open and only variations on the pressure, force and moment level is expected. Today, this is a matter of research and no quantification neither an estimation methodology is available. ADIF is performing a R+D project on this subject.

An issue of particular interest that must be investigated is the behaviour of wagons with curtain walls and piggy-back wagons for trailers, which seems very sensitive to pressure variations and wind induced fluctuations during crossing, in particular inside tunnels.

Saint Gotardo tunnel

4.3.1.3 Aerodynamic considerations in mixed traffic with cross wind

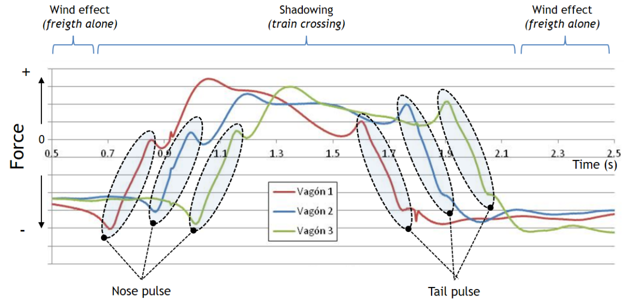
The cross-wind effect on a freight train is more complex than on a passenger one and not enough investigated. While the passenger train presents a uniform external geometry, the freight train usually has discontinuities on its surface, allowing transverse flow between wagons and presenting a highly complex three-dimensional flow structure.

Main parameters affecting the loads and pressures are:

- Speed of both trains
- Freight train composition and cargo
- Windward or leeward position of the passenger train relative to the freight
- Wind velocity and relative direction to the track
- Local topography/infrastructures (track width, embankment, parapets, etc.)

The nose and tail pulse described during a crossing in the open continues affecting loads and pressures, but sometimes the shadowing between trains during crossing is able to have higher impact on wheel loads.

As an extreme example, figure below shows the lateral load evolution for three different wagons in a freight train (120 km/h) during a crossing (passenger train (350 km/h) leeward) with strong wind (100 km/h) normal to the track. It can be identified the nose/tail pulse at each wagon, but main impact, producing even a sign change in forces, is the shadowing of the freight train when crossing with the passenger one.



4.3.1.4 Aerodynamics considerations in mixed traffic on viaducts.

While the aerodynamics of a train traveling without wind, either alone or during a crossing is not very different on a viaduct from open air, with the presence of crosswind there are big differences, mainly because the possibility of higher wind speeds caused by:

- The viaduct is generally elevated from the surrounding terrain, which means a translation to the higher wind speed zone in the atmospheric boundary layer.
- Sometimes the viaducts are located in steep topographies, such as canyons, with a strong effect on the local wind that intensifies wind speed.
- Local viaduct features (such as parapets, cross section, etc.) may influence train aerodynamics.

In addition to this probable increase in wind speed (and therefore on loads, mainly in lateral direction) it has to be added the aerodynamic effects associated to the freight train and the ones related to the crossing itself. Therefore, the aerodynamics aspects of the crossing in a viaduct are not different from the already described ones, being relevant the possible wind speed increases.

4.3.2 Crossing speed objectives

Pressure/suction loads arise when freight trains meet and cross fast passenger trains in opposite directions.

Highest loads usually occur in double track tunnels sections with mixed operation.

Due to this fact, crossing speed between passenger and freight trains is usually limited by railway managers and Undertakings and the objective is to avoid damages with increasing speeds, to freight wagons and loads during operation.

It is necessary to maximize the crossing speed, in order to maximize the capacity. Therefore, it is necessary to find the right balance between capacity (speed) and damage.

In this sense, to allow mixed traffic, countries have taken different approaches, as no regulatory bases are available yet.

Currently the limit of high-speed trains is about 160-200 km/h, depending on the Railway Manager.

It seems reasonable to think that the operation in high-speed lines of the freight trains to be 120 km/h, and the speed limit of the high-speed train 250 km/h. This goal is under study by several Railway managers and associations, including the UIC. In this sense, this statement is being analysed in the CROSS-T UIC Study.

It will be necessary to guarantee the structural resistance of the wagons for this type of traffic, and not to penalize excessively the speed of the high-speed trains.

4.4 Analysis safety design requirements in mixed traffic

Different safety measures required for the infrastructure and the rolling stock when transporting passengers compared to freight traffic. Special safety measures in tunnels when carrying passengers, special safety measures in the open track when carrying dangerous goods.

In Europe, the safety on tunnels has to comply with the technical specification for interoperability (TSI) relating to the 'safety in railway tunnels' of the rail system and it applies on the entire European Union. UIC developed also a document related to Safety in Tunnels, in the same sense.

The purpose of this TSI is to define a coherent set of tunnel specific measures for the infrastructure, energy, rolling stock, control-command and signalling and operation subsystems, thus delivering an optimal level of safety in tunnels in the most cost-efficient way. It has to permit free movement of vehicles, which are in compliance with this TSI to run under harmonised safety conditions in railway tunnels.

Safety in tunnels is the result of an optimum combination of infrastructure, rolling stock and operations measures. A general principle shared by all railways can be summarised by the following:

- Prevent accidents
- Mitigate the impact of accidents
- Facilitate escape and
- Facilitate rescue

Considering that incidents in railway tunnels involving multiple fatalities are rare, it is implicit that there might be events, with an extremely low probability, for which even well-equipped emergency response services would be restricted, such as a major fire involving a freight train.

Manned traction units of freight trains may be equipped with a self-rescue device for the driver and other persons on board, satisfying the specifications of the specification referenced in appendix A of the TSI related to Safety in railway tunnels.

4.4.1 Considerations about fire

Tunnel fires damage the infrastructure and disrupt transportation flows, but the more important effect is that they cause injuries and fatalities to passengers. Ventilation and egress remain the two key concerns from such disasters.

The tunnel structure should be designed so that it is not rendered unsafe by loss of load carrying capacity during a fire. Materials and equipment should have defined smoke emission and flammability characteristics.

The firefighting system has to be designed according the high-water consumption considering the dimensions of a train fire. There must be a sufficient water supply and also an adequate drainage system.

The fire loading on freight vehicles can be very significant in terms of the loading due to the variations and quantities of cargo carried.

In passenger trains a fire can affect a large number of persons. In freight trains, the lorry drivers and the train driver will be the only persons affected. In freight trains it is also difficult to predict the fire load, due to the large number of loads possible. It is not only in freight trains that the fire-load or fire development is difficult to predict, but also passenger trains are available in many different configurations.

"Design fires" are a cornerstone for all aspects of tunnel safety design and accident management. The "design fire characteristics" determine indeed heavily the design of the structure, the ventilation and other safety infrastructure.

Vehicle type	Fire power (MW)	Fire duration (hours)	Smoke flow (m3/s)
Passenger train (electric power)	15	1	60
Freight wagon or diesel locomotive	30	2	80
Dangerous goods freight wagon	10	2	N/A

In case of HSL where dangerous goods transportation is allowed, several aspects are to be considered from the design stage. These aspects have impact on:

- Tunnel concrete structure design to ensure fire resistance for a certain time
  - This could have impact on tunnel section (double track single tunnel 90 m2 instead of single-track tunnel 66 m2)
- Ventilation System ensure that fire will remain under control for the necessary time (forced ventilation could be required)
- Fire protection system design (detection, extinguishment, doors, etc.)
- Gas detectors
- Drainage system for the tunnels: within tunnel; Fuel is flammable (hazardous goods)
  - Segregated systems to separate infiltrations and poured effluents.
  - Fire-breaks siphons
- Cable ducts
- Different collector tasks for different effluents (at tunnel portals)
- Safety facilities at the tunnel portals

Safety facilities at Pertus tunnel South portal Spanish side (Figueras-Perpignan HS line)

4.4.2 Safety goals

The key safety goal is to guarantee railway passengers and freight transportations safety. In case of incident the train may stop before entering the tunnel or, if that is not possible, the train would be allowed to continue its journey without stopping within the tunnel; if an incident occurs inside the tunnel, the train may continue its circulation until it is outside.

In case the train is stopped within the tunnel, the circulation has to be interrupted. The probability of fire in a passenger trainset while it is at standstill inside the tunnel is really low; latest rolling stock generations have a very low fire power compared to that of freight transport.

However, the possibility of a fire in a freight train while it is at stand still inside the tunnel, being at the same time reduced, seems higher. A favourable factor subsists there are few people on board of the freight trains and these staff are professionals with specific training and fire protection equipment like gas masks, for instance.

4.4.3 Safety case

A safety case analysis should be developed to ensure the safety of the line.

The safety installations systems in a tunnel are designed taking into account some management conditions, determined by the number & type of traffic that pass through it, and involve some specific risk situations.

The level of risk associated to the tunnel's use highly depends on the traffic configurations, and its represents a key factor so that the installations system would maintain the right level of safety, being able to five and effective answer to certain risk situations.

Concerning traffic management, a correct management of freight trains may represent the fact of having an acceptable level of safety in the tunnel or not, since they represent a potential risk if they're involved in a fire.

The final solutions concerning the way of operating the tunnel must be a compromise between a desired level of safety and a desired level of capacity.

4.4.4 Regulations for operations

When optimising operations conditions, timetables should be designed to avoid freight trains (especially dangerous goods trains) crossing with oncoming passenger trains in tunnels as far as reasonably practicable.

In some situations, it may be necessary to exclude certain types of vehicles on certain types of routes (e.g. old rolling stock on lines with long tunnels).

The following recommendations are proposed to achieve the safety goal:

- While a diesel train is moving uphill in a tunnel, no other trains (diesel or electric) should be allowed to travel uphill in the tunnel at the same time. This is due to the relative flow velocity between the diesel train and the tunnel air should be kept high, and hence the concentrations of pollutants kept low.
- No more than one diesel train (moving uphill or downhill) should be present in the tunnel at any

time, in order to limit the emission concentrations.

- It is desirable that an electric train should travel downhill as a diesel train moves uphill, in order to increase the relative velocity over the diesel train and hence reduce the emission concentrations.
- In order to ensure that no diesel emissions accumulate in the tunnel, air exchangers should be designed.

Impact on safety

- Elimination or reduction of accidents involving two trains, especially passenger trains and freight trains carrying dangerous goods: collisions, collisions following a derailment, fires (especially large fires involving dangerous goods).
- If e.g. freight trains are diverted on routes without tunnels, the accident frequency may increase (longer route, new risks such as level crossings).
  Further effects
- Reduces the productivity especially for freight traffic due to:
- restricted utilisation of the sections of route concerned,
- provision of additional sidings in marshalling yards (in order to stop/regulate goods traffic)

4.4.5 *Regulations for carriage of dangerous goods*

A general restriction of dangerous goods (a) means in practice, that all freight trains are concerned. To sort out single loads or wagons containing dangerous goods is therefore hardly practicable. Sometimes the mix of different freight loads can be dangerous, and it is impossible to check all combinations.
Impacts on safety

- Elimination or reduction of accidents involving passenger trains and freight trains carrying dangerous goods: especially very serious consequences due to fire or toxic substances released are prevented. It is a safety measure to reduce the risk of a catastrophe.
- Large fires involving dangerous goods can also cause damage to a tunnel structure. Special aspect: underwater tunnels and tunnels closely under built area.
- If freight trains carrying dangerous goods (especially block trains) are diverted on routes without tunnels, risks on these routes may increase if the line passes through a densely populated area, on lines with a lower track standard or in a sensitive environment (ground water, surface water)

Information concerning carriage of dangerous goods should be improved. Notification of movements of exceptionally dangerous goods (to be defined, e.g. chlorine, propane, vinyl chlorine) to inform rescue services concerned along the route to be prepared in the event of emergency and to be able to take the right action in time (e.g. evacuation).

Information system to identify rapidly the loads involved in the event of an accident in order to take the right precautions and action for intervention (precise and rapidly accessible database).

Information of dangerous goods will impact on safety:

- Reduce time delays for rescue operations in the event of an accident involving dangerous goods, take the right action and precautions.
- Reduce risk for rescue services.

4.5 Analysis of the requirements on railway systems

As in the case of infrastructure, the objective of the work will be to determine if mixed traffic would require specific requirements in the basic design parameters of each of the main components of the different railway subsystems in order to guarantee compliance with the essential requirements of the operation of the line.

The following subsystems are considered:

- Energy, power supply subsystem
- Signalling and control-command subsystem
- Telecommunications

The essential requirements to be maintained in the same degree of compliance in the case of mixed traffic lines as in lines dedicated to passenger transport are:

- Safety and Security
- Reliability and availability
- Technical compatibility
- Health and accessibility
- Environmental protection

4.5.1 *Energy, power supply subsystem*

In this subsystem the elements to be considered to identify the specific determinations imposed by the mixed traffic could be:

- Power supply needs, design of substations, autotransformer centres and overhead contact line to allow maintaining a constant level of voltage, (25Kv AC), along the entire alignment
- Electrical protection and harmonics control
- Height of the overhead contact line, which can be affected, for example, by its adaptation to the "piggy pack" gauge (AF), mentioned before on structure gauge design subject.
- Mechanical tension both in support cable and contact wire
- Contact wire horizontal position range
- Length of neutral zone.

- Dynamic Behaviour Control system of overhead contact line

In this subsystem, intended to ensure the necessary traction energy provision for all trains running on the line, and excluding the impact on the height of the contact wire in the event that the mixed line provides for piggyback-type trains, its sizing does not present differences with respect to the technical-functional design requirements that would correspond if the case the line were to be only used for passenger traffic.

- The high demands in power and in the continuity of its supply along the entire line, as well as the high quality required in the contact between pantograph and catenary for passenger's high-speed trains, meet without additional design requirements the traction energy supply needs by the freight trains.

4.5.2 *Signaling and control-command subsystem*

The functional sets of the signalling and traffic control subsystem requirements to be considered to identify the possible specifics imposed by mixed traffic in order to ensure full compatibility between trackside and on-board equipment are basically the following:

- Interlocking components, which include signals, track-side train detection systems, drives of switches and crossings, servers and modules.
- Trains protection system, such as ETCS and if exist the backup system.
- CTC, Centralized Traffic Control system of the line.
- CRC, traffic control centres, both local and central.
- Other equipment, such as energy supply and technical buildings.

Neither in this control and command and signalling subsystem of the line, intended to ensure the fluidity and reliability of traffic in fully safe conditions, its dimensioning does present noticeable differences with respect to the technical-functional design requirements that would correspond if the line were to be only used for passenger traffic.

The only specific dimensioning requirements could come from the greater length of freight trains, which in some line installations, such as common stations, sidings, and so on, may require a specific block distance as well as a different signals positioning.

The design requirements of the locomotives in terms of the on-board signalling equipment fully compatible with trackside equipment, as well as, the proven professional qualification and training of the crew of freight trains with that equipment are fully responsibility of the railway undertaking that operates the freight transport.

- The mixed traffic does not imply any specific dimensioning in the control and command and signalling subsystem to be implemented in the line, except for considering the maximum long of freight trains for the purposes of blocking distances and positioning of signals at stations and sidings, for example.

4.5.3 *Telecommunications*

In the case of telecommunications, the functional sets to consider are:

- Mobile Radio-Communication System, such as GSM-R.
- Landline Telecommunications Network.
- Security control equipment, CCTV, access
- Intrusion centralized control.

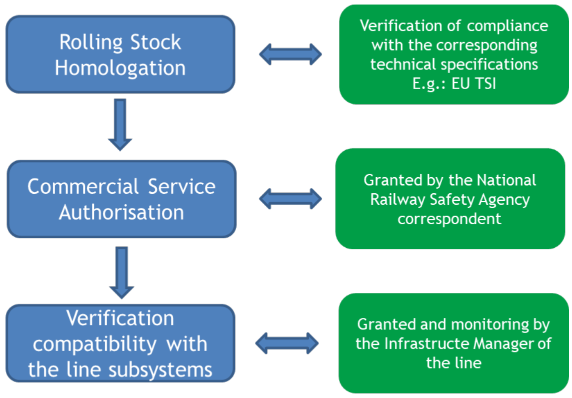
Neither on telecommunications subsystem: its sizing does present noticeable differences with respect to the technical-functional design requirements that would correspond if its lineside equipment were to be only used for passenger traffic.

4.6 Rolling stock requirements Analysis

The main task of this section will be to determine the requirements that the rolling stock must fulfilled to guarantee its technical and functional compatibility with the railway infrastructure and other railway systems of the line, basically that of power supply and signalling and Control-command in order to be accepted to operate throughout the line.

Related to rolling stock, the incorporation of mixed traffic in a high-speed line only adds the need for the Infrastructure Manager to verify the full technical and functional compatibility of all vehicles, locomotives and wagons, as well as that of the trains composed with them, with the line operational requirements ensuring traffic safety and security and transport performance.

As indicated on the following diagram, all rolling stock that circulates on the line must be previously authorized, for which, it must be technically homologated vehicles, in accordance with the technical specifications that govern the use of each railway network and require a specific circulation authorization to operate on the line concerned.



Rolling Stock general acceptance process guidelines Traffic

The scope of these processes of acceptance will cover the possible types of vehicles that can circulate along the line, that is:

- Self-Propelling, electric or thermal, Trains. “Trainset” of high speed or not necessarily
- Traction units, Locomotives, coaches, if any passenger conventional trains
- Freight wagons in case of mixed traffic line
- Maintenance vehicles

The verification process must guarantee full technical and functional compatibility of each type of vehicle with the parameters that characterize each of the line's subsystems: Infrastructure, Power supply, Control and command of signalling and telecommunications.

All rolling stock authorized to operate on the line has to guarantee compliance with the requirements of functional technical compatibility in the following parameters related to the characteristics of the line infrastructure, compatibility with the following parameters of the line infrastructure:

- Kinematic gauge compliance
- Dimensional parameters, total length, axle load, total mass and linear load. Geometric characteristics of axles set and wheels
- Dynamic behaviour in circulation
- Specific Crushing requirements
- Pressure generation running at maximum speeds in tunnels or open-air sections. Proper pressurization sealing affects both passenger cars and the cabins of all locomotives running on the line, whether for passenger or freight trains.
- Cabins of freight train locomotives will need to be soundproofed, isolated and have a certain fire resistance
- Brake types, brake performance and acceleration
- Acceleration and deceleration rates along a 15‰ gradient, time & distance
- Minimum curve radius
- Crosswinds behaviour
- Aerodynamic effects on ballasted track
- The technical-functional compatibility of vehicles with the line energy subsystem must verify the following basic parameters:
- Pantograph gauge, height and geometry
- Functionality within the voltage and frequency ranges
- Parameters related to the performance of the line current system
- Recovery brake (regeneration)
- On-board energy measurement system
- Contact force, quality of current collection, separation and
- Dynamic behaviour of the pantograph
- Electrical protection of the train to disturbances of the power supply system
- Finally, the verification of vehicle compatibility with signalling, control and command and communication systems of the line, must be ensured with the following parameters:
  - Compatibility with track-side train detection systems
  - Functionality of the on-board train protection equipment
  - Guaranteed train braking performance and emergency braking
  - Electromagnetic compatibility between vehicle and track-side and on-board control-command equipment
  - Data interface between train and traffic control centre
  - Exterior visibility from the driver's cab of the track-side control-command equipment

Notwithstanding the foregoing, the reality is that the procedure for the admission of rolling stock on a mixed line does not differ qualitatively with respect to what would apply if the line was dedicated exclusively to passengers, the only aspect that would be added is the compatibility verification and access requirements of the freight vehicles (locomotives and wagons), for which the undertaking would have previously obtained the Commercial Service Authorisation delivered by the pertinent National Railway Safety Authority.

4.7 Technical requirements for longer trains operation

Longer trains are one way to improve the effectiveness and efficiency of the rail freight system, allowing more efficient operation and an increase in transport capacity.

Railway undertakings (RUs) see longer trains as a key approach to competitive rail freight, whereas infrastructure managers (IMs) could face a major investment effort. A win-win situation for both RUs and IMs has to be established as the necessary investments are mainly on the infrastructure side.

Maximum allowed lengths of trains vary in Europe. Infrastructure planning has to consider additional elements for necessary length of tracks.

The operation of longer trains improves the productivity of rail freight traffic, defining longer trains as trains with a total length of more than 740 m. The amount (volume) of goods that can be transported by a single train can be increased and the cost per unit will decrease.

Allowing for longer trains than currently admitted on a network can have an impact on both mobile and infrastructure components of the railway system. It can also raise traffic management issues, which need to be addressed.

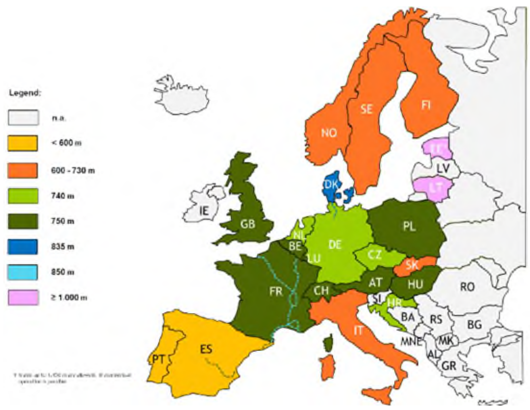
Modifications of the infrastructure may impact power stations capacity, catenary, security installation configurations, signalling systems, shunting yards.

On the locomotive side, security speed control systems could also be affected by lengthening the trains, as some systems do not allow for surpassing a certain dimension.

Tests for longer trains have been undertaken in several countries or are still going on. Longer trains have been established on specific routes in Austria, Denmark, France, Germany, Hungary and Sweden.

In Estonia, nowadays in special cases it is possible to operate trains up to 1,450 m. Research into train lengths of up to 1,500 m are ongoing in Germany (Shift2Rail Project long trains) and are foreseen in France.

According to the current TSI, new infrastructures must allow train circulation for 740 m (see figure below). Nevertheless, the reality in Europe is different. Due to operational restrictions, the allowed maximum train length is not possible on every part of the network.



Overview of standard (max.) train length per country (source: CER)

Operation of longer trains can only be established if solutions are found for all operational and technical issues ensuring a high quality of operation as well as the expected capacity effect. Different approaches exist concerning the marshalling of longer trains, their operation and the management of train failure or infrastructure failure.

The existing solutions for train lengths of 835 m and 850 m long trains vary. Even longer trains require solutions especially for train dynamics and the control and safety systems to ensure safe operations. Depending on the pursued train length, this will include not only solutions and adaptions on the infrastructure side, but also to the equipment for existing rolling stock.

- Sidings: Depending on the existing track length of sidings, works could be required in order to allow crossing and/or overtaking. Depending on the site constraints, lengthening tracks can be difficult, and lead to minimum size adapted for a given train format; it should also be underlined that the side track must be well positioned to be useful (for example, near a congestion point, on heterogeneous traffic sections, etc.), or regularly positioned along the path.
- Hotbox detection and treatment: Train length is one parameter to calculate the minimum range between the hot box and the dedicated stop signal. Therefore, a check of the existing distances is required. If the number of train axles exceeds the maximum axle counting capacity of the hotbox detection, it could be that overheated or warmed axles would not be properly detected.
- Weight restrictions on bridges. The cruised tracks and bridges have to be suitable for longer trains and their permissible axle loads, load meters (according to the rules of train formation) and the changed load spreading on a bridge.
- Fixed installations of electric traction (energy equipment). Measures to be taken are strengthening of installations (substations) and operational measures (additional spaces between trains, limitation of power). Increasing power of substations also causes an upgrade of the transmission lines.

5 OPERATIONAL REQUIREMENTS ANALYSIS

5.1 Mixed traffic specific operational installations. Sidings and Crossovers

Due to functional requirements, the implementation of crossovers and sidings, passing stations, is always necessary on high-speed lines and this regardless of whether they are dedicated to passenger traffic or mixed traffic lines.

The establishment of crossovers is due to the need to ensure the two-way double-track operation along entire line. This will allow the continuity of traffic on the line in the event of an incident that affects one of the tracks at any point on the line.

The design and deployment along the line of crossovers responds to the same parameters, whether they are dedicated or mixed traffic lines.

- They should allow their passage at the maximum speed of the line in direct route.
- They limit their passage to diverted track to a maximum of 200 km/h, which is usually the speed limitation when a line stretch is in a two-way double track operation.
- And finally, the separation between two consecutive crossovers could be approximately 10 km.

Image of a Crossover on a High Speed Line

The need for sidings arises from the fact that the distance between stations on a high-speed line is much greater than existing on conventional lines.

Therefore, appears necessary to insert along the high-speed line, intermediate passing stations, where trains can be passing, crossing and stabling, neither obstructing the main track nor restricting the movement of the other trains running on the line.

These needs to take away running trains from the main track of the line may be due to:

- Incidents on whatever train that impede its normal circulation
- Overtaking of slower trains by faster trains

In addition, the maintenance activity requires the mobilization along the line of trains of works, whose base sites along the line are generally spaced every 150 km.

Distance that for the points of the line furthest from the maintenance bases, would provide higher mobilization times for these maintenance trains. Therefore, sidings also result quite suitable in whatever high-speed line as:

- An ancillary stabling point for maintenance equipment, working trains, intended to cut its positioning time from / to workplaces furthest from maintenance bases.
- A structural component that allows to improve the productivity of the line maintenance and the availability of the track for commercial traffic.

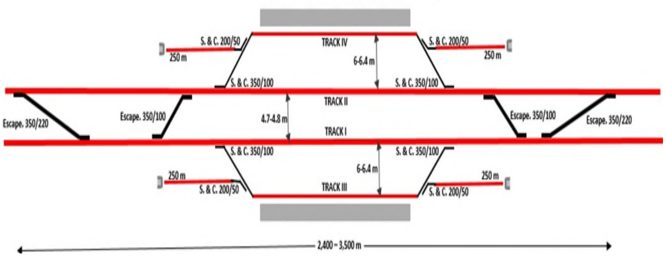
Being the sidings a structural component of high-speed lines, however, its number and configuration depend on conditions of use of the line, just dedicated to passengers or mixed traffic line, in two basic aspects:

- Its length, which must be according to the length of longer trains using the line. In the case of mixed lines, the maximum long of the freight train
- Its spacing, will depend on the intensity of traffic and the diversity of types of trains that use the line according to their different operating speeds.
- Sidings spacing will depend on the operation plan, traffic density, passenger versus freight train speeds and possibilities of tracks banalization.

Reviewing the cases of mixed traffic lines included by the study, a model of sidings scheme has been developed, the result of which is incorporated below.

SIDINGS OUTLINE

(for 350 km/h as maximum design speed of the line)



Regarding its dimensioning in new high speed lines, the following table provides some basic parameters for its design, depending on whether it is mixed traffic lines or dedicated to passenger traffic.

Type of Traffic	Maximum design speed of the line	Design of sidings on the line	
		Average distance between consecutive sidings	Average deployment of sidings
Mixed traffic Line	250 km/h	30 to 50 km	1.9 to 2.4 km
	350 km/h	25 to 38 km	2.8 to 3.5
Line dedicated to Passeger traffic	350 km/h	55 to 80 km	2.4 to 3.0 km

Sidings basic characteristics on high speed lines

Consequently, it can be concluded that:

- Crossovers is a structural component to operation of any type of high-speed line and must be deployed along the line with an average separation of 10 km, approximately.
- The implementation of intermediate passing stations, sidings, is also always necessary in high-speed lines, regardless of whether they are lines for mixed traffic or lines dedicated to passenger traffic.
- However, In mixed traffic lines, other things being equal, will need, on average, double the number of sidings, which will also be 15% longer (depending on the longest foreseen freight train), than those lines dedicated to passenger traffic.

5.2 Mixed traffic and operational capacity of the high-speed line. Analysis of Capacity

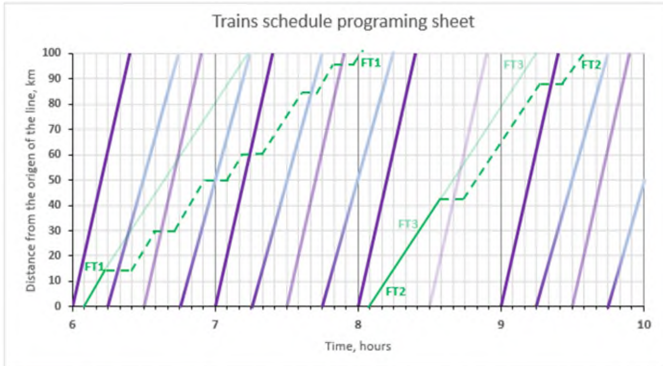
The running capacity of a given line is maximized with the full homogeneity of the trains running on it.

The greater the heterogeneity of the service offer, in terms of maximum speed, stops number, acceleration and deceleration of the trains, the less capacity the line offers and more complicated is the train planning and the traffic management.

Freight trains need a path much greater, in terms of journey time, than the one consumed by a high-speed train to carry out same route or distance throughout the line.

Consequently, mixed traffic reduces the capacity of high-speed lines by a proportion that, at least, is equivalent to the relationship between the speed of operation of the passenger train and that of the freight train.

The figure including below is intending to show this reduction in capacity caused by mixed traffic on a high-speed line.



Faster passenger High Speed trains, Vmax = 300km/h, running at every daily hours o'clock.

Faster passenger high speed trains, Vmax = 300 km/h, running at each half daily hours o'clock.

Regional Passenger high speed trains, Vmax = 250km/h, running at 15m pass and to every daily Hours o'clock.

Freight trains path allocation on a high speed line daytime schedule, depending on passenger trains traffic intensity.

This mixed traffic timetable planning exercise shows that on a high-speed stretch of 100 km long:

- Mixed traffic on high-speed lines significantly cuts capacity, which in the most favourable case would be cut in half that available if only passenger trains were running.

- Planning nonstop freight trains is unworkable in time zones in which passenger trains interval is one hour or less, unless the length of the line, or the route of the freight train on it, is less than 65 km and the maximum speed of the freight train is at least 120 km/h.

- The minimum spare time window needed to allow running a nonstop freight train will be:

  $$T = (L*60/V^F{}_O) +15$$

  Being:
  T = minimum spare time window in min.
  L = line stretch in km.
  $V^F{}_O$ = effective average running speed of the freight train on the stretch in km/h. which will mainly depend on the profile of the line, the traction performance and total load carry on by the freight train. Its value is to be obtained from the result of tests on the line during its commissioning process.

  As a first approximation, a theoretical value could be adopted such as:

  $V^F{}_O \approx 0.78\ V^F{}_{max}$ (maximum speed of each type of freight train running on the line)

- To facilitate the operation of non-stop freight trains on a line or section of line with capacity available during daytime, the maximum speed of the slowest freight trains should be as close as possible at half of the maximum operational speed of fastest passenger train.

  VFmax ≥ 0.44 x VPOmax

  The farther from this value the greater, the reduction in line capacity and the less the possibility of running daytime freight trains.

- If overtaking of freight trains is not planned and this minimum spare time window is not available at daytime, freight trains must operate at night-time only, considering the night period from the departure time of the last passenger train, usually around 22:00h, until the departure time of the first train at next day, habitually around 6:00h.
- The scheme of operation of passenger trains during the day and freight trains at night, affects the availability of the window for line maintenance works. Which it will be reduced in time available and works of maintenance will require additional safety requirements in operation and specific labour protection measures during the performance of maintenance works.

5.3 Mixed traffic and specific safety installations. Centralized Detectors along HS line

Their function is detecting any abnormal or dangerous situation in whatever point of the line, to be immediately reflected in the line control centre to take consequential with restrictive measures, which may vary from requiring the driver to perform the appropriate checks to stop the train and / or divert it from the general route and stable it.

The incorporation of mixed traffic is likely to increase the need or number of wayside control devices and safety facilities, such as:

- Hot boxes and stiff brakes detectors
- Dragged objects and derailed axle detectors
- Gauge excess detectors
- Vertical track impact (flat wheels) and unbalanced loads detectors are to be installed as a minimum after each connection of incorporation of the freight trains to mainline. It is also recommended that the spacing between two consecutive detectors not to exceed 40/50 km (similar spacing as siding loops)
- Cross Wind (gusts) Protection Systems (wind risk areas)
- Scale Weighing
- Falling objects detectors
- Fire detectors in tunnels
- Emergency facilities
- Pantograph behaviour detectors

Hot bearing detector

The quantity of each kind of device along the line has to be designed according to the availability required to the line.

The location of the devices has to be coordinated with the sidings, in case of an alarm, and the train has to be sided to the loop. Typical siding loops spacing is 25-50 km, depending on the operation conditions of the line.

According to the characteristics of the line and the different type, characteristics, composition and goods transported of the freight trains, it will be necessary to consider in each case the additional needs that in this type of security systems recommends incorporating mixed traffic.

Other detectors are needed to check environmental or line conditions, but these are not specific for freight, but for a general HS Line, and should be present anyhow.

Then the question is in what way mixed traffic determines the configuration of this type of equipment either in constitutive aspects or in additional needs with respect to exclusive passengers' service.

5.4 Capacity Allocation process and mixed traffic HS Lines

The functional characteristic of the non-simultaneity of the use of a section of the railway infrastructure by more than one train, requires that access to it pass through a previous process of allocation of the available capacity in each line or section of the railway network.

Thus, capacity allocation process is absolutely crucial for a railway system to function efficiently, especially in the moments and sections of network in which the availability of capacity is insufficient.

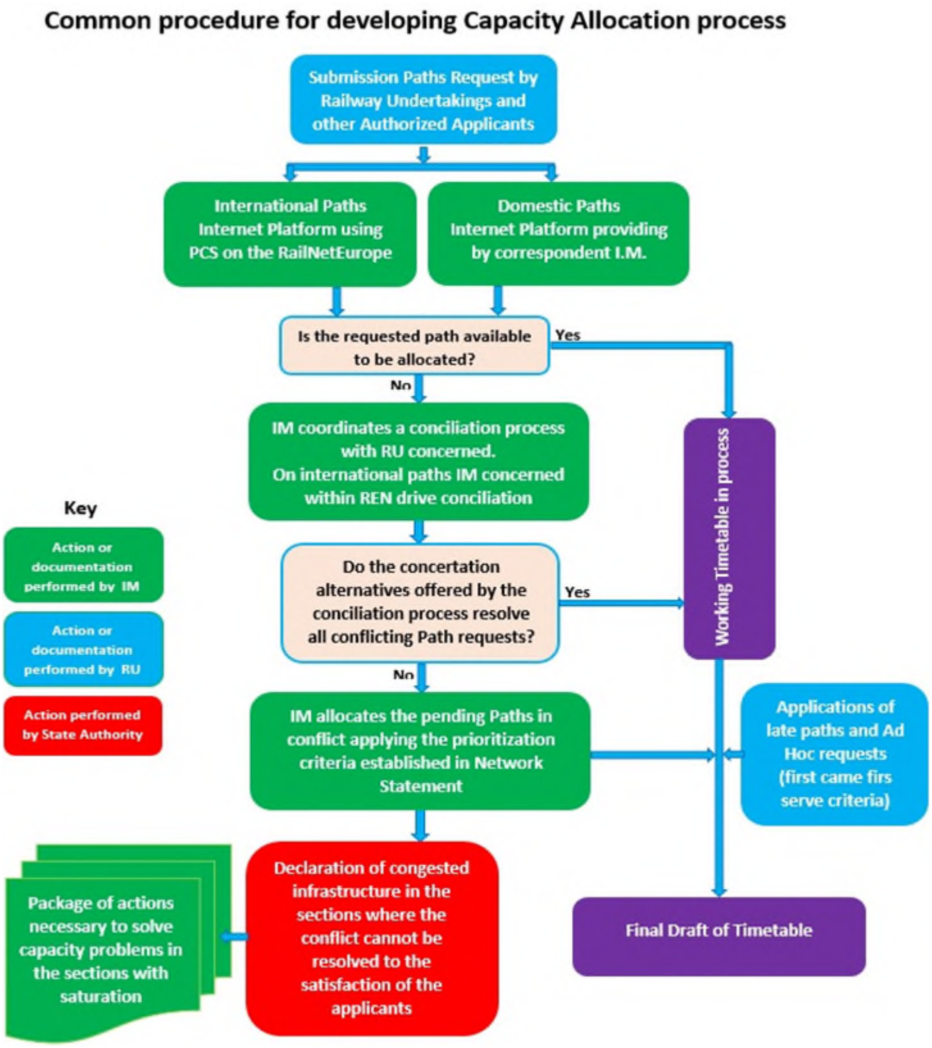
Infrastructure capacity should be allocated by an Infrastructure Manager through a process that ensure the operator awarded the capacity is the one that provides the best value for consumers.

Under that philosophy, Section 3 of Directive 2012/34/EU of the European Parliament and of the Council within the scope of the European union of 21 November 2012 laying the groundwork for developing the capacity allocation process, in accordance with the following general provisions:

- The right to use specific infrastructure capacity in the form of a train path may be granted to applicants for a maximum duration of one working timetable period, normally one year
- However, an Infrastructure Manager and an applicant may enter into a framework agreement for the use of capacity on the relevant railway infrastructure for a longer term than one working timetable period.
- Infrastructure managers must cooperate to enable the efficient creation and allocation of infrastructure capacity which crosses more than one network of the rail system within the Union. Using a cross-border Path Coordination System, (PCS), on the RailNet Europe (RNE).
- Each Infrastructure Manager must set specific requirements with regard to applicants to ensure that its legitimate expectations about future revenues and utilisation of the infrastructure are safeguarded. Such requirements may be the most appropriate to ensure the efficiency of rail transport, transparent and non-discriminatory.
- The infrastructure manager may respond to ad-hoc requests for individual train paths as quickly as possible, and in any event within five working days. Information supplied on available spare capacity has to be be made available to all applicants who may wish to use this capacity.
- The procedure and criteria applied in the allocation of capacity must be stated in the Network Statement published annually by the infrastructure manager.

The practical application of these essential principles that govern the allocation of capacity in the railway networks, is translated into the construction of the programme of the services, Timetable, to be provided in the network, a long process of more than one year, which complexity will depend on the volume of traffic to schedule, their typological heterogeneity, and especially the degree of coincidence of conflicting services, that is, those that aspire to coincident or incompatible paths.

The following diagram shows the process normally followed by the railway infrastructure manager in order to develop the capacity allocation process corresponding to each validity period of the line timetable. Process concludes with the publication of the yearly Timetable corresponding to each railway line.



Common procedure for developing capacity allocation process

Naturally, this is the process of capacity allocation followed in the liberalized railway markets. In the railway markets with vertical integration, that is, in which the management of infrastructure and the operation of all services is carried out in the same company, as would be the case for example of the Japanese high-speed network, the process is developed internally and possible conflicts between services do not require reconciliation between different parties as they are resolved in accordance with the interests of a single company.

Conversely, in the case of liberalized rail markets, as it is the most common in Europe, clear and transparent coordination mechanisms and prioritization criteria are necessary for the resolution of possible conflicts due to time coincidence of path requests submitted by different applicants, which may arise during the path allocation process.

The resolution of possible persistent conflicts due to not agreeable coincidences between path requests of different operators, necessarily involves the application by the Infrastructure Manager of objective and transparent prioritization criteria.

The following table provides an overview of the procedure, mechanisms and prioritization criteria applied by different European railway networks in the process of concluding their service Timetable.

Procedure applied in different networks in the elaboration of the final Timetable of trains

(Info Source: UIC Railway Capacity Allocation Study. **vti**)

Country and Entity responsible for carrying out the process	Conflict resolution among competing paths requests		
	First approaching	Coordination Phase	Last phase using prioritization criteria to resolve remaining path conflicts
Belgium *Infrabel (IM)*	Not apply	With concerned RU. considering alternative paths	**Type of line** — **Prioritization criteria** 1st All lines — RU did not under-utilize previously allocated capacity. 2nd High-speed lines — 1. Passenger trains (by speed). 2. Others Freight lines Freight lines — 1. Freight trains (by speed). 2. Passenger trains (by speed) 3. Others Passenger or mixed lines. Passenger or mixed lines — 1. Domestic passenger trains (by speed). 2. Other passenger trains (by speed) 3. Freight trains (by speed) 4. Others 3rd All lines — Highest monthly access charge on Belgian Railway For conflicting late and ad hoc path requests, first come-first served criteria is used.
France *SNCF Reseau*	Preconstructed Timetable with long-term frequent train paths covering all year	Capacity conflicts are first handled within the coordination procedure	**Prioritization criteria** Traffic on European freight corridors. Distance covered by the path Commercial importance for the applicant. Financial importance for SNCF*R*. SNCF Reseau resolves any remaining capacity conflicts by either upholding requested paths or reassessing the capacity with the applicants
Germany *DB Netze*	Making a fit with a tolerance principle of +/- 3 minutes for passenger train paths and +/- 30 minutes for other paths	Capacity conflicts are first handled within the coordination procedure	**Prioritization criteria** 1st 1. Regular interval services. 2. Cross-border services. 3. Freight services. 2nd 1. At least two connections to other services. 2. Forming a circuit with return service. 3rd At least 70% use of awarded train paths in the last two years. 4th Highest access charge to the overall train path. 5th Highest bid procedure A final draft of the working timetable is prepared before ad hoc services and late requests start being included.
Great Britain *Network Rail*	All operators require a track access contract from ORR	Train Timetable is prepared in consultation phase with applicants.	If there are conflicting path requests after the consultation phase, certain **decision criteria** are used based on the network code rules such as: 1. Improvement of the network capability. 2. Reflection of demand. 3. Short journey time. 4. Commercial interest of Network Rail. If the conflict is not resolved using these decision criteria a dispute resolution process starts and a timetable panel and the Access Disputes Resolution Committee (ADRC) takes over and uses the Dispute Resolution Rules as follows: 1. Mediation. 2.Arbitration. 3 Expert determination.
Spain *ADIF*	Not apply	timetabling process allows Adif to adjust and modify the requested train paths to accommodate them in the working timetable	In the case of competing path requests, the allocation process uses **Prioritization criteria.** criteria used are, in order of priority: 1. Public services. 2. International services. 3. Services with framework agreements. 4. Frequent services 5. Overall system efficiency Sections of the infrastructure with conflicts are dealt with as congested in future planning tasks.

Table 7 Procedure applied in different networks in the elaboration of the final Timetable of trains

- In summary, the sequence of work in preparing the annual Timetable responds to progress in its construction, covering the following steps drive by the Infrastructure Manager body responsible of capacity management: Collect and analyse all requests of railway transport services, - train type, schedule and route -, submitted by railway companies and authorized applicants at the set date and for which path capacity is applied.
- Incorporate in Working Table all requested paths, services, for which there is available capacity.
- Make small adjustments, with or without the need to consult the applicants, in those coincident paths requested in which there are very close service alternatives in times and routes to those requests. ± 3min to passenger services and between ± 10 to ±30 min for freight trains, incorporating these paths adjusted to the Working Timetable
- Carry out a coordination process with the different applicants for conflicting path requests to try to solve them with alternative options of schedule and / or route, incorporating the alternative paths accepted by the applicants in the Working Timetable.
- Infrastructure Manager applies the Prioritization criteria to allocate competitive paths requests that remain in conflict. In which, as can be seen in the table, in the cases of high-speed lines,

passenger paths requests in competition with freight trains almost always prevail.

Then a final draft of the working timetable is prepared before ad hoc services and late requests start being included, for which, first come- first served criteria is performed.

Finally, sections of the infrastructure with conflicts are dealt with as congested in future planning tasks.

Regarding mixed traffic on high-speed lines, the capacity allocation procedure would indicate that:

- Given the notable greater absorption of capacity that freight train paths have with respect to passenger trains, their operation on high-speed lines will make the capacity allocation process more complex by significantly reducing available capacity and consequently increasing the probability of conflicting paths.
- Logically, in mixed traffic high-speed lines, the effect of freight trains on the normally applied capacity allocation procedure, will depend essentially on:
  - Infrastructure characteristics of the mixed line, line layout basic parameters and its length.
  - Performance parameters and operating conditions, such as maximum speed gap between passenger and freight trains
  - Passenger train traffic intensity.
- The greatest difficulties in fitting paths of freight trains into daytime periods, will be manifested in long-distance high-speed mixed lines with high intensity of intercity demand, because, logically, there would be many conflicts along the route between the paths of passenger trains and those of freight trains, as they are much longer. As seen in the priority table, these conflicts would be resolved by making the circulation of passenger trains prevail, given their greater commercial interest. Which in these cases could give rise to the paradox that freight trains were stopped longer, to be overtaken by the passenger trains, than running along the line, making rail freight service offer dissuasive.
- However, in the case of shorter high-speed infrastructures, the fitting of freight traffic in the daytime period is feasible, given that the shortest route offers the possibility of exploiting the infrastructure, forming batches of homogeneous trains, slow (freight) and fast (passenger) speed, running sequentially in share daytime slots.
- On high traffic intensity lines and under conditions of equality of the rest of the characteristics of the line, the shorter be the mixed high-speed route the more possibilities to schedule freight trains into the daytime Timetable. At the opposite end, the less possibilities to schedule freight trains into the daytime Timetable and, consequently, freight traffic must be schedule at nighttime timetable.

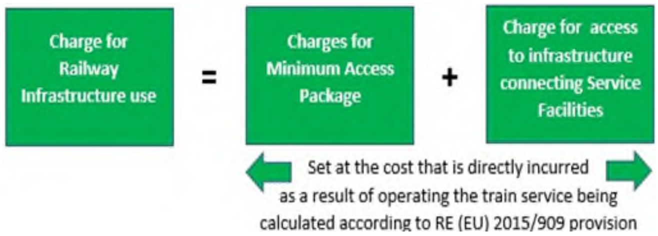
5.5 Infrastructure Charging and mixed traffic HS Lines

At the European level there is a common framework that regulates charging for the use of railway infrastructure.

Indeed, Section 2 of Directive 2012/34 / EU develops the common procedure for the establishment and application of charging for the use of railway infrastructure and other services provided by the Infrastructure Manager and Regulation (EU) 2015/909 of 12 June 2015 which sets the modalities for the calculation of the cost that is directly incurred as a result of operating the train service.

The essential principle on which pricing is based for any type of railway line is that:

- The charges for the minimum access package and for access to infrastructure connecting service facilities may be set at the cost that is directly incurred as a result of operating the train service.



The minimum access package should comprise:

- Handling of requests for railway infrastructure capacity.
- The right to utilise capacity which is granted.
- Use of the railway infrastructure, including track points and junctions.
- Train control including signalling, regulation, dispatching and the communication and provision of information on train movement.
- Use of electrical supply equipment for traction current, where available.
- All other information required to implement or operate the service for which capacity has been granted.

In addition, the charge for the use of infrastructure includes access to the infrastructure of connection to service facilities, where they exist, and to the services provided in these facilities. Among those who would be:

- Passenger stations
- Freight terminals
- Marshalling yards and train formation facilities, including shunting facilities
- Storage sidings

- Maintenance facilities, with the exception of heavy maintenance facilities dedicated to high-speed trains or to other types of rolling stock requiring specific facilities
- Other technical facilities, including cleaning and washing facilities
- Refuelling facilities and supply of fuel in these facilities, charges will be conveyed separately.

Also, and with separate invoicing, Infrastructure Manager would provide access to additional services and ancillary services, such as:

- Traction current
- Pre-heating of passenger trains
- Control of transport of dangerous goods
- Assistance in the operation of special configuration trains.
- Access to telecommunication networks.
- Provision of supplementary information.
- Technical inspection of rolling stock.
- Ticketing services in passenger stations.
- Heavy maintenance services supplied in maintenance facilities dedicated to high-speed trains or to other types of rolling stock requiring specific facilities.

Hybrid locomotive for freight train

As it is mentioned above, the charge for the minimum package of access and use of the track, which include access to the service facilities has to be based on the direct cost caused by the train,

While the cost of each of the Additional and Ancillary services provided to the train will be billed at full cost plus a reasonable profit.

Although regardless to the application of the direct cost principle, infrastructure managers:

- May include a charge which reflects the scarcity of capacity of the identifiable section of the infrastructure during periods of congestion.
- May modify pricing to take account of the cost of environmental effects, noise, caused by the operation of the train according to the magnitude of the effect caused.
- Charging of environmental costs however be allowed only if such charging is applied to road freight transport in accordance with Union law
- May, if the market can bear this, levy mark-ups on the basis of efficient, transparent and non-discriminatory principles, In order to obtain full recovery of the costs incurred by the infrastructure manager
- Although level of charges should not, however, exclude the use of infrastructure by market segments which can pay at least the cost that is directly incurred as a result of operating the railway service, plus a rate of return which the market can bear.
- Infrastructure managers can also apply discounts as long as; are limited to the actual saving of the administrative cost, are related only to charges levied for a specified infrastructure section and for specified traffic flows, granting time-limited discounts to encourage the development of new rail services, or discounts encouraging the use of considerably underutilised lines.

In summary, although there is a general principle of common application in the entire European railway network, focused on the recovery of direct costs caused by each train, however, the truth is that in practice a considerable number of different concepts are applied in the formation of the price for the use of railway infrastructure.

European legislation requires that the charging system is explicitly included in a clear and concise way in a specific chapter of the Network Statement. What does not prevent that according to the networks there are important differences in the 30 variables applied, as shown in the following table taken from the correspondent Network Statement.

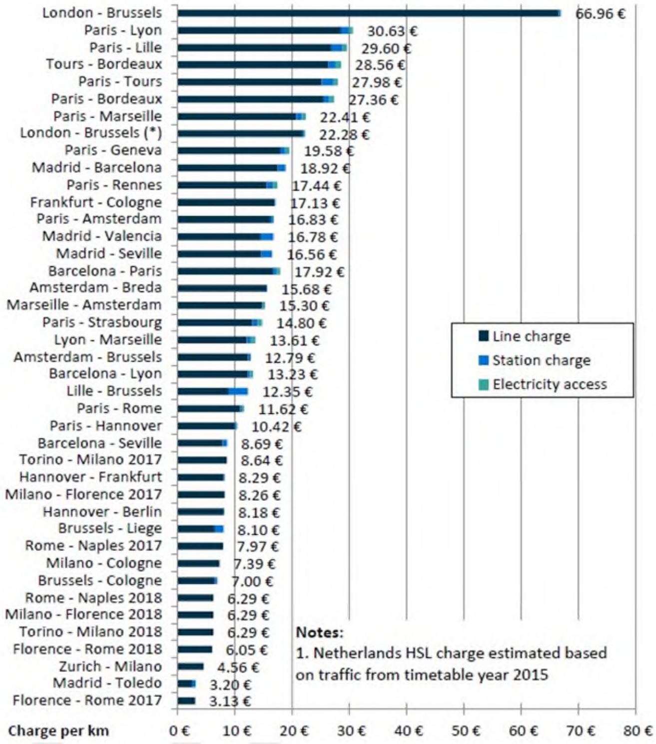
List of charging concepts applied	Variables applied in infrastructure use charging in each national railway network (Source UIC Study of Infrastructure charges for freight)							
	Austria	France	Germany	Italy	Netherlands	Portugal	Spain	Switzerland
Time of day pricing	X	X		X			X	X
Train Speed	X			X			X	
Train Type (physical)		X	X				X	
Train Path quality			X					X
Loco Traction Type	X					X		X
Service Type/Pattern-Distance		X					X	
Line type/importance	X	X	X	X	X	X	X	X
Line type /Capacity		X	X			X		
Capacity maximazation Charge	X		X					
Scarcity Surcharge			X					
low-speed penalty			X					
Fee per train-km	X	X	X	X	X	X	X	X
Fee per seat-km							X	
Fee per tonne-km	X				X			
Fee per min				X				
Node fee				X				
Reservation Fee		X	X	X		X	X	
Cancelation Fee		X	X					X
Running Charge	X	X	X	X	X	X	X	X
Administration Fee		X					X	
Security Fee		X					X	
Enviromental Surcharge								X
Special infrastructure Fees								X
Dangerous goods transport		X						X
Noise Fee/discount			X		X			X
ETCS Fee/discount								X
Performance Scheme	X	X	X	X		X		
Freight subsidy discount		X						
Traction current access		X		X		X	X	
Traction current management						X	X	
Traction current use				X	X		X	X
Fuel management and dispensing							X	
Varying rates for Diesel/Electric						X		X

Table 8 Variables applied in infrastructure use charging in each national railway network

However, this great plurality of pricing variables comes from the different concepts applied according to the different railway networks, so that in networks with a more complex tariff system less than half of that total of variables are applied.

- Regarding mixed traffic, the most interesting thing about the applied railway charging system is that the highest level of coincidence in the charging variables applied by the different railway networks corresponds to the following concepts:
  - A Path fee per Train-km, basically depending on:
    - The line category, according to its performance level, mainly maximum speed
    - Time of day and, and
    - Performance scheme setting
  - To which is added the price of additional and ancillary services consumed by the train.
  - Other relevant concepts for mixed traffic, such as those related to line capacity and environmental aspects, take on significance in circumstances of saturation and neighbourhood with highly populated areas.
- However, the consideration of concepts such as train load or speed, once the train meets the operating requirements on the line, - maximum axle load and per linear meter, and maximum total length and minimum operating speed -, are not among the variables of common application in the railway infrastructure charging system.

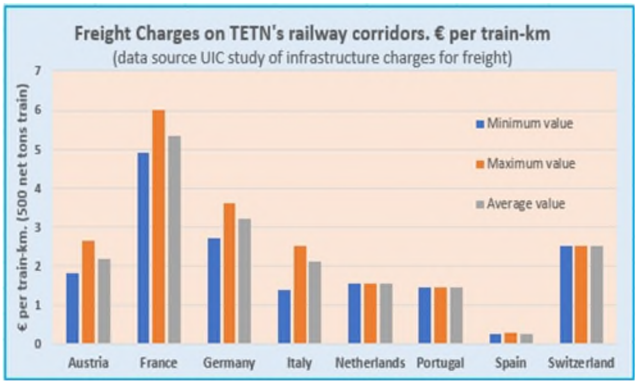
Even so, the qualitative diversity of the charging system according to networks and its discretionary application, translates in practice into a great dispersion in the quantitative price levels applied in each network, both in passenger and freight services, as evidenced by the graphics that are attached below.



Infrastructure Charges on European high-speed lines (Source: UIC)

In the passenger service, for example, it is observed that the dispersion of prices is manifested not only among the different networks considered, but also and notably within the same network, which indicates the following:

- The specificity of each segment of the interurban mobility market has a great influence on the formation of the final price, particularly in terms of volume and competitiveness, the dominant position or the opposite, of the railway service. The great dispersion of the final prices applied in each network makes it difficult to set prices that are easily understandable, competitive and with equitable distribution in international services.



Also, in the case of freight services, the dispersion of prices of railway infrastructure use among networks is manifestly considerable, although in this case the differences in the same network are small. With this, the problem of pricing in international freight rail services is also reproduced in this case.

The following table, which reflects the real train-km fee applied in some high-speed mixed-use lines, shows the problem underlying payment for the use of rail infrastructure in the case of rail freight.

Since freight trains are more efficient mostly when the distance is long, these trains suffer even more than passenger trains from this diversity or this discrepancy of charging systems. This is even more true for international freight trains at a time when huge financial efforts are made to overcome the natural barriers by large engineering structures and tunnels.

This idea emphasises the need to make progress in clarifying and harmonising the system of infrastructure charging for the use of the rail network in order to encourage the development of rail freight on the routes where this mode of transport is most efficient.

As can be seen, in all cases, the actual infrastructure use fee paid by freight trains is lower, and in some cases much lower, than that paid by passenger trains.

Despite the fact that freight trains are heavier, longer and they consume much more capacity than a passenger train using the same line, in practice, there are lines in which high-speed passenger trains pay up to 7 times more than freight trains for the use of the same high-speed infrastructure.

This is the result of the fact that in the case of freight traffic, there is a contradiction between the principle of payment for use according to directly attributable costs and the real capacity of the freight transport service to be able to pay for it.

	H-W HSL	NEC	HS1	LFP Figueres-Perpignan HSL	Barcelona-Figueres HSL
Domestic High speed		No values available	€ 48.24		€ 11.65 (Avant service)
High speed passenger service	€ 8.40		€ 44,4 (€27.72 with 60 % discount of IRC for services between St Pancras and Brussels)	€ 52	€ 14.64 (AVE service)
Freight service	€ 5.09 € 3.17 in conventional line roughly parallel		€ 6.14	€ 44	€ 1.74 (Container and Automobile trains)
Criteria applied in charging of infrastructure use: Passenger Charges	Toll per train-km. Use of passenger stations per stop. Electrical energy consumption.	Pay an "avoidable" operating and maintenance costs	Investment Recovery Charge (IRC). Additional Investment Recovery Charge (AIRC). Operations, Maintenance and Renewal Charge (OMRC). Other charges (Capacity Reservation Charge, Congestion Tariff, Other Services Charge, Freight Supplement, Carbon Costs). Traction Electricity Charge.	Flat-rate fees scheme is applied for the use of line which depends on trains type and class. Up to 25% discounts for loyalty agreements	Train-km charge for use of infrastructure is the result of the addition of: Capacity allocation charge. (CAC) Infrastructure use charge, (IUC), that can add Markups depending on Line performance and scarcity of capacity. Energy subsystem use charge, (EUC).
Criteria applied in charging of infrastructure use: Freight	As above	Shared costs based on car miles	Based on the distance travelled		

Table 9 Railway infrastructure access fees examples to the in mixed high-speed lines (€ per train-km)

Imbalance between direct costs incurred and payment capacity, which is exacerbated in the case of high-speed mixed lines, which, given their high performance, have much higher maintenance and operating costs than conventional lines, and the gap between direct costs for the use of the line and the payment capacity of the freight service provided increases. In high-speed mixed traffic lines, charging system for the use of railway infrastructure, given the existing gap between direct costs incurred and the payment capacity for freight services, should have a multiple selective effect:

- It will concentrate in these mixed high-speed lines the traffic of goods of greater value, those more sensitive to transport performance improvements.
- It will concentrate the operation of the freight trains in the sections and / or periods of time with the greatest free capacity window available.
- In the case of lines or sections of lines with high daily time occupancy by the passenger service and to avoid take the path of a passenger train, that covers direct costs and even part of the long-term costs, freight traffic it should only be operated at nighttime period.
- Given that the current situation of the rail freight sector makes it difficult to transfer the costs directly attributable to this service to its railway operators, and in view of the need to boost its growth, given the advantages that railway presents reducing the external costs of transport, it would seem reasonable to consider for freight transport in high-speed lines the application during a transitional period of the charging principle based on "avoidable costs".
- Nevertheless, the possibilities of applying the charging principle based on "avoidable costs", should be limited to cases in which the circulation of the freight train does not impede or disrupt the circulation of another train that responds to the general principles of charging for the use of railway infrastructure.

It can be seen that in the cases of high-speed lines with high intensity of passenger transport, the possibilities of shared use necessarily go through the fitting of freight trains at times in which they neither impede nor impair the circulation of passenger's trains, as this service is much more interesting commercially due to its greater capacity to pay for the use of the infrastructure.

Which again concludes with the fact that freight trains should be scheduled in hours with no traffic or hardly any high-speed passenger traffic, that is, at night-time, provided that passenger traffic is important, and it is not a short length high-speed line.

5.6 Conditions for access of freight trains to a high-speed line

5.6.1 Introduction

This section aims to establish the minimum access conditions to be met by freight trains needing access to a high-speed line.

5.6.2 Conditions for Interoperability with passenger lines

The main aspects to ensure the interoperability of freight trains as are follows:

5.6.2.1 Alignment and track

In relation to the previous point and the operation requirements, the existing slopes will mark the maximum length of the freight trains compositions.

5.6.2.2 Structures (viaducts)

The maximum axle load for freight trains will be defined with the regulations and load combinations with which the line structures were designed (UIC, EUROCODE; AREMA, etc.).

Exceptional transit of freight wagons transmitting higher loads could be allowed provided that the corresponding structural verification analysis is submitted.

5.6.2.3 Rolling Stock

Main line gauge depends on the pertinent guidelines (UIC; AREMA; etc.) where the line design is based.

Freight trains dynamic envelope, defined on the basis of the characteristics of the trainset to be run on the line, must in all cases respect the infrastructure gauge so that each train does not interfere with this gauge (tunnel, platform, bridges/viaducts, overpasses/underpasses).

The load on each wagon should be arranged so that the maximum gauge, axle weight, or unbalanced load that may cause damage to the infrastructure or other trains on the line can never be exceeded.

Geometry and mechanical characteristics of the vehicle wheels must provide adequate mechanical interaction between the wheels themselves and the line rail and its inclination.

5.6.2.4 Signalling and Train Control

Locomotives for freight trains must be equipped with on-board equipment corresponding to the system they have implemented on the line (ERTMS, PTC, etc.) For example:

- Antennas for train-track communication.
- Trackside reading device for beacons
- Computer centre responsible for the system
- Devices for displaying all relevant data to the driver
- Legal recording equipment to store the events produced during a certain time.

5.6.2.5 Communications

The driver of any freight train must have means on board to communicate with the operators in the Control Centre to alert them to specific problems on board (evacuation, fire, etc.).

5.6.2.6 Traction

Locomotives may be diesel or electrified with the same voltage as the line being accessed.

The installed power must be such that the load combinations can negotiate the route parameters (in particular the line gradients).

If diesel locomotives will access to the line, additional considerations should be taken during the design, please refer to section 4.2.6 and 4.4.

5.6.3 Homologation

The procedure of homologation of locomotives is one of the crucial aspects to be improved in order to facilitate free movement of trains. According to manufacturers and railway undertakings, these procedures remain often very long and costly, and some of the requests of competent authorities seem even hardly justifiable, as far as technical aspects are concerned.

Increasing the length of freight trains in operation (mainly across EU corridors) is a key objective to achieve an increase in capacity and strengthen the competitiveness of rail freight transport by decreasing the cost of rail haulage without affecting safety standards.

The definition of technical and homologation requirements, together with safety standards and protocols for radio-remote controlling is of paramount importance to ensure that longer freight trains are put in operation.

As an example, “FERRMED Locomotives” should be interoperable and homologated in all EU countries, so they should meet following requirements:

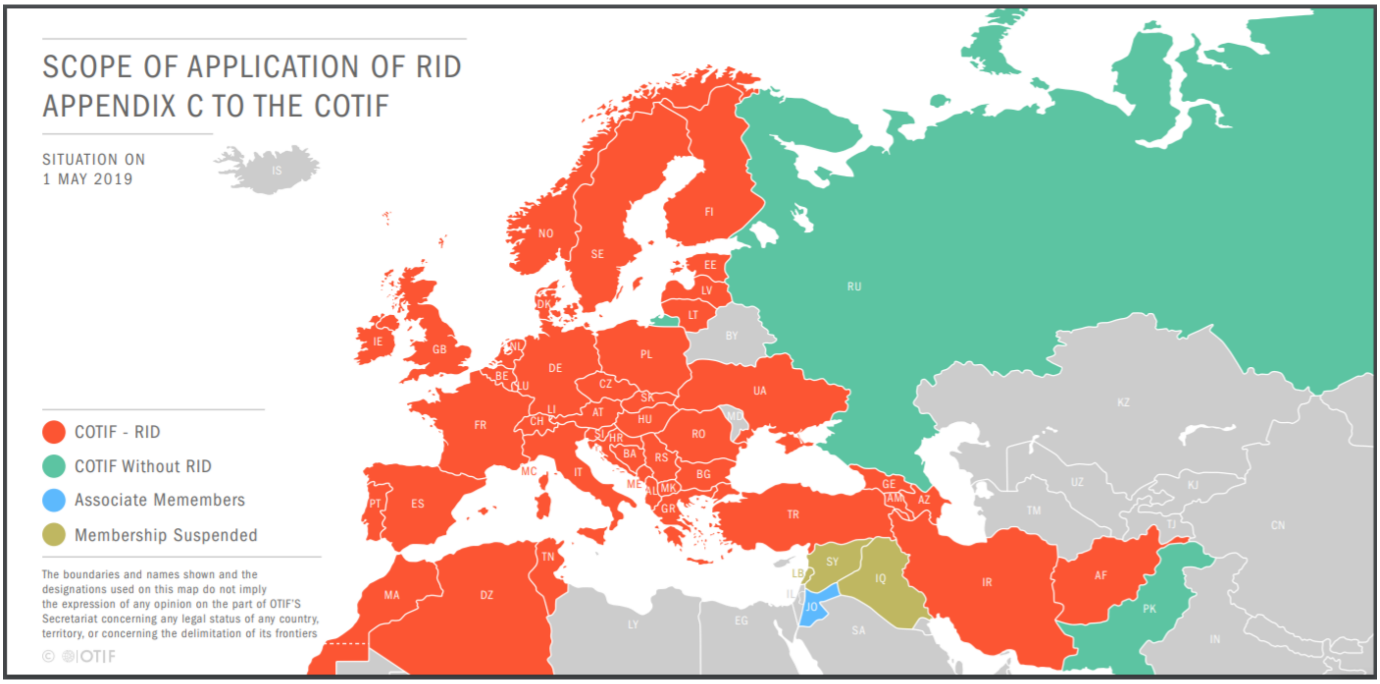
- Fulfil all applicable TSI, European Directives and country-specific norms
- Be able for track gauge 1435mm
- Diesel or electrical multi-tension at least until the whole network has the same voltage, 25kV
- Equipped with European Central Desk
- Be able for ERTMS Level 2: equipped with ETCS and GSM-R radio system

5.6.4 Safety

The safety-related conditions to be met by freight trains in order to gain access to a high-speed line can be as follows:

- It must be possible to detect any freight train entering the line
- All vehicles to be deployed on the line, regardless of their type (passenger or freight trains) must be equipped with on-board train control systems compatible with the field signalling system
- For the transport of dangerous goods, RID (Regulations concerning the International Carriage of Dangerous Goods by Rail) or the corresponding regulations in force may be applied.

The objective of RID is to establish requirements to ensure safety and to protect persons, property and the environment.



Scope of application of RID

5.6.5 *Operations*

Rrail transport undertakings which operate railway vehicles accepted to run in international traffic should be required to comply with the prescriptions relating to the operation of vehicles in international traffic-

Railway undertakings and infrastructure Managers should be required to comply with the technical prescriptions and satisfy them permanently in respect of the construction and the management of that infrastructure.

High Speed line with mixed use should have detectors deployed along the line to check that rail operation, particularly freight, as described in this handbook.

5.6.6 *Maintenance*

The freight operator wishing to access the high-speed line must demonstrate to the relevant traffic manager that it is complying with the freight trains maintenance plans provided for in accordance with the manufacturer's requirements and with its own duly approved plans.

This condition applies to freight trains for which permission to enter the line is requested.

The operation of freight will respect the established schedules and maintenance activities, so that these tasks are not affected.

6 PHASE II. HIGH SPEED LINES MIXED TRAFFIC RELEVANT IMPACTS ASSESSMENT

High-speed mixed traffic lines imply, with respect to a dedicated high-speed passenger line, relevant effects related to both its implementation and its operation.

These specific impacts should be considered and correctly evaluated in order to carry out a new mixed line the appropriate determination of the possibilities and needs to guarantee its operation and sustainability as a mixed traffic line.

The most relevant effects to consider are the following:

- Implications on operation and traffic management and safety assessment. Procedures and equipment.
- Additional infrastructure facilities and maintenance needs.
- Implications on the essential quality requirements of the line and service.
- Implications on the line construction costs
- Implications on the line maintenance and operation costs.
- Identification and assessment of the main benefits caused by the mixed lines. KPI expected.

6.1 Implications on operation and traffic

It is understood as operation and management of a line, the set of procedures and equipment that allow an efficient and safe operation of the traffic line both during normal and degraded conditions, which includes:

- Train Planning optimization.
- Train dispatching and on time departure.
- Traffic management at actual time.
- Ensuring traffic safety and security.

This study section aims to identify and evaluate the main impacts that freight trains may cause in the activities that integrate operation and traffic management on a high-speed line.

6.1.1 Train Planning optimization

Includes the set of processes and procedures needed to grant the path allocation of whatever train on the high-speed line optimizing its route and the line capacity availability.

Train planning is, essentially, an activity of preparation, presentation, analysis and issuing of documentation covering the following tasks depending on responsible entity:

Train definition, which is a responsibility of the Railway Undertaking applying for capacity to line use, includes.

- Train identification
  - Origin, Destination and other stopping points
  - Type and load type for freight trains
  - Maximum long, weight and axle load and kinematic envelop
- Operating days, if needed
- Train composition. Identification of each vehicle on the train.
  - type, number and characteristics of traction vehicles, Trainset or LOCOs
  - type, number and characteristics of each wagon/coach on the train
- Train performance
  - Running performance, maximum speed, acceleration and braking
- Train Path application

Train scheduling, which is a responsibility of the Infrastructure Manager, the entity responsible for authorizing and managing the movement of trains along the line, which should do:

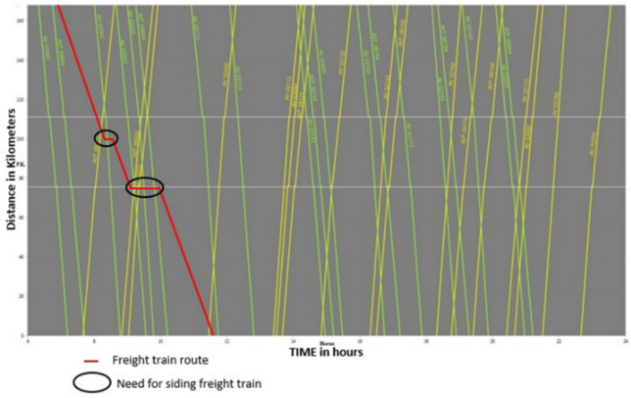
- Generates the train routing along the line, train path allocation, optimizing line timetable and capacity.
- Determines of all functional, technical and operational requirements of the train consistent with the path allocated and the safety management system.
- Provides to the Railway Undertaking all documentation needed to issue the train Route Book, those related to the line general operation characteristics, such as:
  - Line diagram. Stations, tunnels, speed limits, neutral sections...
  - Railway systems equipment, signalling, radiocommunications, traction power supply
  - Rising and falling gradients levels by line section
- Establishes the capacity reserve for each train and produces and approves the Timetable for the period considered.

Given that all of these are procedural activities and formalization of documentation to allocate the capacity reservation in terms of safety and efficiency, the impacts caused by mixed traffic in train planning will come and depend exclusively on the number and degree of diversity of the type of trains to be planned.

The more homogeneous the trains on the line, the easier path allocation process and the greater the circulation capacity of the line.

The greater heterogeneity of the type of trains running on the high-speed line complicates the optimization of their corresponding routes, in addition to the agility in their modification and adaptation to changing situations or incidents that may arise during daily operation.

Sometimes it happens that to avoid planning the overtaking of the slower trains by a faster one, the route of the passenger train must be moved to a schedule perhaps less attractive for its capture of demand, or even the route is penalized.



Insertion of freight trains in a high speed service chart

In a high-speed line, mixed traffic reduces its capacity depending basically on the variety and performance differential, maximum operating speeds, number of stops, accelerations, braking, of the various types of trains that are going to use the line.

It has been already identified, when analysing the capacity requirements on a mixed traffic line, that in the most favourable case, when the maximum speed of the freight trains approaches to the half of speed of the fastest passenger trains, the capacity of the line might see reduced by the half at least.

In summary, the impact of mixed traffic on service planning activity on a high-speed line could focus on:

- Greater complexity of train scheduling process, due to the greater train operational diversity, and timetable less easy to modify and updating.
- Greater difficulties to provide the most suitable path for all trains planned.
- Reductions in line capacity, especially damaging during daytime intervals, due to the greater need for track occupancy time during the journey of freight trains compared to that required by passenger trains.
- Logically, the degree of incidence of these impacts of mixed traffic in service planning on a high-speed line, will vary according to the intensity of use required by the passenger service, which in the case of high demand, would see diminished the availability of more and better high speed line paths.
- In cases of high demand for passenger traffic, the daytime / night-time segregation scheme for planning, - scheduling -, passenger and freight traffic will be necessary.

6.1.2 *Train Dispatching and on time Departure*

Train dispatching and departure is also an activity of processes and procedures needed in this case to ensure that the departure authorization of the train's fulfilment every technical, functional, operational and safety requirements that rule the use of the line.

The prior process to train departure authorization is again an activity of preparation, presentation, analysis and issuing of documentation, that in this case have to cover the following tasks depending on responsible entity:

Ensuring train is ready to be running in order, which is a responsibility of the Railway Undertaking that operate the train, which includes:

- Train documentation
  - Train composition. Train running number, O/D, train type and type of load, if applicable, driver identification, maximum speed, total length and mass, braking performance, …
  - Individual identification of each one of the train's vehicles and their position in it. Registration number, physical, technical, functional characteristics, capacity and load...
  - Route Book. Detail of the relevant data in the movement of the train along the route updatable on real time. On each relevant points and sections of the route, distances, timing, maximum speed, gradients, power supply sectioning, train block system
  - Verification of the operability of the train and each of its vehicles with the technical, functional, operational and safety requirements of the line.
  - Based on its updated approval and current authorization for running along the line, as well as on the compliance with the maintenance plans of each vehicle that is part of the train.
- Driver documentation
  - Availability of the qualifying driver licence to drive the train on the line and current certification of good health.
  - Knowledge and availability of the train Route Book and its updated on real time.
  - Train driving normal and degraded operation and managing an emergency situation handbook.
  - Train Document corresponding to that date and that service. Train identification, type, number, crew, origin-destination, vehicles number and composition, capacity, occupation, load, length, total mass, total brake weight and minimum % required.
  - Communication protocols with the traffic control centre
- Train crew, other than drivers

  - Qualified on board staff to attend, advice and help, when necessary, passengers.
  - Inform the driver of the passengers' accommodation and completion of their boarding.
- Other staff involved in train dispatching
  - Attention staff at passenger stations
  - Staff preparing and verifying the load of the freight train, at the cargo terminals.
- Safety checks of passengers boarding and accommodation
- Safety verifications of the load stowage and its correct fastening, if any
- Driver checks and test before departure
  - Traction and energy supply
  - Drivers' cab signalling and control and command equipment including the radio communication system, if any.
  - Communication and information equipment on board.
  - Check braking system and braking performance, brake weight % available.
  - Safety of passenger or load
  - All on-board crew ready to train departure and train doors closed.
- Reporting the train operational status to the person of the infrastructure manager responsible of authorise its departure.

Authorize the departure of the train, which is the responsibility of the staff of the Infrastructure Manager working in the traffic control centre, this activity includes:

- Ensures that the in-order train to depart meets the path allocation requirements.
- Checks the update of the train Route Book and informs about the last-minute route conditions, if any, due to possible modifications in normal operation caused by any failure in facilities or operation changes.
- Performs the route of train departure to the line in the traffic control system and authorizes its movement by informing the train driver.
- Train driver can start the journey from that moment incorporating the train to the line.

The potential impacts of mixed traffic related to the activity of dispatch and departure of trains has to be compliant with the time train departure scheduled.

Logically, the verification and arrangement of freight trains, constitutively more complex and diverse than those of passengers, usually trainsets of a fixed composition, has a greater risk of causing delays in the departure time of freight trains that could also reach affect the schedule of passenger trains.

- Delayed departure is the main impact that mixed traffic can cause in the dispatch and departure activity of trains, which may be due to:
  - Delays in train formation due to unavailability or unreliability of any of the vehicles, mainly wagons.
  - Delays caused in train loading or checking load stowage and its secure fastening.
  - Delays caused in the routing of the train along stretches of connection and junctions with the high-speed line, mostly shared traffic conventional lines.

6.1.3 Traffic Management at real time

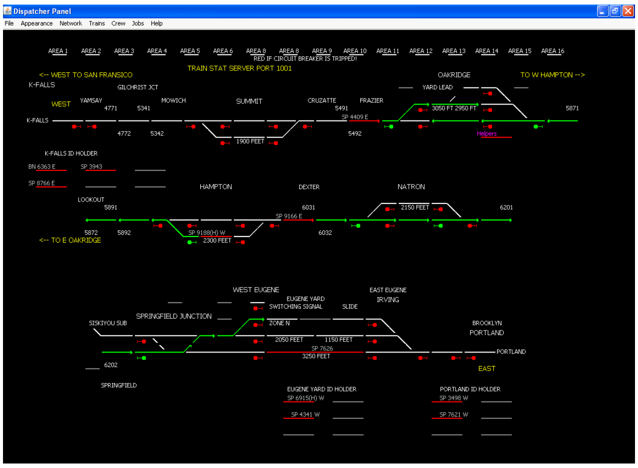
Traffic management is an activity performed by the Infrastructure Manager intended to make an at actual time the daily keeping track of entire trains operation to ensure the compliance of the line scheduled service in terms of safety and reliability.

In high-speed lines, traffic control is carried out centrally from a Control and Command Centre, equipped with telematics applications that provide at actual time, trains positioning and status of all the line subsystems in order to control and manage in safety manner all trains movement along high the line.

Traffic Management at central control room

The main tasks of traffic management are:

- Tracking trains and service at actual time.
  - Trains positioning reporting, space-time.
  - Specific tracking and control of dangerous goods trains, if any.
  - Train Routing updating overlapped with scheduled.
  - Predicted train arrival - handover time.
- Provisioning telematic applications for the access of operators to information on tracking its trains at actual time.
  - Monitoring of passenger trains
  - Tracking of marshalling and running of freight trains and its goods, especially hazards goods.



- Managing incidents and emergency situations.
  - Captures information and spreads it to entities involved on solves the incidence.
  - Informs to service operator.
  - Makes decisions and performs operational measures that rerouting the line service.
  - Degraded operation management
  - Train's crew support
- Line operation data recording, analysis and reporting.
  - Service quality, total and breakdown by the various services on the line: Punctuality and deleted trains, actual operational speed, service reliability.
  - Line production performance: total mileage and per type of service, total trains run and by type, used and available capacity.
- Line incidents recording, analysis and reporting.
  - Total incidences, breakdowns by causes and quantified consequences.
  - Relevant indicators of incidentality by type of service, with cause-effect cross analysis.

Obviously, the possible negative impacts of mixed traffic on the operation of the line and the performance of traffic management, that is, on the quality of the service provided, will be caused by the lower reliability of the vehicles that make up the freight trains, compared to that of the vehicles that make up high-speed passenger trains.

The commercial success of high-speed rail is the result of two fundamental factors:

- A very competitive travel times, consequence of both line equipment and trains high performance
- Secondly, but not least, the high reliability of the service offered, measured at passenger trains on time.

On average, for example, the HS AVE service in Spain has a punctuality of over 98%, that is, less than 2% of the high-speed passenger trains operated on the high-speed lines have a delay of 10 minutes or more.

The assurance of this high quality of service requires the suitable maintenance of both the constituent subsystems of the line, as well as each one of the vehicles that composed the high-speed fleet, which must maintain their high technical, functional, comfort and safety specifications on highest level.

Trains destined for Spanish high-speed lines specify a contractual guarantee in their maintenance of a minimum average of 750,000 km of distance covered between breakdowns, which is equivalent to a maximum of one train incidence every 20 months of commercial circulation. An incident caused by a train is understood to be any breakdown in it that causes service delays of more than 10 minutes.

According to the experience freight trains vehicles presents a much lower reliability rates. For instance, the most modern and powerful electric locomotives that circulate on the Spanish network specifically dedicated to freight traffic, have a reliability rate of 200,000 km, that is, almost the fourth that the reliability index of high-speed trains.

The significant reliability differential of high-speed trains with respect to freight trains makes the probability of incidents significantly higher in mixed traffic lines than in passenger-dedicated lines.

This greater incidentality could negatively affect the quality of the passenger service, which would translate into a decrease in demand and corresponding revenues.

- The lower the reliability of the freight train vehicles, the greater the probability of failure in their operation and, therefore, the greater the risk of disruptions to the normal development of the entire service scheduled on the line.

As in other cases, the degree of actual impact caused by the reduction in reliability of service in mixed traffic lines, will depend on the intensity, structure and sequence of traffic on the line, as well as the reliability requirements and rolling controls at impose freight trains, locomotives and wagons on the rolling stock. All this should be subject to consideration and specific valuation in the planning and design process of the mixed HSL.

- Reduced service reliability may be the main and significant impact that mixed traffic can cause in the operation and traffic management performance on a high-speed line. This higher risk of line service quality losses, could be mitigated by:
  - Require the pertinent rates of availability and reliability in the maintenance service provision of freight trains vehicles with the highest possible performance standards.
  - Incorporate in the composition of the trainload additional traction, supplementary loco, to what is theoretically necessary to hauled maximum load trains, fulfilling the path assigned in its scheduling.
  - Increase the number, probably double, and extend the length of the sidings, a minimum

of 900 m of its stabling track length, with respect to their need and dimension in a passenger dedicated high-speed line.

- Install flat-wheel detectors on the track, - TID Track Impact Detector-, at least at an intermediate point located between the access of the freight train to the high-speed line and the first existing siding on its route.

  Require sensors on the freight train locomotives pantographs for automatic descent of the same in case of overstress on the contact wire.

6.1.4 Ensuring traffic safety and security. Specific operating constraints

The safety objectives of the line must not be reduced at all by their exploitation in a mixed regime by the movement of freight trains, nor are they reduced when different types of passenger trains run throughout the line.

However, the incorporation of freight trains adds new risks in traffic safety and in the security level of people and installations on the line, in relation to those existing in a line dedicated to passenger transport.

These potential risks induced by mixed traffic must be subject to their specific identification, evaluation and assessment, within the risk assessment and management study that is required to be carried out in the general framework of the commissioning process of a new line, or a new transport service substantially different from those that they had been previously performed in a line already in commercial exploitation.

The scheme incorporated below states the Common Procedure for Commissioning a new HS line or new relevant services in which the risk assessment and management analysis stands out as a relevant fact.

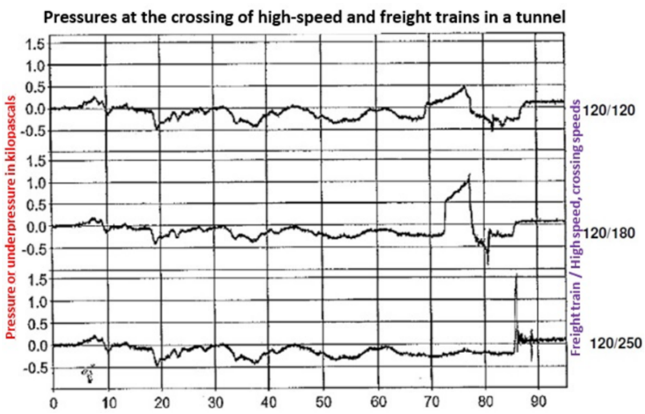
So far, therefore, in the area of guaranteeing the achievement of the safety and security objectives of a high-speed line, the impact of mixed traffic has been reflected in two aspects.

- Mixed traffic enlarges the quantitative content of the risk assessment by incorporating specific potential risks in meeting the line's safety and security objectives.
- And most important think, the management of these risks, guaranteeing compliance with the line's safety and security objectives, will give rise to the implementation of specific operating conditions and constraints as well as particular requirements to the maintenance works of the line.

This increase in risk management affects all procedures, people and equipment involved in the operation of the line and mainly come from the diversification of the types of traffic and consequently in different characteristics of the rolling stock, which are translated into the circulation of trains with quite different technical-functional performance, all of which may translate:

- Increased need for train overtaking actions
- The transport of hazardous goods
- The traffic on adjacent tracks of trains of quite different composition and rolling stock configuration. Specific problems and ad hoc requirements for train crossing.
- Specific problem of traffic and crossing of trains in tunnel line sections
  - Safety and security requirements in case of time coincidence with maintenance works site
  - Requirements for the control of possible movements, detachments or spills of load

Thus, for example, one of the important risks to evaluate and manage in the line operation, is that derived from the suction phenomena produced at the crossings of high-speed and freight trains, both on the open track and especially in the tunnels. Phenomenon that can be the cause of displacements and even detachment of the trainload, with the increased risk to traffic safety on a high-speed line.



Pressure at the crossing of high speed and freight trains in a tunnel

The management of this risk, such as those of others that can be identified in each specific case, should result in the consequent prevention actions that prevent its manifestation.

The known practice in safety management at train crossings is the speed limitation of high-speed trains both in tunnels and open-air sections.

Depending on the specific characteristics of design and effective use of each line, the specific security requirements and measures related to operation and traffic management on a mixed traffic line, such a operating constraints, will be specified and applied on line operation, for example, in terms of :

- Limiting maximum speed or set train crossings restrictions.
- Traffic scheduling restrictions (traffic hourly specialization or segregation, night /day, or not)

- Tunnels traffic restrictions (speed limit, coincidence different train types,..)
  - Crossing of passenger and freight trains in tunnels of high-speed lines is not allowed in Germany
  - Emergency brake override in tunnels – just for rescue reasons.
- Bridges/viaducts restrictions (same previous)
- Restrictions on the movement of certain types of wagons and / or goods (hopper wagons, hazards goods, etc.)
- Environmental restrictions (noise, vibrations, threats to the environment, etc.)
- Maintenance requirements on planning and specific safety and security measures
- Need to incorporate or add specific facilities designed to control and manage certain risks of their own or increased by the mixed traffic (dragging objects, derailed axle detectors, gauge excess detectors, etc.

Hannover – Würzburg	Northeast Corridor	High Speed One
• Due to aerodynamic phenomena within double track tunnels trains must be pressure sealed and Vmax of passenger trains limited to 250km/h • Passenger trains stopping within a tunnel should be avoided • Passing freight in tunnels limited to 160 km/h • Day-time/night-time operations scheme is applied	• **No diesel** through the North river tunnels, Penn station or East River tunnels. (Except maintenance trains)	• Due to the slower speed of freight trains they are restricted to night-time operations only • However the operation of High Speed (300 km/h) freight trains,-postal/parcels -, are allowed during day-time

Operating constraints examples

In each mixed traffic line, it will be necessary to determine what requirements and operating constraints will be necessary to implement on its traffic operation to better guarantee full compliance with the safety and security objectives.

6.2 Additional infrastructure facilities and maintenance needs.

The mixed traffic on HSR will have a considerably bigger effect on the maintenance of the infrastructure and will reduce the time that is available for maintenance. There is a need to better coordinate cooperation between infrastructure managers when major maintenance is needed.

The track maintenance policy needs to consider the daily traffic load made up of all trains (passenger & freight).

Maintenance of mixed lines is expensive and needs much longer time to be done. However, there is a good example at Trenitalia, whereby introducing the Dynamic Maintenance Management System (DMMS) on Trenitalia trains, the maintenance cost could be reduced by 7-8%. Increasing the preventative maintenance instead of the reactive one and increasing the number of real-time sensors that monitor the conditions of existing railway infrastructure and rolling stock may mean that there will be a sufficient reduction in maintenance and decreases in the time window that is allocated for maintenance in addition to the fact that it would be possible to allocate more time at night for freight services.

A shared-use HSR system's increased need for maintenance ripples through the system. It means more facilities for maintenance workers, more maintenance yards, more equipment, and so on. Recommendations that should be considered for improving maintenance in the planning process include the following:

- Infrastructure—Most of those interviewed for this research recommended building a higher quality infrastructure for shared-use HSR systems, including installing more reliable equipment. Other infrastructure planning strategies include providing sufficient space to enable track maintenance equipment to operate efficiently and building additional track maintenance facilities. Implementing a significant preventative maintenance program can minimize the need for major infrastructure replacement projects or emergency repairs.
- Maintenance Equipment — Another important strategy is to build maintenance equipment that minimizes capacity impacts on the system. For example, on the Northeast Corridor, Amtrak has maintenance equipment that can travel to worksites under the same operating rules as freight trains and can be set up or taken down quickly to minimize its impact on capacity.

Maintenance Staff working on catenary system

- Operations—Maintenance staff must be well trained to maximize their efficiency and to remain safe while working in the high-speed rail environment.
- Rolling Stock—Rolling stock from all operators sharing the HSR line must be well maintained. Improperly maintained trains can have a disproportionate effect on track quality, compounding operating costs and problems

6.2.1 *Maintenance Plan*

Maintenance planning could have technical-operational challenges between daily operation and maintenance activities:

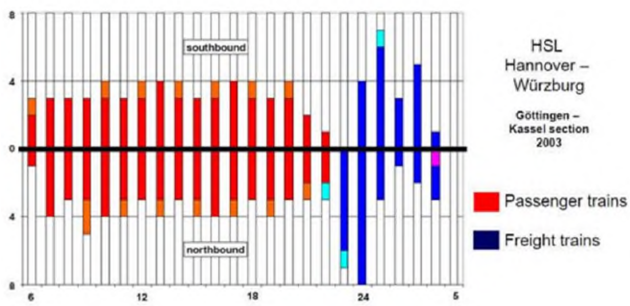
- Capacity and track possession. In fact capacity shortage and track possession for maintenance activities is the main challenge between daily operational activities and maintenance concerns. The impact of maintenance on capacity is especially critical in shared-use HSR systems because a key shared-use strategy is to operate freight trains at night when high speed trains are not running. Unfortunately, most track maintenance is done at night, which creates a conflict between freight movements and maintenance (please refer to section maintenance windows)
- Safety concerns. Safety-maintenance major interaction is related to the safety problems which might be occurred through maintenance activities not only for maintenance workers and gangs but also for other trains and rolling stocks who pass through the same line or adjacent line with normal or even restricted speed. Because of this fact that during maintenance and renewal tasks, one or some failures have been occurred, the level of safety is decreased in comparison to the ordinary operation time, especially when some signalling or communication failures have been happened.
- Train scheduling interruption. The priorities between trains are more complicated and changing the schedule because of some predicted or unpredicted maintenance practices can be more challengeable.
- Allocation and availability. Thus, availability of gangs and machines to be assigned for all the maintenance demand that are announced by network operator is another major challenge between maintenance planners and rail service providers.

The planning problem applies to organisations that are responsible for coordinating railway traffic and network maintenance, such as infrastructure managers, transport administrators or railway companies that own and operate the infrastructure network. The planning horizons of train services and maintenance tasks can differ substantially, which—depending on the planning procedure—may favour early applicants and leave costly or even insufficient track access possibilities for other actors.

6.2.1.1 Maintenance Windows

The maintenance windows are times when segments of the track network are set aside for maintenance and repairs. Including regular maintenance windows in the operating plan for the shared-use sections of track improves the system's reliability and efficiency. One reason for the high efficiency of dedicated high-speed rail systems (and shared-use systems with significant shares of dedicated line) is that they have long track availability windows during the night when high-speed trains are not operating, during which infrastructure can be maintained and improved.

The impact of maintenance on capacity is especially critical in shared-use HSR systems because a key shared use strategy is to operate freight trains at night when high-speed trains are not running.



Train Distribution on the Hannover-Würzburg Line (Section: Göttingen-Kassel)

It can be seen that the maintenance window for this line is only two hours (from 4 to 5 and 5 to 6 a.m.)

Unfortunately, most track maintenance is done at night, which creates a conflict between freight movements and maintenance. If freight trains cannot be restricted to night operations, additional infrastructure will be needed to provide capacity for operating freight trains during the day. Since freight trains have different operating characteristics from high-speed trains, providing this additional capacity can be expensive.

The maintenance windows will reduce the train scheduling possibilities, the window patterns should be designed such that maintenance activities and train operations are coordinated in a well-balanced manner, which is non-trivial.

Maintenance activities

6.2.1.2 Conclusions

Maintenance planning and especially preventive maintenance scheduling is an important criteria through decision making process whether a given HSR line should be constructed as a dedicated HSR pattern or it can be operated as mixed HSR traffic regime. This evaluation is more demanded especially when there is an opportunity to upgrade an existing conventional line for HSR traffic in future.

- Mixed traffic could reduce the time available for maintenance
  - Require deep coordination between infrastructure managers and Operators
  - Effects on maintenance windows if freight traffic occurs during nights
    - Reduction on time
    - Increase safety requirements if traffic is available
  - Possible solutions: Increase the number of real-time sensors to monitor the condition of infrastructure and rolling stock to reduce reactive maintenance so it would be possible to allocate more time at night for freight services

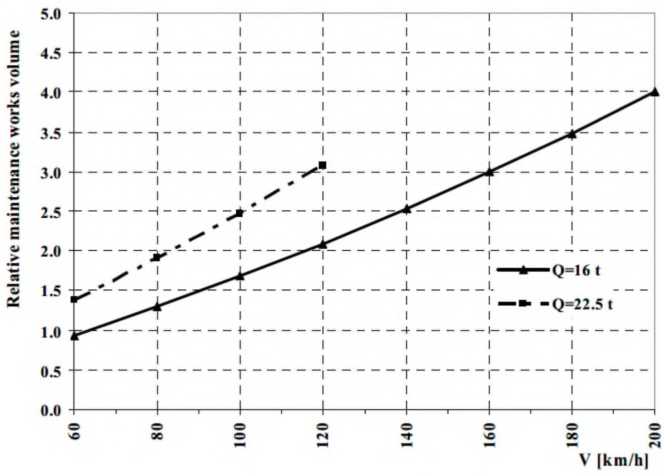
As a conclusion, using an integrated planning approach (where maintenance windows and trains are jointly planned) instead of a sequential approach (where an existing or new train timetable has precedence over the maintenance windows), could give maintenance cost savings of 11–17%, without incurring any large cost increases for the train traffic.

6.2.2 *Impact of the train speed and maintenance requirements*

Considering two railway tracks with the same daily traffic load, where trains are routing with equal axle load. It can derive the influence on the volume of maintenance works and on relevant cost respectively.

- Increased infrastructure maintenance requirements
  - Freight traffic stands to be dominant part of track deterioration. Track deterioration may increase significantly with increasing axle load and loading gauge, especially in curves negotiated with uncompensated lateral acceleration.
  - The design of track components and therefore track maintenance features/practices for such traffic conditions requires proper understanding of various important track design parameters.
  - Increase on preventive maintenance. For example, grinding, realignments.

For example, an 100 % increase of speed result in an increase greater than 100% of maintenance cost.



Influence of train speed to maintenance work volume (passenger & freight trains)

From the figure above it can be derived the influence of train speed on maintenance work volume for passengers and for freight train.

For example, the maintenance work volume for a passenger dedicated track (Q=16t and V=160km/h) it can be until 50% greater than the maintenance work volume for a freight dedicated track (Q=22.5t and V=80km/h) for the same daily traffic load.

6.3 Implications on service key quality requirements.

The important differential of reliability of high-speed trains with respect to freight trains means that in traffic mixed lines the probability of incidents is significantly higher than that existing in passenger-only lines.

For example, currently, the contractual requirements for high-speed train maintenance in Spain require a minimum of 750 km between incidents. In the case of the most powerful and modern locomotives, this rate is about 200,000 km.

The reliability of high-speed trains is four times higher than that of the best locomotives dedicated to freight transport.

Punctuality in passengers dedicated traffic lines, and in the most favourable operating conditions from the point of view of traffic homogeneity, exceeds 99%. In those lines the quality index perceived by passengers, IQP, reach of 8 points over a maximum of 10. Index obtained from direct surveys periodically carried out on passengers who value the main aspects of the high-speed service and score especially its reliability.

This increased risk of incidentally or disruptions on the service on mixed traffic lines might result in impacts on:

- Reduction in the reliability of the passenger service
- Reduction of speeds and increase of travel times
- Impact to the assessment of the customer experience
- Effects on the operating costs of the service and the income of passenger service

As in other cases, the degree of real impact caused by the reduction in service reliability in mixed traffic lines will depend greatly on the intensity, structure and ordering of traffic on the line, as well as the requirements and reliability controls to impose on the rolling stock of freight trains, locomotives and wagons. All this should be subject to particular consideration and specific assessment in the planning and design process of the specific mixed traffic line.

6.4 Implications on construction costs

Due to its demanding performance parameters, the high-speed rail line infrastructure is quite expensive.

The attached table shows the significant average construction cost per km of groups of high-speed lines representative of this type of infrastructure in Germany and Spain.

As the table below shows, at 2014 base prices, they were higher than 28 m€ the average km of high-speed line in Germany and of 22 m€ in the Spanish case.

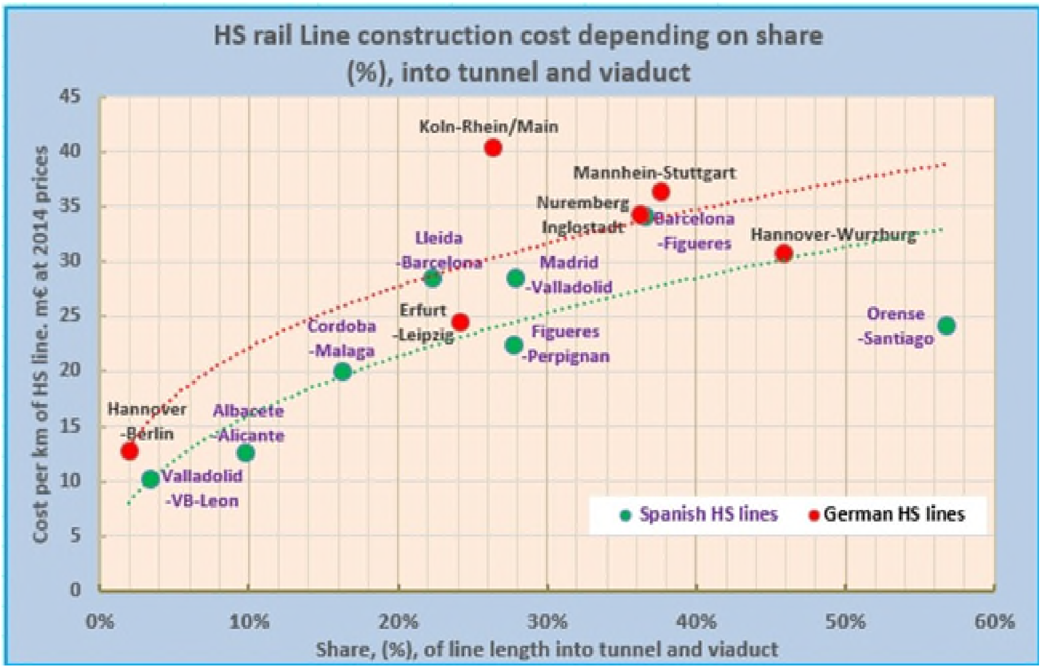
Average cost HSR line		
	DB HS network	Adif HS Network
Number of lines considered	6	8
Total km	1,062	1,107
Share of Tunnels and Viaducts	22.8% and 5.2%	15.1% and 7.2%
Total Capex at 2014 prices	29,802 m€	24,652 m€
Cost per line km at 2014 prices	28.06 m€	22.26 m€

On average, the cost of a high-speed line is around 4 times higher than that of a conventional line for maximum speeds of up to 200 km / h.

Nevertheless, these average costs resulting from the high-speed lines considered, vary considerably from one line to another depending basically on the type of area through which the line runs. They are especially the topographic difficulties of the terrain, the proportion of its route through consolidated urban areas and in some cases the need to building new stations, the aspects that mainly affect the cost of high-speed lines.

As a consequence of this diversity of situations the average construction cost ratio can exceed the 5 to 1 proportion between extreme conditions of degree of difficulty of the territorial insertion of the line layout of a new high-speed line.

In the graph below, the individualized cost of each one of the lines considered in the previous table has been represented. In it, it is possible to observe the significant cost variation depending on the need to build major civil works, tunnels and viaducts, that is, costs increasing notably according to the degree of difficulty of territorial insertion of the line layout.



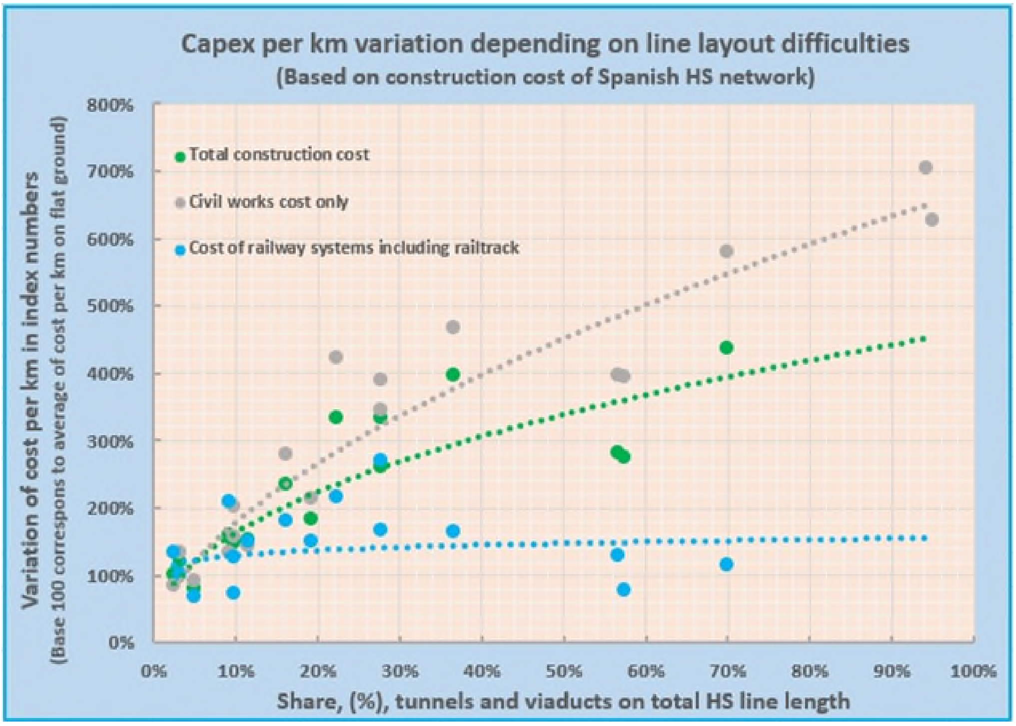
HS rail construction cost depending on share (%), into tunnel and viaduct

Naturally, as the following graph shows, the significant increase of the construction costs comes basically from the civil works component, due to the greater need for the construction of more and longer tunnels and / or viaducts as the difficulties of inserting the line into the territory increase, which is what happens when the line has to cross very mountainous areas or densely populated urban areas.

In Madrid, for example, a new 7.3 km urban tunnel for the north-south connection of the high-speed rail network is in the commissioning phase. This new urban tunnel for high speed, has had a total cost of 45 m€ per line km, without considering the underground station that will be located in the basement of the current high-speed station of Madrid Atocha.

This figure of 45m per km, fits with what would result when considering in the previous graph a line with 100% of its route in a tunnel, because according to the graph its cost would be almost 5 times greater than a line running over flat ground.

That is to say that approximately, the cost of inserting a line in a consolidated urban area is equivalent to that of a line crossing the hilliest area.



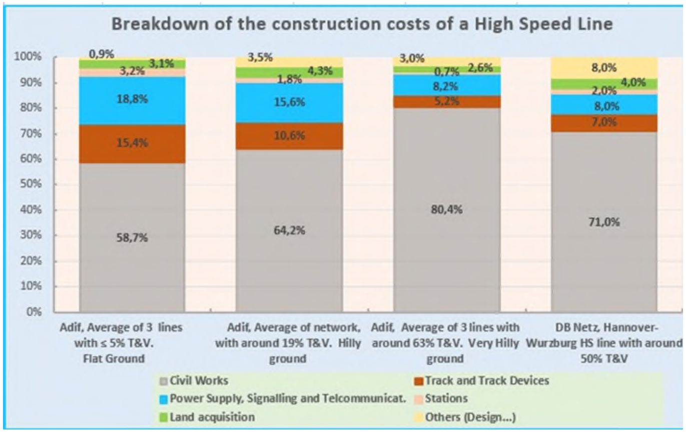
Cost per km variation depending on line layout difficulties

It is observed that is the civil works cost component of HS line, what is the extremely sensitive to the difficulties of the terrain. The cost per km of the civil works, - earthworks + tunnels+ viaducts-, in the most hilly sections, in which is can be reached an almost absolute need for tunnel and viaduct line layout, may be up to 6 times higher than the same type of cost corresponding to a line section constructed onto a flat ground.

For this reason, the cost significance of the civil works component in a high-speed line varies markedly from one line to another. The following table and the corresponding graph show the cost breakdown according to the subsystems in different high-speed lines and depending on the topographic difficulties for which the line layout runs.

Construction costs breakdown of HSR lines depending on share,(%), of tunnels and viaducts in total length

	HS lines and Share, %, tunnel and Viaducts	ADIF HS Network (Average of 3 lines) ≤ 5% Flat ground	ADIF HS Network (Average of Network) Around 19% Hilly ground	ADIF HS Network (Average of 3 lines) Around 64% Very Hilly ground	Hannover-Wurzburg HS line Around 50%
Construction Costs Breakdown by High Speed line component	Civil Works	58.7%	64.2%	80.4%	71.0%
	Track and Track Devices	15.4%	10.6%	5.2%	7.0%
	Power Supply, Signalling and Telcommunicat.	18.8%	15.6%	8.2%	8.0%
	Stations	3.2%	1.8%	0.7%	2.0%
	Land acquisition	3.1%	4.3%	2.6%	4.0%
	Others (Design...)	0.9%	3.5%	3.0%	8.0%
Cost per Km of HS line. m€		8.82	16.31	29.55	28.27



It can be seen how in the sections with the greatest topographic difficulties, the civil works component of the construction of a high-speed line represents more than 80% of the total cost.

These important costs that the construction of a new high-speed line already has, can be seen significantly increased when it is considered, whatever purpose be, that their mode of operation must be as a mixed-use HS line, where both passenger and freight trains can run.

In this case of mixed operation, other things being equal, the impact in costs caused by the construction of a high-speed mixed traffic line, will largely depend on the type of route through it will lay down, mainly depending on topographical difficulties or land uses, but also by the needs of specific facilities and systems to facilitate and ensure the freight traffic integration in the operation of the line.

For the same maximum design speed, mixed traffic lines require more "generous" line layout parameters than those that would correspond if it were a dedicated passenger traffic line,

The economic impact of this specific alignment requirement will again depend on the topography and territorial planning throughout the line runs, urban or rural areas.

The more topographic difficulties or urban crossing the greater needs of civil works will require the alignment layout of the mixed lines and consequently greater increase in the cost of the line, as can be seen in the above graphs, which show how construction costs notably varies depending on the proportion of the line length onto tunnels and viaducts.

The possible infrastructure extra costs caused by the mixed traffic lines in Europe, will basically come from:

- Increase of distance between track centres due to crossings trains with different aerodynamic profile.
- Almost double the maximum length of trains running on the line, up to 750 m vs 400m.
- Greater minimum radius in horizontal curves and limitations in the maximum gradients, which implies greater lengths of civil works, tunnels and viaducts, in overcoming geographical barriers or urban crossings. Specific structural design and particular equipment
- Increased the number of tracks banalization facilities, crossovers, throughout the line
- More and longer sidings throughout the line
- Possible need for reinforcement the track side safety and security systems to monitoring on real time of line traffic.

The greater distance between track centres of the mixed lines results in a wider cross-section with the consequent extra constructive costs, which will be especially noticeable in the tunnels and viaducts that may exist in the route.

The Infrastructure TSI sets up minimum values of this parameter according to maximum speeds and type of section. Being that the mixed traffic to equality of Vmax of passenger trains can increase the size of this parameter about 20%.

The economic impact of this oversizing will be highly dependent on the orography and planning of the territory through where the line runs.

The largest minimum horizontal radius is based on the operation of freight trains that does not allow setting up the maximum admitted cant of 180 mm when only passenger trains run on the line.

The movement of freight trains reduces the maximum design cant to values below 150 mm, which implies to increase the radius of the curve to maintain uncompensated centrifugal acceleration in the comfort zone for passengers, - 0.65 m / sec2- .

The oversize of the radius of the horizontal curves caused by freight trains with Vmax between 100 to 120 km/h is of the order of 12%. Also, in this case its economic impact on investment depends on the topography and territorial planning where the line runs.

Freight trains are not only slower but also heavier than passenger trains, so to ensure their performance in continuous regime, freight trains require the line to have quite lower maximum gradients than the lines dedicated to passenger traffic. In this case, standard maximum ramps up to 35 mm/m are allowed, however, in mixed lines, they should approach 12.5‰.

Specific structural solutions, oversize in certain sections or additional equipment may be designed based on the mixed traffic line, for example in tunnels, freight trains and in particular dangerous goods. They can impose twin tunnels solutions to enable the accommodation of segregated drainage systems for normal leaks and for possible spills of transported goods.

The needs of greater needs of being able to operate in both directions in each track, and number of sidings, will basically depend on the intensity of traffic of the line. In this sense, it is hardly recommended that a mixed traffic line should have a siding facility, at least, spaced every 40 to 50 km along the line.

It seems that mixed traffic does not increase the investment needs in trackside equipment for the control of traffic safety, but what is necessary in some of them, for example, those dedicated to dynamic control of the passage of trains, or those required by the traffic of dangerous goods, that certainly demand greater attention due to the traffic of freight trains.

All in all, it can be concluded that the main causes of the increase in construction costs of the Mixed Traffic HS lines come from:

- Additional investment caused by limitation of maximum gradient on vertical alignment design of the mixed traffic high speed line.
- Additional investment added for facilities such as connection links with existing network, crossovers, passing loops, sidings, specifically required by freight trains operation on the high-speed line.
- Additional investments required by the freight train traffic to provide the line with facilities that guarantee its RAMS levels, specific detectors for centralized and continuous verification of the quality of the train's rolling, such as: Vertical Impact Detectors, Dragging Objects and Derail Axles Detectors and Pantograph Behaviour Detector, fundamentally.
- Additional investment in shunting yards located near the junction points where freight trains enter and / or exit the high-speed line.

The few cases for which information on the impact on the cost of construction of the mixed lines could be contacted, see section 3.2 of the document, have concluded that depending basically on the difficulties of the terrain through which the route of the line runs, a high-speed mixed traffic line may present higher construction costs that can even reach 40% in the sections with more difficult terrain, than a passenger dedicated line with the same performance parameters. Notwithstanding the foregoing, the most accurate determination of the impact on construction costs according to the mode of operation of the high-speed line, mixed or dedicated, must be evaluated individually for each project in the decision-making process prior to development of the new high speed line programme.

6.5 Implications on maintenance and operation costs

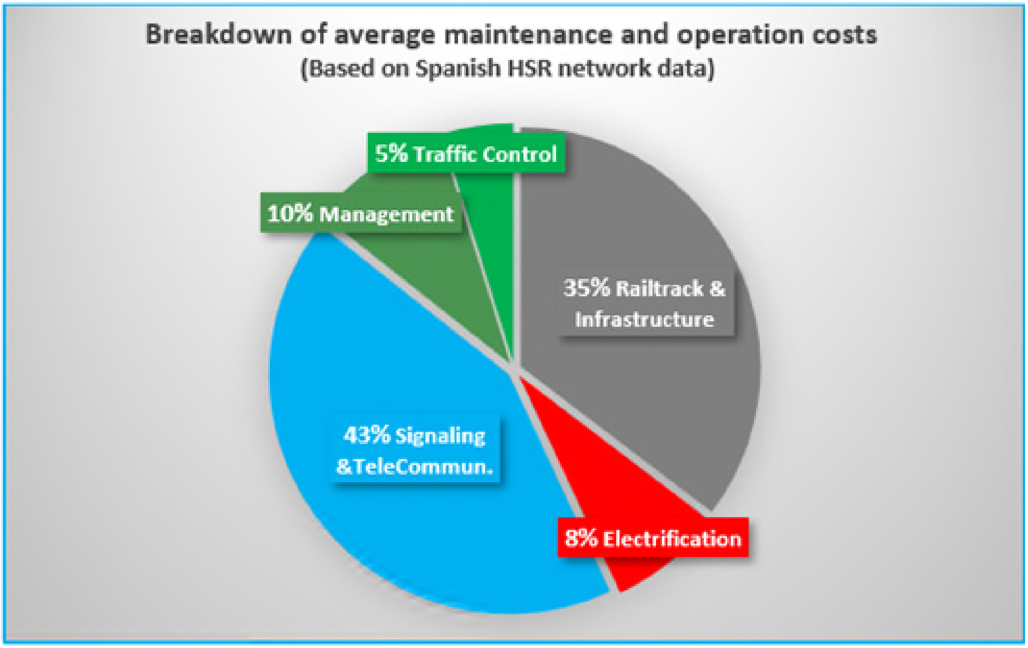
The essential function of maintenance is none other than ensuring that the performance and quality of service parameters of all the subsystems that make up the high-speed line remain at the highest level throughout their useful life.

This gives rise to variable expenses will depend, among other factors, on the amount and type of traffic that the line supports.

Given the high performance of these infrastructures and the high-quality requirements necessary to guarantee them, these operating costs for high-speed lines are of a significant amount.

For example, in the entire high-speed network currently operated by ADIF, the Spanish railway Infrastructure Manager, the operation cost, - OPEX-, of that network, which includes all maintenance activities plus its management and also traffic control, is around 1.75% to 2% of the whole capital expenses, -investments -, subject to depreciation, which is equivalent to an average operation cost of 115.000 euros per km of line and year.

The following graph represents a structure of the average of the operation cost of a high-speed line.



Breakdown of average maintenance and operation costs

It is observed that the highest maintenance expense on high-speed lines is located in the maintenance of all the installations devoted to providing the signalling, traffic control and telecommunications subsystems, half of the total expenses if line traffic control costs are excluded.

The infrastructure subsystem, basically the rail track and track devices, consumes 40% of the total maintenance costs and power supply represents the 10% left.

The increase of maintenance cost of a high-speed line caused by mixed traffic, it must be logically the consequence of the increased use of the line by an additional traffic of trains that are not only slower but also heavier and with higher axle loads than trains of passenger.

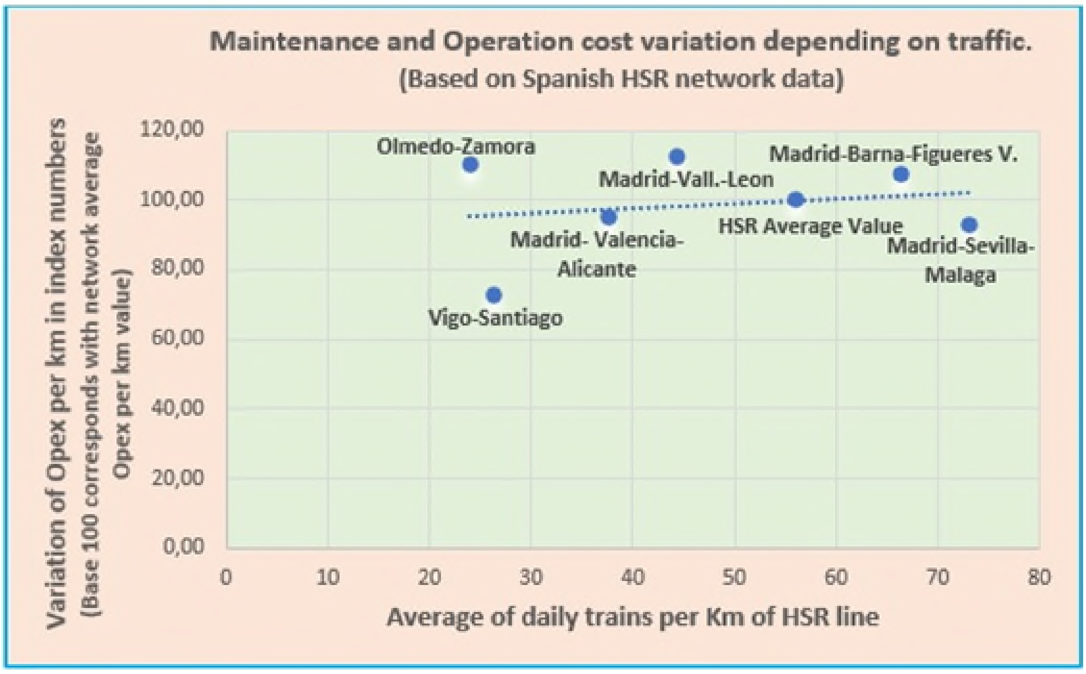
Thus, the expected impact in maintainability of a HS line caused by mixed traffic should come from:

- Increase of gross load running along the track, measured in gross tons hauled over a certain period of time. Incremental traffic that could accelerate the degradation of the geometric quality of the track required by passenger HS trains and consequently, shorten the immediate action intervals to correct possible defects in the track geometry that exceed the limits required by high-speed lines.
- Higher maximum axle load, 22.5 in Europe (more than 25-30 ton in American lines), compared to 17 t that at most the high-speed passengers' trains have. This could lead to more punctual wear on the track, but in general limited to a greater degradation of the track in curves with the strictest radius, that is, for example, in horizontal curves where the maximum excess and insufficiency of cant coincide.
- Greater risk of trains running on the line, freight trains, having less control over their rolling components than high-speed passenger trains do. Important defects may appear on the track caused by the rolling of some "flat wheel".
- In components other than the plain track, mixed traffic could also cause greater maintenance needs due to the greater use of track devices, specifically, the line switches and crossings. Circumstance whose intensity will depend on the operating conditions of the line, that is, the greater or lesser need for overtaking of slow trains by the fastest.

Notwithstanding the foregoing, it is not verified that freight trains, which although they have quite higher axle loads, run at a lower speed and also less frequently, cause more damage to the track than passenger trains that, even though they have less axle load, run however, much faster and more frequently, therefore, in practice, for the purpose of impact on maintenance, only the increase in gross weight hauled per track and time period, (Δ of gross tons/time transported per track), should be considered.

Even so, and in practice, the possible cost overruns caused by the increase of weight on the track that comes from freight trains, could be not truly relevant at all, as the graph that appears below indicates and which represented how the maintenance cost vary according to the traffic intensity, traffic measured in this case in number of passenger trains running on the line.

Indeed, the graph below, which again refers to the case of the Spanish high-speed network, indicates a low correlation between traffic intensity and maintenance expenditure, or, if anything, an elasticity of hardly 0.13 between line traffic and maintenance expenses.



Maintenance & Operation cost variation depending on traffic

That is, it seems that in HS lines there is an extremely high fixed maintenance cost regardless of the volume of traffic.

The breakdown of maintenance costs presented above already indicated something about it, revealing that most of the maintenance costs of a high-speed line, 60%, come from the maintenance of subsystems least affected by the volume of traffic, especially when this is measured in weight hauled along the line.

Besides, this will surely also due to the fact that the high-speed track has a resilient design that is determined by its ability to withstand the dynamic stresses caused by high speed, which results in a structural track design sufficient to compensate for the stresses caused for possible increase of traffic such as those provided by the freight trains in the case of mixed lines.

In conclusion, it seems that under normal conditions of circulation of freight trains in Europe (where the difference between passenger and freight axle load is not great), the additional weight to the track generated by mixed traffic does not translate into a relevant increase in line maintenance costs.

As a conclusion, according to the information available, mixed high-speed lines do not generate substantial additional maintenance costs (only on operating costs due to traffic control and safety), when freight trains running at night-time. The low impact on maintenance costs is influenced by the fact that in known practice there is agreement that:

- Maintenance and track renewal and reprofiling is more predictive based in HS rather than corrective.
- Ensuring high speed of passenger trains, Vmax > 250 km/h, requires the maintenance of high and very strict parameters of track geometry, that is, very short inspection intervals.
- Commonly on existing high-speed lines with mixed traffic, freight traffic is basically carried out on types of trains: in which the axle load does not exceed 22.5 tons.

However, each and every one of these factors will acquire their greatest incidence in the additional cost of maintenance caused by mixed traffic, when the circumstance of a dynamic bad behaviour of the freight trains rolling might occurs, for example due to the existence of "flat wheels" in one of their wagons. This fact does have a great influence on the degradation of the track and, consequently, on the sensitive increase in the cost of maintaining the line.

The circulation of freight trains with flat wheels causes significant damages to the quality of the track and therefore considerably reduces the performance of the line, since, for safety, traffic constraints must be applied until damages have been repaired.

Consequently, mixed traffic increases the risk that trains with "flat wheels" may circulate on the HS line, which has a double negative effect, reduces the quality of the service offered and affects the maintainability of the line by increasing its maintenance costs.

Wheel flats

To mitigate this security risk and preserve the maintainability of the line, the installation of "*Vertical Impact Detectors*", VID, is recommended, being settled in sections of the track, immediately after the points where freight trains come into the HS Line and controlled from the Traffic Control Centre.

The last aspect indicated as a possible impact of mixed traffic on the maintainability of the high-speed line, refers to the need for frequent use of switches and crossings, when passenger and freight trains coincide at the same time periods and the conditions of line operation, traffic intensity, length etc., so require.

This impact is not so much due to damage that freight trains could cause on this track devices, but due to the fact that its frequent use increase the falls of these track devices, mainly its self-checking system, which affects to signalling system of the line and finally causes important disturbances to the normal traffic development along the line.

In this regard, it is important to underline that even on high-speed lines dedicated to passengers, more than 25% of incidences causing delays to trains come from failures in switches and crossings, so the much more frequent use of these devices required by the integration of freight trains in the same hourly mesh, would undoubtedly translate into an increase of these kind of incidences and greater traffic disturbances.

To avoid or mitigate the risk of greater traffic disturbances due to the greater need of use of the track devices required by the mixed lines, there are two possibilities:

- Strengthen the quick maintenance response capacity, acting immediately to resolve this type of incident, that is, increase its cost permanently by having to deploy specialized personnel, in standby, close where switches and crossings are located.
- Segregate passenger and freight trains path in different time periods, in this way it will not be necessary to program the overtaking of slower trains by the faster trains.

On lines with high or very high traffic density and long routes, the option of segregation in different periods of time for passenger and freight traffic is the most recommended.

In the traffic segregation option, and in the case of lines with high traffic density and of long length, segregation will result in passenger traffic during the day and freight traffic at nighttime, so the effect on maintenance will lead to the need to carry it out on one track while the adjacent track will remain open for freight trains traffic.

Then the impact of mixed traffic on lines in which the operation is performed in a segregated day / night manner, will translate into an increase in the maintenance cost from the expenses necessary to guarantee the safety of all maintenance works with freight train traffic in the adjacent track, whose maximum speed will necessarily be limited to 160km/h, as well as the need to establish a highly coordinated maintenance programme.

- It does not seem that the additional weight per track caused by freight train traffic generates significant maintenance extra-costs, that is, mixed traffic does not require shorter intervention intervals than those programmed to maintain the geometric quality of track and safety parameters required by high-speed lines dedicated to passenger traffic.

A summary of examples of tables with inspection frequencies in high-speed lines is shown in the accompanying diagram below, taken from the UIC study "Railway Application- High Speed-Maintenance of High-Speed Lines. IRS 60662: 2019". As can be seen, the maintenance intervention needs depend on the type of line according to UIC classification, mainly depending on the line performance parameters, but not so much on the type and proportion of traffics.

Examples of tables with inspection frequencies on High Speed Lines

In relation to UIC Line categories according to UIC leaflet 714 (not only for High Speed Lines)

Inspection and verification List during normal commercial operation mode

Type of inspection	Object of inspection	Interval		
		UIC 1 and 2	UIC 3 and 4	UIC 5 and 6
Inspection of turns	Running track and OCL on foot	2 months	2 months	2 months
	Running track in front or rear cabin	2 weeks	2 weeks	3 weeks
	Switches and crossings	5 weeks	5 weeks	6 weeks
	OCL in front or rear cabin	6 months	6 months	8 months
	Line sides	5 weeks	5 weeks	5 weeks
Recordings of - Track - OCL system	Track level and alignment faults, including long waves: - conventional recording car • ballasted track • slab track - vertical and lateral accelerations (axle boxes and body)	 2 months 3 months 1 week	 3 months 4 months 2 weeks	 4 months 6 months 3 weeks
	Geometry of the OCL	6 months	6 months	8 months
	Wear on the contact wire	1 year	2 years	3 years
	Ultrasonic testing	See details in table	up right	
	Corrugation testing*	1 year	2 years	3 years
	Recording of the ballast profile	1 year	1 year	1 year

Recommended frequencies for Ultrasonic inspection

Ultrasonic inspection with heavy equipment	UIC Category		
	1 & 2	3 & 4	5 & 6
Before commencement of operations	Once	Once	Once
Cumulative load carried < 200 million tonnes	Once per year	Once per year	Once per year
Cumulative load carried > 200 million tons and <400 million tonnes	Twice per year	Once per year	Once per year
Cumulative load carried > = 400 million tonnes	Three times per year	Twice per year	Once per year

Recommended frequencies for detailed inspection of switches and crossings

Type of inspection	Age of the switch	UIC Category		
		1 & 2	3 & 4	5 & 6
Detailed inspection	< 3 years	Once in the period	Once in the period	Once in the period
	> 3 years < = 6 years	Twice in the period	Once in the period	Once in the period
	> 6 years	1 year	1 year	1 year
Visual safety check	< 6 years	1 year	1 year	1 year
	> 6 years	6 months	1 year	1 year
Inspection of safety-critical dimensions	< 6 years	3 months	6 months	1 year
	> 6 years	2 months	4 months	6 months

Source UIC: Railway Application - High Speed - Maintenance of High Speed Lines IRS 60662

- Only in some points of the track where the greatest stress is concentrated, for example, in the zones with strictest radius with maximum values of excess and insufficient cant, and more rail wear and ballast deterioration occur, a somewhat higher frequency of the replacement cycle of these elements will be necessary at these points.
- To avoid major damage to the track and consequent extra maintenance costs that could cause for running "flat wheels", it is highly required to install Vertical Impact and loading unbalanced Detectors with centralized control, at the points on the line through which the freight trains enter on it.
- In lines of high intensity of passenger traffic and enough length, the segregated operation scheme, passenger trains in daytime and freight in nighttime is the most convenient, consequently, freight trains shares the use of the line with maintenance works, for which these should be very well scheduled, highly efficient and adequately protected from slow trains running on the adjacent track.
- This simultaneity of maintenance with traffic generates at least extra costs derived from specific maintenance work safety measures.

- However, given that in high speed lines it is usual for the supply voltage to be 25kV, which induces a high risk of high voltage arcs when there are works on the adjacent track, it is quite recommended that the maintenance works to be carried out with a total cut of tension in the line, due to safety reasons, with what the possible traffic on the adjacent track on working site, can only be of diesel trains.
- There should be hourly segregation between freight traffic and maintenance works at night, which limits the maintenance window to 2 hours at night on weekdays and up to 4 hours on weekend nights, when freight traffic is significantly reduced.
- Additional equipment could be needed for achieve maintenance during maintenance windows.
- Due to this, in the high speed mixed lines with high traffic intensity and therefore with freight traffic night operation, maintenance equipment and high productivity work procedures are required as well as extraordinary coordination on programming the maintenance works of the different subsystems of the line.

The effective impact of each of these additional maintenance efforts, measured for example in economic terms, should be evaluated for each new line studied based on known and certainly comparable experiences.

In summary, it can be concluded that mixed traffic on high-speed lines does not in practice generate additional maintenance costs, only on operating costs, those of traffic control and safety, when freight trains running at nighttime.

The high quality and safety requirements imposed by the maximum speeds of passenger trains on the structural components of the line; line layout, track parameters, switches and crossings, track resistance, overhead contact line, ..., together with the strict immediate action limits in the event of defects imposed by high speed in each of those components of the line, is what truly determines the cost of line maintenance, regardless of whether it is dedicated or mixed traffic line.

Thus, the fundamental thing so that freight traffic does not increase maintenance costs on high-speed lines is that the following requirements are met:

- Find and set the most suitable balance point between the deficiency and excess cant for each specific route. Avoiding untimely wear on small curves.
- limit and ensure the maximum axle load of freight trains in 22.5 tons, and the mass per unit length less than or equal to 8.0 ton/m Ensuring track and structures resistance to traffic loads during its complete life cycle.
- Ensure the homogeneous distribution of the load throughout the train and its fastening. Avoiding unbalanced loads and load shifts.
- Require and verify compliance with the Maintenance Plan for rolling stock of freight trains, locos and wagons.

- Provision along the line of centralized detectors, in the Central Control Centre, which control the dynamic behaviour of the train's rolling and pantograph. Specifically, Vertical Impact Detectors, Dragged Objects Detector and Pantograph Lift Detector. Avoiding infrastructure damages and traffic disruptions.

6.6 Main benefits by the mixed lines. Expected KPIs

The selection and decision between a dedicated high-speed system, and a shared-use high-speed line system, (Mixed Traffic HS), is the fundamental question ever since the preliminary phase in planning and designing of a new High-Speed program.

Potential lines advantages that can provide freight traffic on high-speed lines should be taken into consideration with the appropriate evaluation of the possibilities and convenience of its implementation.

The main expected advantages of a mixed traffic line with regards a dedicate passenger line with identical Vmax are as follows:

- Decongestion of saturated lines or sections of the pre-existing rail network and enhancement of overall capacity for the rail system
- Improve the cost-benefit ratio of the high-speed line depending on the balance of new income contributed and the additional costs incurred
- Improved competitiveness of freight transport by rail and opening up to new higher value markets
- Reduction of the environmental impact of global freight transport due to the shift of freight traffic from the road

The effect of these positive impacts of a mixed traffic line should be evaluated based on known experiences.

Once each of the possible negative and positive **expected impacts of the implementation of mixed** traffic has been established and evaluated, a dashboard mode is established a set of character indicators:

- Technical
- Functional
- Quality of service
- Economic balance

Which will serve as a guideline to determine the opportunity and convenience of implementing a mixed traffic line or not.

7 CONCLUSIONS

Mixed traffic lines implementation can directly contribute to the decongestion of network sections, bottlenecks where there are saturation problems.

Throughout this handbook it has been described the main conclusions that have been drawn for decision making and implementation of mixed traffic lines.

The different features of passenger and freight trains have a significant influence on the design, construction, operation and maintenance of a railway system.

Mixed networks satisfy primarily passenger transportation. So the features of passenger trains predominate on the constituents of a railway system and in extend on the construction cost of a railway project. On the other hand, the increasing needs for freight transport can lead to the saturation of the capacity of the mixed traffic high speed lines, limiting the growth of passenger demand, actually main support of its justification and sustainability.

Mixed traffic will impact on:

- Infrastructure basic parameters
- Operation restrictions
- Reliability & quality
- Construction cost
- O&M cost

Emphasizing that the practical development of whatever be the main motivation generating a high-speed project must be carried out by applying the proven but more advanced railway technologies, in order to provide truly competitive transport solutions. The following sections summarize are the main conclusions of this document.

7.1 Related to planning and decision making aspects

It is highly advisable to take advantage of the construction of a new high-speed line not only to improve the competitiveness of rail in intercity passenger mobility, but also that of all rail transport present in the corridor.

In this respect, adopting a global vision with a very long-term perspective is essential in the planning and design phases of the structural characteristics of the new railway infrastructure to be developed.

Although currently high-speed rail infrastructure is mostly dedicated to passenger service, the truth is that in the European high-speed network, where the maximum speed of the lines is equal to or greater than 250km/h, around 15% of this network are lines sharing use both passenger and freight trains.

A new high-speed line designed and built as a mixed line, that is for shared use by both passenger and freight trains, will always have the possibility of being used as an exclusive passenger dedicated line, this is as a high-speed line only used by passenger trains with Vmax of at least 250km/h.

This was the case for example with the first Spanish high-speed line, Madrid-Seville, and also with the Italian Direttisima line, Rome-Firenze, both of which were originally conceived for mixed traffic, but in practice have always been used as dedicated high speed passenger lines.

Conversion that also makes it possible to increase the maximum speed of faster passenger trains, due to the fact that the original design cant may be raised to the maximum design cant limit admissible for passenger traffic, 180 mm, as the limitation imposed on the cant excess by the heavier and slower trains disappears.

However, the opposite reconversion is not possible, that is, a dedicated high-speed line, one line designed and built to allow only passenger trains to run on it, cannot be used for conventional freight trains, mainly because of the limitations imposed by freight trains on the maximum gradient, about 10 thousandths, but not for passenger trains which can run on gradients of up to 35 thousandths.

Therefore, this conversion from a dedicated line to a mixed line would only be possible by over-dimensioning the original dedicated line, which, except for sections with very easy topography, would lead to construction costs that are much higher than those corresponding to strict dimensioning as a dedicated line. Overcosts that could lead to the unsustainability of the original dedicated line.

Initially, the first mixed lines only scheduled freight trains at night, case of the first German high-speed lines, but later mixed high-speed lines have been developed with shared use also during daytime hours, as evidenced by the fact that a part of the new high-speed lines lately commissioning or under development in Europe, have been performed with design parameters of mixed high-speed lines.

This situation proves that the coexistence of passenger and freight trains is technologically and functionally compatible on high-speed lines and that the respective service objectives are also reconcilable in a share use operation of passenger and freight trains.
The motivations for the development of mixed high-speed lines have been of a diverse nature, each one having more or less influence on decision-making depending on the case of the line. Basically, the motivations that have supported the decision to develop mixed traffic high-speed lines can be specified in the following:

- Apply a transport policy aimed at reversing the sustained loss of competitiveness of rail transport in interurban corridors with the highest concentration of population and activity, - in the distance range of 150 to 800 km -, through the development of a high-speed rail line, in which the contribution of freight transport can improve the cost-benefit ratio of the line compared to the results achievable with passenger transport only.

- Need to solve endemic saturation problems in main sections of the railway network that impede the growth of railway traffic, through the application of up-to-date technological solutions in the programming of a new section or railway line.
- Convenience to solve structural deficiencies in connectivity, "lost links", within the existing rail network or between different neighbouring networks, overcoming barriers that impede the continuity of rail transport to link high mobility markets.

In the chapter related to inconvenience associated with the share use of a high-speed line, the main issues to consider in the decision-making process are basically those of an economic nature and those of an operational nature.

- Economically, due to the fact that the operation of freight trains requires more “generous” design parameters of the line, - curves of greater radius, lower gradients, as well as the need to incorporate specific facilities imposed by freight train traffic, - more and longer sidings, sections of connection with the conventional network, specific safety and security detectors -. Which logically leads to additional investment costs for the same Vmax of the line, being logically very noticeable, up to 40%, in very hilly and urban areas. However, it does not appear from known practice that freight traffic increase line maintenance costs.
- Regarding operational terms, due firstly to the higher occupancy of line capacity that freight trains need as they are notably slower, and therefore, reduce the frequency ceiling of passenger services. But also, and without being less important, due to the need to establish specific operating conditions for the line to ensure its quality of exploitation in RAMS terms at levels comparable to the case that the line was dedicated.

In return, mixed traffic high-speed lines offer advantages that are highlighted below:

- Its contribution to improving the economic sustainability of those lines that exclusively dedicated to passenger services will not meet the required business/results expectations.
- The stamp of quality that they transfer to the rail transport of goods, with the consequent effect on the improvement of the capture of traffic and the market share of the railway.
- Its best and most direct contribution to solving saturation problems in critical sections of the existing network or with structural dysfunctions that penalize the development of rail transport, both for passengers and freight market.
- Contribution to the improvement of the environmental performance of the global mobility of the transport market served by the mixed traffic line, due to the diversion of traffic from modes of transport with worse environmental performance than the railroad.
- Enhance capacity for the entire rail network and eliminate bottlenecks.
- Improve the efficiency of high-speed lines, taking advantage of the use of its capacity available.
- Contribution to improve the cost-benefit ratio of high-speed lines.
- Improving the competitiveness of rail freight transport.

In many cases the capacity release brought about by the diversion of all long-distance traffic to the new high-speed line is not sufficient to solve the problems of saturation of the pre-existing lines, especially in those sections where the lines run through and cross densely populated urban areas.

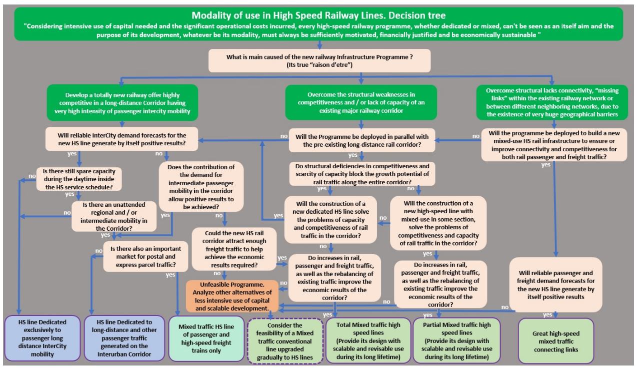
This immediately results in the limitation of the circulation of freight traffic and therefore significantly affects its competitiveness, so where these circumstances exist it seems reasonable to consider design options to solve this problem when planning the new high-speed lines taking into account the following:

- All high-speed lines serve large passenger markets which are composed of heavy flows on a few number of origin-destination (OD) pairs. Generally, these lines link 2 big cities (OD cities) located at their ends. To reduce the travel times, the straightest route will be sought adopting high and very high gradients (up to 4%) to accommodate hilly areas if any, besides Investments will be saved because the route will be shortened and the need for tunnels and viaducts can be significantly reduced.
- Generally, In between these end-of-end cities, the HS lines are parallel to the conventional network which go through several intermediate cities and whenever the HS lines layout are not so far from those intermediate cities, also conventional line by-passes can be created take advantage of the route used for the HS lines, both for interest of shorter travel time of non-stop high speed passenger trains in this intermediate cities, as well for routing freight trains to avoid crossing urban areas. In that by-passes the gradient of the HS lines will have to be softened.
- This means that for short sections, by-passes, the infrastructure to create will be composed of four tracks, two for passengers and two for freight. The economy coming from the high gradients characterising the HS lines on their biggest lengths will help investing in such freight loops.

The freight services will benefit from this new design, avoiding being mixed with local and regional trains without impacting the quality of high-speed services.

Naturally, decision-making in each case must be based on a specific study in which they are evaluated in terms of cost-benefit, these being accounted for in all their socioeconomic and financial dimension, each of the possible exploitation scenarios and consequently configuration of the line and its service. It will be the results of this evaluation that allow to select the option of line to implement as well as the most convenient transport service to offer, either as a dedicated or mixed traffic line.

In order that it can serve as an orientate guide to the decision process, the study has developed and included in its section 3.3 a proposal for a decision tree for the selection of the type of line to be implemented.



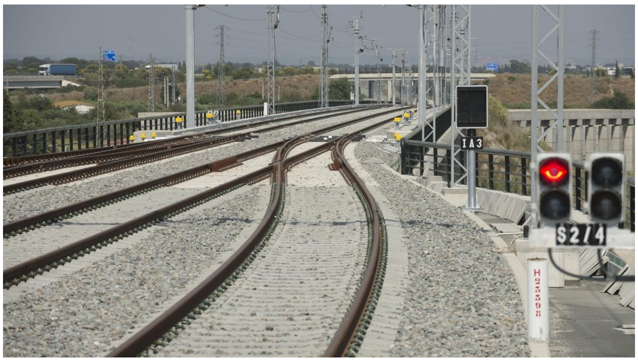
Decision tree for selection of the type of line

Depending on the type of line chosen, the essential performance parameters of the line will be set, basically: its maximum speed, axle load and maximum train length, which will determine the basic structural parameters that characterize the design of the line infrastructure.

7.2 Related to the Infrastructure characterization parameters

As a synthesis of what was analysed in the study and as an abstraction of the most common practices that make the coexistence of passenger and freight traffic on high-speed lines feasible, below is summarized characteristic values proposed for infrastructure parameters directly affected by the design of a high-speed line with a shared use by passenger and freight trains.
Parameters not included in the following list maintains the same values of a dedicated high-speed line, so its inclusion does not apply.

- Line performance.
  - Maximum speed: 250 ≤ Vmax ≤ 300 km / h, the closer to 250 the more feasible will be the mixed line.
  - Minimum speed of slower trains, freight, Vmin≥100 km/h: the higher the more feasible the operation of mixed traffic will be.
  - Maximum axle load. 25 tonnes.
  - Maximum total train length. Passenger 400m, freight 850-1050m, (including traction locomotives).



- Requirements (only those affected by mixed use of the line).
  - (If there is not a pre-established) Structure Gauge. GC as minimum gauge, recommended AF. Kinematic gauge that must be respected corresponds to UIC 505-1 and 506 standards and the Rolling Stock TSI 2002/735/EC. Study the convenience of establishing the freight gauge, according to piggyback transport market expectations on the corridor served.
  - Distance between track centres ≥ 4.7 m.
  - Maximum gradients. Standard 12.5 mm/m, maximum exceptional 18 mm/m, (in short sections and if possible, with sawtooth profile).
  - Minimum radius of horizontal curve, according to the cant limit values and the design speed. For example, for the speed pair (maximum and minimum) of 250 and 100 km / h, the minimum radius would be 3,400m and it would be 5,000m in the case of 300 and 100 km / h, as maximum and minimum speed of the trains that run on the mixed line.
  - Design cant. 110-120 mm, exceptional 140mm.
  - Maximum Cant Deficiency, 100 mm. (due to best passenger comfort, just for safety reasons the limit could be raised up to 150mm).
  - Depending on the volume of freight traffic it is recommended a maximum cant excess could be 80-90 mm to mitigate the damages caused of slow trains loads on the inside rail. EN 13803: limiting value for cant excess is 110 mm

7.3 Related to specific infrastructures/ facilities

The implementation of crossings and sidings along a high speed line is always necessary regardless whether it is a dedicated line or mixed traffic; in the case of mixed traffic, less distance between sidings is required (greater number), and greater length of the stabling tracks.

- Crossover implementation on the line every 10 km approximately.
- Average distance between consecutive siding loops 30 to 50 km.
- Average length of outline of sidings 1.9 to 2.4 km.

The mixed use of a high-speed line will require specific connectivity infrastructures with the conventional freight network, that is, the provision of:

- Connection links and passing loops.
- Conditioning works in shunting yards located near the junction points where freight trains enter and / or exit the high-speed line.

Mixed traffic requires reinforcement and also the incorporation of specific safety and security equipment in the tunnels which, depending on the type of goods accepted (dangerous or not), will basically affect the:

- Sizing of fire-resistance and fire-fighting elements
- Dimensioning of a forced ventilation system
- Evacuation network for possible spills caused by dangerous goods traffic

Mixed traffic increases the needs and number of trackside devices/equipment with a centralized control to guarantee the safety and maintainability of the line, specifically:

- Vertical track impact and unbalanced loads detectors. To be installed as a minimum after each connection of incorporation of the freight trains, it is also recommended that the separation between two consecutives along the line does not exceed 40/50 km.

Lift Pantograph detector

7.4 Related to Operational Restrictions/Conditions and RAMS requirements.

Mixed traffic reduces severely the capacity of high-speed lines by a proportion that, at least, is equivalent to the relationship between the speed of operation of the passenger train and that of the freight train, consequently:

- Limits and complicates the allocation of capacities by increasing the probability of conflicting paths.
- The difficulties of path allocation to freight trains increase with the intensity of passenger traffic and the length of the line.
- Given the greater commercial interest of passenger trains, their circulation will prevail in case of conflict on freight trains.
- The segregated operating model, passenger trains during the day and freight at night, is the most appropriate when passenger demand is high and requires train intervals of less than 30 minutes. In that case full coordination with maintenance works scheduling is essential.
- However, on high traffic intensity lines the shorter the mixed traffic route is, the more possibilities to be able to schedule freight trains into the daytime timetable, through a batch operation model of homogeneous trains with sequential circulation.

On high-speed mixed-traffic lines where freight trains are scheduled to run during daytime, it will be necessary to limit the maximum speed of high-speed trains when crossing, due to the importance of the stress on the structural elements of the wagons, their loading and its fastening elements when the freight trains cross with the high-speed trains.

All the other characteristics of the line being the same, the importance of these structural stress - resulting from the effects of the pressures and suction produced when two trains with very different aerodynamic profiles cross each other - depend essentially, exponentially, on the maximum speed of the high-speed train and the place where the crossing takes place, either in the open air or inside a tunnel.

On the basis of tests carried out under various crossing conditions for freight and high-speed trains, and in accordance with the practices followed by networks operating mixed traffic high-speed lines, due to the aerodynamic phenomena, it is advisable to apply the following operational restrictions for reasons of traffic safety on mixed traffic HS lines with freight trains running on daytime periods:

- Limit the maximum speed of high-speed trains on open air routes to 250 km/h, provided that the distance between track centres is at least 4.7m.
- Limit the maximum speed of high-speed trains to 200 km/h in double-track tunnels whenever there

is a possibility of crossings with freight trains inside the tunnels.

- To guarantee and verify the structural resistance, the integrity and fastening of the load of the wagons admissible for circulation on the mixed traffic high speed lines.
- Logically, on mixed traffic high-speed lines with a segregated operating model, i.e. freight trains only run at night-time, the above maximum speed limitations due to the aerodynamic phenomena of crossing with freight trains do not apply.

Key aerodynamics aspects on mixed traffic lines is as follows:

- The aerodynamics of crossing at open air originates on the freight wagon and its cargo a set of pressure pulses, which translate mainly to lateral forces and bending moments.
- Pressure pulses are moderated (some hundreds of Pa, local and change from overpressure to underpressure in a short time (0.1 to 0.5 seconds). They have to be considered both in structural and dynamic aspects. The case of wagons with fabric covers need further studies and must be considered as a potential problem.
- During crossing in sections at open air with cross wind, the pressure pulses caused by the high-speed train continues acting, but in some way they are less important when wind speed increases. However shadowing effect impact is greater, pressure levels are again of the order of hundreds Pa but they affect greater surfaces (of the order of the passenger train) during a larger time (some seconds).
- Some regions of the cargo can present suction peaks of pressure (per instance at container corners) of the order of one kPa. Both dynamic effects and fabric covers are more critical that in the previous point.
- Crossing effect in viaducts can be considered as a particular case from the previous ones. Particular attention should be paid to the existence of higher wind speeds
- During the crossing inside a tunnel in a mixed traffic line, the already commented effect of the pulse also appears and it seems to be comparable with the existing in the open air. However, pressure waves travelling along the tunnel produce fast over/under pressure changes, or vice versa, that can act during seconds on wagons or cargo. These pressures waves, of the order of some kPa, are expected to have a relatively small impact on lateral forces and moments. However, they can result in a strong effect on compression/tension loads which can produce fatigue in the material, damage in cargo, risk of door opening, necessity of prevision for venting in some containers or goods, etc.

7.5 Effects on the reliability and quality of the line's service

The important differential on reliability of high-speed trains with respect to freight trains means that in mixed traffic lines the probability of traffic disruption is significantly higher than that existing in passenger-only lines. The reliability of high-speed trains is quite higher than that of the best locomotives dedicated to freight transport.

This increased risk of disruptions on the service on mixed traffic lines might result in impacts on:

- Reduction in the reliability of passenger service
- Reduction of speeds and increase of travel times
- Impact on customer experience
- Effects on the operating costs of the service and the income of passenger service

The degree of actual impact caused by the reduction in reliability of service in mixed traffic lines, will depend on the intensity, structure and sequence of traffic on the line, as well as the reliability requirements and controls to be imposed to freight trains, locomotives and wagons on the rolling stock.

All this needs to be subject to consideration and specific valuation in the planning and design process of the mixed HSL.

7.6 Related to construction cost & O&M cost

7.6.1 Construction cost

The costs that have been analysed, vary considerably from one line to another depending basically on the type of area through which the line runs. They are especially the topographic difficulties of the terrain, the proportion of its route through consolidated urban areas and in some cases, the need to build new stations, that is an aspect that affect the cost of high-speed lines.

The most accurate determination of the impact on construction costs according to the mode of operation of the high-speed line, mixed or dedicated, must be evaluated individually for each project in the decision-making process prior to development of the new high speed line programme.

The possible infrastructure extra costs caused by the mixed traffic lines in Europe, will basically come from:

- Increase of track centres distance (> 4.5 – 4.7 m) due to crossings trains with different aerodynamic profile.
- Almost double the maximum length of trains running on the line, up to 750 m vs 400m.
- Greater minimum radius in horizontal curves and limitations in the maximum gradients, which implies greater volumes of civil works, tunnels and viaducts, to overcome geographical barriers or urban crossings. The proportion of V and T and urban renewal works in a line due to geotechnical restrictions to support this gradient is on the side of freight, but in the other hand, the radius increment in passenger services is a cost to be added to the passenger lines.
    - Specific structural design and particular equipment. Whose degree depends essentially on the topographic difficulties of the line layout.
- Increased the number of passing loops, crossovers, throughout the line or including bypass if necessary.
- Additional and longer sidings throughout the line
- Possible need for reinforcement safety and security with trackside systems to monitor on real time the status of the rolling stock.

7.6.2 Operation & Maintenance cost

According to the information available from the study mixed traffic on high-speed lines does not generate additional maintenance costs, only on operating costs, due to traffic control and safety, when freight trains running at nighttime. The low impact on maintenance costs is surely influenced by the fact that in known practice coincides that:

- Ensuring high speed of passenger trains, Vmax > 250 km/h, requires the maintenance of high and very strict parameters of track geometry, that is, very short inspection intervals.
- Commonly on existing high-speed lines with mixed traffic, freight traffic is basically carried out on three types of trains: container *trains*, *manufactured goods* trains, mainly automobiles and their components and express parcel trains, higher value trains and in which the axle load does not exceed 22.5 tn.
- Ensure the homogeneous distribution of the load throughout the train and its fastening. Avoiding unbalanced loads and load shifts.
- Require and verify compliance with the Maintenance Plan for rolling stock of freight trains, locos and wagons.
- Provision along the line of several kind of detectors, in the Central Control Centre, to control dynamic behaviour of the train's rolling equipment and pantograph. Specifically, Vertical Impact Detectors, Dragged Objects Detectors and Pantograph Lift Detector, avoiding infrastructure damages and traffic disruptions.

It can be concluded that mixed traffic on high-speed lines does not generate additional maintenance costs, only on operating costs, due to traffic control and safety, when freight trains running at nighttime.

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- Great sector expert response
  - *VIA OC Kevin Uba,* Michel Leboeuf *and Jeff Moller.*

APPENDIX – QUESTIONNAIRE TO THE UIC MIXED TRAFFIC STUDY

Chapter 1. General information and structural characterization of the High Speed Railway line

Element or Topic	Question	Answer	Explanatory comments (if needed)
1.1 Identification and Characterization data	1.1.1 Name of the Line. Ownership and Management entity		
	1.1.2 Geographical limits & connections (end stations & links)		
	1.1.3 Total Length (km) and Opening date in current situation		
	1.1.4 Are there Intermediate stations and/or freight terminals?		
	1.1.5 Number of tunnels and total line length underground		
	1.1.6 Individual length and type of the longest tunnels		
	1.1.7.Daily average of passenger and freight trains on the line		
	1.1.8 Line Classification according to TSI Code		
1.2 Basic Line Design Parameters	1.2.1 Maximum and Minimum speed of Passenger trains (km/h)		
	1.2.2 Maximum long of Passenger trains. (m)		
	1.2.3 Maximum and Minimum speed of Freight trains (km/h)		
	1.2.4 Maximum long of Freight trains. (m)		
	1.2.5 Maximum axle load and trains weight limits, total & per m		
1.3 Line Layout Parameters	1.3.1 Structure gauge. Loading Gauge		
	1.3.2 Distance between track centres. m		
	1.3.3 Type of tunnels and clear section. m^2		
	1.3.4 Maximum line gradients, $^{0}/_{00}$, and its length		
	1.3.5 Minimum radius of horizontal curve. m		
	1.3.6 Minimum radius of vertical curve. m		
1.4 Relevant Track Parameters	1.4.1 Track Typology and Nominal track gauge. mm		
	1.4.2 Maximum Cant/superelevation. mm		
	1.4.3 Deficiency (PT)/Excess(FT) of Cant. mm		

Chapter 1. General information and structural characterization of the High Speed Railway line

Element or Topic	Question	Answer	Explanatory comments (if needed)
Power and Traction Energy Supply System	1.5.1 Rated voltage and frequency and limits (AC/DC kV & Hz)		
	1.5.2 Contact wire geometry, height & max. lat. deviation (mm)		
	1.5.3 Phase and Systems separation sections provisions, length		
	1.5.4 Does OCL equipment allow regenerative braking?		
	1.5.5 Are there Pantograph Behaviour Detectors?		
	1.5.6 Is there an On-ground Energy Data Collection System?		
Traffic Control and Communications Systems	1.6.1 Signalling System and Train Protection System		
	1.6.2 Signalling and Train Protection backup System		
	1.6.3 Train Positioning Detection system		
	1.6.4 Traffic Control System, CTC , and supervision and management line equipment and security Systems, CRC		
	1.6.5 Mobile Radio-Communication System		
	1.6.6 Landline Telecommunications and telephone Network		
	1.6.7 Landline Communication Network for control and monitoring all Railway Systems		
	1.6.8 Communications Management System		
	1.6.9 Is it available radio coverage in all the line, are there any radio blind zones?		
	1.6.10 Are there any specific operational regulation concerning mixed traffic (freight and HS or HS and regional trains), please could you identify the main characteristics of the regulation		

Element or Topic	Question	Answer	Explanatory comments (if needed)
Service Facilities	1.7.1 Passengers' Stations. Number, uses and length of its tracks		
	1.7.2 Freight Terminals. Number, uses and length of its tracks		
	1.7.3 Number of Sidings throughout the line and its length		
	1.7.4 Average distance between Sidings		
	1.7.5 Other service Facilities, specify		
Safety and Security Detectors System	1.8.1 Does mixed traffic add and/or require more Safety Risk Detectors on the Line? such as: hot boxes, flat wheels, gauge excess, lateral wind Detectors,… if so, quote them		
	1.8.2 Does mixed traffic add and/or require more Safety Risks Detectors on the Line? such as: fire, hazards emissions, Intrusions, falling objects Detectors, etc. if so, kindly quote them		

Chapter 2. Access conditions and/or possible traffic restrictions to provide rail transport services along the High Speed Railway line

Element or Topic	Question	Answer	Explanatory comments (if needed)
2.1 General Access Requirements	**2.1.1** It is a railway line for exclusive use by a single operator, or currently is an open line to various railway undertaking?		
	2.1.2 Are diesel powered trains allowed in the line? if not, why?		
	2.1.3 Type and competent body issuing documentation needed to operate on the line as a Railway Undertaking, RU		
	2.1.4 Does the RU must be in possession of an insurance of liability that covers the risks arising from its activity?		
	2.1.5 Are there other certificates required, such as staff qualification and/or rolling stock homologation?		
	2.1.6 Is the infrastructure use subject to the prior signature of a commercial agreement which set up the rights and obligations between the parties? Mention modalities		
	2.1.7 Is the infrastructure use subject to the prior aerodynamic compatibility study of traffic? Which are the formulas applied?		
2.2 Traffic Restrictions	**2.2.1** Are there any restrictions on trains traffic through tunnels? if so, indicate what requirements are		
	2.2.2 Are there any restrictions on trains traffic on bridges and viaducts? if so, indicate what requirements are		
	2.2.3 Are there any environmental restrictions on the circulation of trains on the Line? If so, indicate what are		
	2.2.4 Is there any limitation for the circulation of hazard goods along the entire line? If so, mention which and the reason		
	2.2.5 What requirements and regulations are applied to authorise the circulation of dangerous goods on the line		

Element or Topic	Question	Answer	Explanatory comments (if needed)
2.3 Admission of special transports	2.3.1 Are special transports accepted but always subject to a prior studies and specific authorization?		
	2.3.2 Regardless, only special transports are accepted if they are also accepted in the lines with which it is connected		
	2.3.3 Can line perform as a "rolling motorway"		

Chapter 3. Types and main performance of the Rolling Stock and trains using and accepted on the High Speed Railway line

Element or Topic	Question	Answer	Explanatory comments
3.1 Self-Propelling, thermal or electric, Trains. Trainset"	3.1.1 Standard Configuration and Train Total Length. **m**		
	3.1.2 Maximum Design Speed and actual on the line. **km/h.**		
	3.1.3 Maximum composition and Passenger capacity, total seats		
	3.1.4 Maximum Train Total Mass and Axle Loads. **Ton**		
	3.1.5 Braking and acceleration performance from/to Vmax.		
	3.1.6 On-board Signalling Systems available in the train		
	3.1.7 Has the Train a dynamic behaviour control system?		
3.2 Traction Units "Locomotives"	3.2.1 Traction type and kind of service performed on the Line		
	3.2.2 Service Weight, axle loads and maxim. per meter by type		
	3.2.3 Power (Kw) and maximum service speed (km/h) by type		
	3.2.4 Functional performance along a $20^{0}/_{00}$ gradient, maximum speed, load, acceleration and braking in distance and time		
3.3 Trains of Passenger Carriages "Coaches"	3.3.1 Type of passenger service performed on the Line		
	3.3.2 Train composition, total length & weight, max. axle load		

Element or Topic	Question	Answer	Explanatory comments
	3.3.3 Actual max. operation speed and capacity, km/h and seats		
	3.2.4 Functional performance along a $20^{0}/_{00}$ gradient, maximum speed, load, acceleration and braking in distance and time		
3.4 Freight Trains	**3.3.1** Type of freight trains performed on the Line		
	3.3.2 Standard composition of each type of train performed, total length & weight, maximum axle load and per meter		
	3.3.3 Both maximum and actual operation speed and hauled capacity, km/h and Ton, and acceleration and braking performance in distance and time		
	3.2.4 Functional performance along a $20^{0}/_{00}$ gradient, maximum speed, load, acceleration and braking in distance and time		

Chapter 4. Line Operation, Safety and Security, Maintenance and Environmental on the High Speed Railway line

Element or Topic	Question	Answer	Explanatory comments
4.1 Line's Operational Characterization	**4.1.1** Opening hours to traffic and daily average capacity		
	4.1.2 Daily current traffic according to type of trains. Timetable		
	4.1.3 Annual trains performed and its mileage by type of trains		
	4.1.4 Actual Maximum Operating Speed of fastest trains		
	4.1.5 Passenger trains, unpunctuality data and causes ranking		
	4.1.6 Actual Maximum Operating Speed of Freight Trains		
	4.1.7 Freight trains, unpunctuality data and causes ranking		
	4.1.8 Main Operational restrictions due to Mixed Traffic, such as; train crossings, speed limits, trains sequence, other...		
4.2 Safety and Security	**4.2.1** Does mixed traffic affect the incidentally on the line?		
	4.2.2 Are there Specific Safety provisions due to mixed traffic?		

Element or Topic	Question	Answer	Explanatory comments
	4.2.3 Specific Safety & Security provisions for traffic in Tunnels		
	4.2.4 Does mixed traffic increase security risks? quoted them		
	4.2.5 Specify Safety & Security equipment due to Mixed traffic		
4.3 Maintenance	4.3.1 Is regular maintenance procedure affected due to mixed traffic?, if so, in what way and in what amount		
	4.3.2 Does mixed traffic result more corrective maintenance ?, if so, in what way and in what amount		
	4.3.3 Line operational and functional availability and reliability Indicators, are they affected by mixed traffic?		
4.4 Environmental Behaviour	4.4.1 Environmental events index, breakdown by type; noise, leaks... and service; passenger, freight, other		
	4.4.2 Has mixed traffic resulted in additional environmental protection systems and means on the line? such as; leaks detectors, noise and vibration mitigation equipment...		

Chapter 5. Economic records and financing sustainability

Element or Topic	Question	Answer	Explanatory comments
5.1 Line Construction Costs	5.1.1 Total Infrastructure investments, including rail track		
	5.1.2 Total Railway Systems investments, including telecom.		
	5.1.3 Passengers Stations investments, if possible individualized		
	5.1.4 Freight Terminals and Sidings, if possible individualized		
	5.1.5 Other Investments to the line management and operation		
	5.1.6 What part of the investment would be caused by mixed traffic? Please, write down components and their amount		
5.2 Line Operation Costs	5.2.1 Infrastructure Maintenance Costs, including rail track		
	5.2.2 Railway Systems Maintenance Costs, including telecom.		
	5.2.3 Passenger Stations Operation Costs, individualized		
	5.2.4 Freight Terminals and Sidings Operation Costs,		
	5.2.5 Traffic Control and Safety and Security Costs		
	5.2.6 What part of the operational costs would be caused by mixed traffic? write down components and their amount		
5.3 Economic sustainability	5.3.1 Does the line have a charging system implemented for its use? If not, how is ensuring its financial sustainability?		
	5.3.2 Is infrastructure charging based on a system of recovery of marginal, -whatever be social or economic-, or total costs?		
	5.3.3 Line total annual revenues directly obtained by its use and its split between freight and passenger trains		
	5.3.4 Does the line receive any kind of public grants? If yes, specify its amount and purpose		
	5.3.5 Annual total income and share of the income by its use		

LIST OF FIGURES

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