Towards an Integrated Railway Network along the Genoa–Rotterdam Corridor

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Abstract New scenarios arose with the development of high speed rail (HSR) services: their shorter travel times make them competitive against the car on short distances and the aeroplane on medium to long distances. HSR integration is best realised if a hierarchical system is conceived whereby cities not served by HSR lines are well connected by rail [Chen and Hall (J Transp Geogr 19:689–704, 2011)]. Such integration among the different railway services, e.g. HSR, long distance and regional trains, and freight, plays a crucial role in being able to take advantage of these new opportunities. Moreover, the integration with interregional and local services would help provide better regional accessibility to HSR, allowing people living in the hinterland along the corridor to travel easily between regions. Better use of existing tracks will also contribute to avoiding or alleviating the saturation of the lines, thus allowing railways to achieve a better level of service without large new infrastructural projects. This chapter focuses on the current provision of high speed and long distance services along the Rhine–Alpine Corridor and presents a new methodology developed to assess their integration.

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1 Introduction

In recent years, an increasing number of high speed rail (HSR) operations have been witnessed at national and European levels, and the EU's commitment to developing high speed rail corridors has been highlighted in the TEN-T (Trans-European Transport Network) policy (EC 2010). Among other EU policies, the TEN-T policy has largely influenced major infrastructure developments in the field of transport (Marshall 2014). As a main planning methodology for future TEN-T development, the concept of a 'core network' was introduced to combine and integrate all transport modes and intelligent transport systems. Corridor 24 has become one of nine core network corridors, i.e. the Rhine–Alpine Corridor (EC 2013) and the integration of different railway services, e.g. high speed, long distance, regional and local trains, and freight, should play a crucial role in providing seamless travel along the Rhine–Alpine Corridor.

Although the initial focus of the CODE24 project was on improving the flow of rail freight and its implications for corridor development, there is a need for exploring better ways of maximising passenger rail services in parallel with rail freight, given the increasing importance of integrating HSR on existing tracks.

The Rhine–Alpine Corridor has been served by HSR over the last two decades and some high speed services are operated at a transnational level. Key challenges for HSR and long distance rail services along the corridor are to improve their service reliability and frequency as well as to integrate with other railway services. Since additional new infrastructure is difficult to envisage due to limited financial and spatial resources, a better use of existing rail tracks before building new infrastructure will help in easing congestion on existing lines.

This chapter focuses on discussing passenger rail development with a particular emphasis on HSR provision along the Rhine–Alpine Corridor, which is based on work performed for one of the action plans of the CODE24 initiative. The aim of the action is to develop guidelines for pursuing an integrated railway network along the corridor through the introduction of an integrated international timetable that encompasses HSR as part of its long distance services, regional trains and freight transport. The chapter starts with presenting a review of HSR experiences and the current flow of passengers along the corridor. After a brief summary about high speed (HS) lines and service structure on the corridor, the major outcomes of the analysis on the level of integration of high speed services within the corridor railway services are presented. Two types of integration have been considered: (1) corridor accessibility: integration between HS and long distance (LD) services to connect the main stations along the corridor; and (2) regional accessibility: integration between high speed and long distance (HS/LD) and interregional and local (IR/L) services to connect the main stations along the corridor with their hinterland. The chapter concludes by highlighting important factors in the integration among different railway services and suggesting open issues for future investigation.

In the following text, the original language is used for cities' names of railway stations as it is common in the railway sector.

2 High Speed Rail: A Review of Experiences

In many cases, HSR is focused on passenger long distance rail services with an operating maximum speed of 250 km per hour (kph) if new infrastructure is considered, but also of 200 kph and upwards if services are run on upgraded conventional rail lines (Council of the European Union 1996). However, "speed" as referring to the notion of maximum speed is not everything in terms of HSR and needs further specification (Chen and Hall 2011; Givoni 2006). Givoni and Banister (2012) argue: "While maximum speed of 350 kph is considered the new standard for HST (high speed trains), most HST services are provided at a much lower average speed, and the world's most successful HSR line in terms of passengers carried, between Tokyo and Osaka in Japan, operates at an average speed of less than 240 kph (for the fastest service)." Givoni (2006) provides a broader HSR definition: ". . .high capacity and frequency railway services achieving an average speed of over 200 kph". Table 1 summarises the average and maximum speed of HSR between relevant cities. It confirms to a certain extent that, with a maximum speed of 270 kph, the Tokyo–Osaka line attains a higher average speed than the fastest German line Köln–Frankfurt with a maximum of 300 kph. On the Milano–Roma line, the effect of additional stops can be appreciated. Overall, the notion of average speed appears more appropriate for assessing the effectiveness of rail performance than maximum speed.

It becomes apparent that designing HSR for maximum speed may reduce the number of stations served and thus requires longer station headway. In literature, a station headway of 150–200 km is proposed (Vickerman 2013) or even lower as an additional stop within a metropolitan area can be suitable as suggested by Garmendia et al. (2012). Thus, a trade-off between speed/travel time and potential ridership is required (Givoni 2006). Vickerman (2013) discusses the potential of HSR generating demand among commuters, as is the case for the Javelin HST,

Table 1 Comparison of HSR lines: speed and distance

Origin–destination	Distance (km)	Travel time (h)	Average speed (kph)	Maximum speed (kph)
Köln–Frankfurt	179	1.05	170.48	300
Brussel/Bruxelles–Paris	310	1.42	218.31	300
Tokyo–Osaka	515	2.42	212.81	270
Torino–Milano	125	0.90	138.89	300
Milano–Roma (nonstop)	515	3.00	171.67	300
Milano–Roma (with stops)	515	3.50	147.14	300
Madrid–Puertollano	209	1.08	192.92	270–300
Madrid–Toledo	75	0.50	150.00	240–260

Source: Adapted from Guirao (2013) and Germanwatch (2013) which allows daily commuting from Kent to London, and the French TGV in the Nord-Pas de Calais region. Rebmann (2011) considers commuting as a less important trip purpose for long distance travelling. Therefore, a frequency of every 4 h appears to be sufficient in order to bundle those groups who mostly undertake planned trips. Analyses from the Roma–Napoli corridor suggest that around 6 % of trips are made for commuting purposes, but a high proportion of trips are made for business reasons (ranging from 38.7 % on Sundays to 57.4 % on weekdays), while education-related trips (percentages ranging from 3.4 % on Sundays to 6.2 % on weekdays) and “other purpose” trips (percentages ranging from 52.5 % on Sundays to 30.2 % on weekdays) show lower, but still very significant rates (Cascetta et al. 2013).

In addition to trip purpose, the mode shift effect for HSR needs to be assessed. Shifting demand from air to HSR is one aspect. This is confirmed by the substantial shift in the Paris–Lyon line and the Madrid–Sevilla line achieved 3 years after their opening in 1981 and respectively in 1991 (Givoni 2006). In Madrid–Sevilla, the market share of air travel was reduced from 40 to 13 %, while train ridership rose from 16 to 51 %. For Paris–Lyon, the share of air travel was reduced from 31 to 7 % and train travel increased from 40 to 72 % (Table 2). The impact on the amount of car travel is lower if one considers the overall increase of train trips of 37 % in the Paris–Lyon case and 35 % with respect to the Madrid–Sevilla line (Givoni 2006). Givoni and Dobruszkes (2013) stress the mode shift effect from air to rail while referring to HSR services such as London–Paris respectively Brussels/Bruxelles or lines in China, Taiwan or South Korea. Dobruszkes (2011) raises awareness for the supply side, since he has observed an overall increase in air traffic in Europe, though HSR is successful on some connections. The substitution effect on car use appears less evident, first because figures are not often available and second, because a HSR network with fewer stations may require more car use to get to the stations and thus increases the amount of car kilometres travelled. Moreover, it is often neglected that there are considerable shifts from conventional rail to HSR (Givoni and Dobruszkes 2013). Nonetheless, the car is an important competitor for HSR, especially for shorter distances. For the Barcelona–Madrid HSR line, opened in 2007, a survey carried out in 2009 revealed that 44 % of the customers used the car before shifting to rail, 8 % used the bus, 16 % made their trip by plane and

Table 2 Mode shift effects of HSR introduction in %

Mode	Paris–Lyon (TGV)			Madrid–Sevilla (AVE)		
	Before 1981	After 1984	Relative change (%)	Before 1991	After 1994	Relative change (%)
Air	31	7	−77	40	13	−68
Rail	40	72	80	16	51	219
Car/bus	29	21	−28	44	36	−18
Total	100	100		100	100	

Source: Adapted from European Commission (1996), quoted by Givoni (2006)

Table 3 Evolution of modal split in the entire Italian travel market

Mode	2009 (million trips)	2009 share (%)	2013 (million trips)	2013 share (%)	Δ 2013–2009 (abs.)	Δ 2013–2009 (%)
Car	38.7	57.3	31.4	45.2	−7.3	−19.0
Air	7.1	10.5	5.0	7.3	−2.1	−29.0
HSR	17.0	25.2	30.8	44.3	13.8	81.0
Intercity	4.7	7.0	2.3	3.2	−2.5	−52.0
Total	67.5	100.0	69.6	100.0	2.0	3.0

Source: Adapted from Cascetta and Coppola (2015)

another 23 % "moved" from other conventional trains to HSR. The remaining 10 % can be considered induced traffic (Frontier Economics et al. 2011).

A before-after study in Italy comparing the modal split between 2009 and 2013 made by Cascetta and Coppola (2015) proves that HSR can gain market shares also from the car, which was reduced by 19 % in relative terms, but started from a higher level than the airplane. The number of air trips was reduced by 29 %, but that share is relatively low. HSR increased by 81 % from 2009 to 2013, but conventional train travel lost about 52 % of its users within 4 years (Table 3). This latter case and the Madrid–Barcelona case reveal another aspect: the loss of customers for conventional rail services. Givoni and Dobruszkes (2013) report that up to 94 % of users in the case of Madrid–Sevilla did not use any more conventional trains once HSR was introduced. On the Sanyo Shinkansen in Japan, 55 % of the traffic was diverted to the new line from conventional rail lines, while the rest comes from other travel modes (23 % from air, 16 % from car and bus, and 6 % new induced demand) (Sands 1993b, quoted by Givoni 2006).

In view of this information, it should be discussed at what cost rail infrastructure is designed to deliver air substitution if the land-use transport nexus may be threatened as mentioned above. The emergence of new stations at the edge of towns or in greenfields, which the authors qualify as "TGV-generation stations",[1] are promoted by the European Commission, makes integration between rail and land-use and between conventional rail lines and their supply more difficult (EC 2010). Moreover, railways as a backbone for development loses its overall quality if a loss in conventional rail service takes place.

Integration into the existing rail network also becomes more difficult if regional accessibility with the possibility of transferring at relevant nodes to the long distance network is neglected. In essence, HSR is suitable to serve a wide range of purposes and is able to shift demand from other modes. This should not prevent

[1] This term is based on the French TGV-planning strategy with the creation of additional, predominantly peripheral stations for cities like Mâcon, Avignon or Belfort with a "TGV" label in order to distinguish them from the traditional "main" station mostly located in the respective city centre.

from neglecting the effect of induced traffic and cannibalisation of conventional rail.

3 An Analysis of Passenger Flow along the Rhine–Alpine Corridor

The Rhine–Alpine Corridor covers some of the most important economic regions in Europe. Its catchment area includes 70 million inhabitants. However, specific data on passenger mobility along the corridor are partial and not up-to-date. Eurostat publishes some data related to different modes of transport (air, rail and road), but there is a lack of information concerning origin-destination flows (OD) between the corridor zones. Road OD matrices are not available. The only data available are total passenger-km per country (travelling by car, motorbike and public transport) up to 2012. Railway OD matrices between NUTS2 regions are available for 2005 and 2010, but several OD are not included, especially for 2010. Finally, air OD matrices containing the number of passengers travelling between the main airports along the corridor are available from 1993 to 2013. However, not all airports are considered and transit passengers,[2] which are included, cannot be separated from the mobility directly originated or destined for those ODs. As a result, it is impossible to build modal OD matrices, e.g. road, rail, air, with a high level of detail, i.e. between NUTS3 zones, only using data coming from official statistics.

However, the ETIS+ project[3] provides modelled data with this level of detail. All means of transport are considered, but data are only available for 2005 and 2010 and, being modelled data, there could be a deviation with respect to observed data. Nevertheless, those data are useful to provide an overview on the corridor mobility and identify the main OD relations. Therefore, the Rhine–Alpine Corridor area was divided into zones and the corresponding demand data provided by ETIS+ were analysed.

In order to have comparable data, zones were defined on the basis of their population. The zones correspond to provinces (NUTS3) in Italy and France whereas in Germany, Switzerland and the Netherlands the zones correspond to regions (NUTS2). Only zones along the corridor were considered, e.g. the Bayern Region in south-east Germany was not included, and only interzonal demand (trips between different zones) was analysed. This is because the present research was aimed at analysing medium- to long distance mobility demand along the Rhine–Alpine Corridor that can be served by HS/LD services properly integrated with interregional and local services. However, it is noteworthy to highlight that internal demand (intrazonal demand) usually represents most of the mobility of each zone.

[2] People going by plane to an airport to catch another plane to go on to a different destination.

[3] ETIS+ (http://www.etisplus.eu) was a project funded by the EC through the Seventh Framework Programme for research with the aim of building a European database on the flow of goods and people.

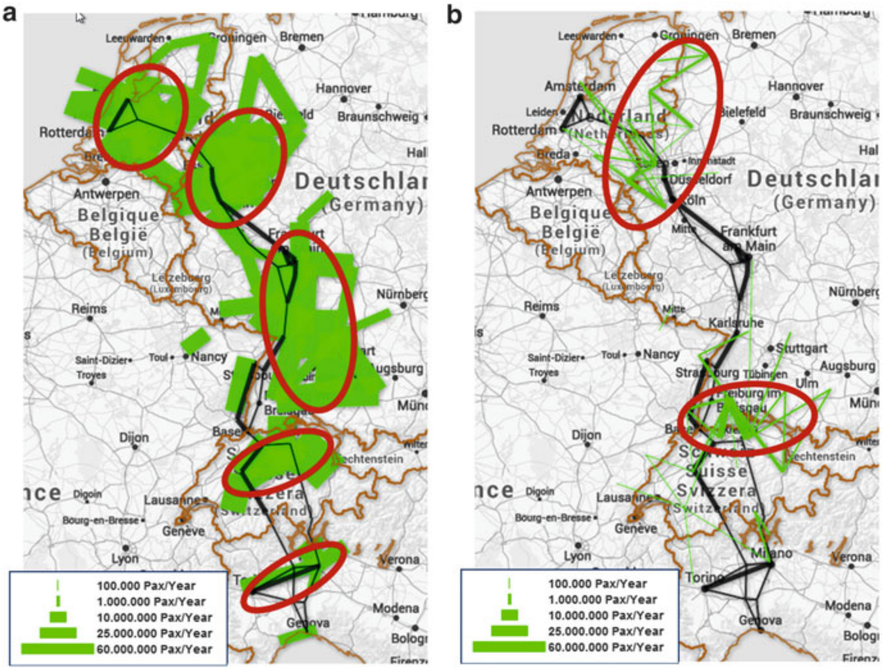


Fig. 1 (**a**) Most relevant interzonal OD relationship along the Rhine–Alpine Corridor for all modes of transport. (**b**) Most relevant transnational interzonal OD relationship along the Rhine–Alpine Corridor for all modes of transport. *Source*: Elaborations of ETIS+ data; base map: Google Maps, Google Inc.

The ODs with the highest passenger mobility (relationships with more than five million passengers per year) are represented in Fig. 1a. The most relevant OD relationships are at the national level: five large passenger demand clusters (indicated with circles in Fig. 1a) can be identified:

1. The Netherlands
2. North-West Germany
3. Central/Southern West Germany
4. Switzerland
5. The Piedmont-Lombardy axis in Italy

It is remarkable that most passengers travel between zones that are less than 100 km apart.

If only significant transnational mobility demand is considered (more than 0.2 million passengers per year), it becomes evident that there are fewer trips between different countries (Fig. 1b). These ODs are always characterised by less than 0.5 million passengers per year. Two main cross-border relationships can be identified: one between Northern Germany and the Netherlands and another between Southern Germany and Switzerland. The relationships between France-Germany, France-Switzerland and Italy-Switzerland appear to be less significant.

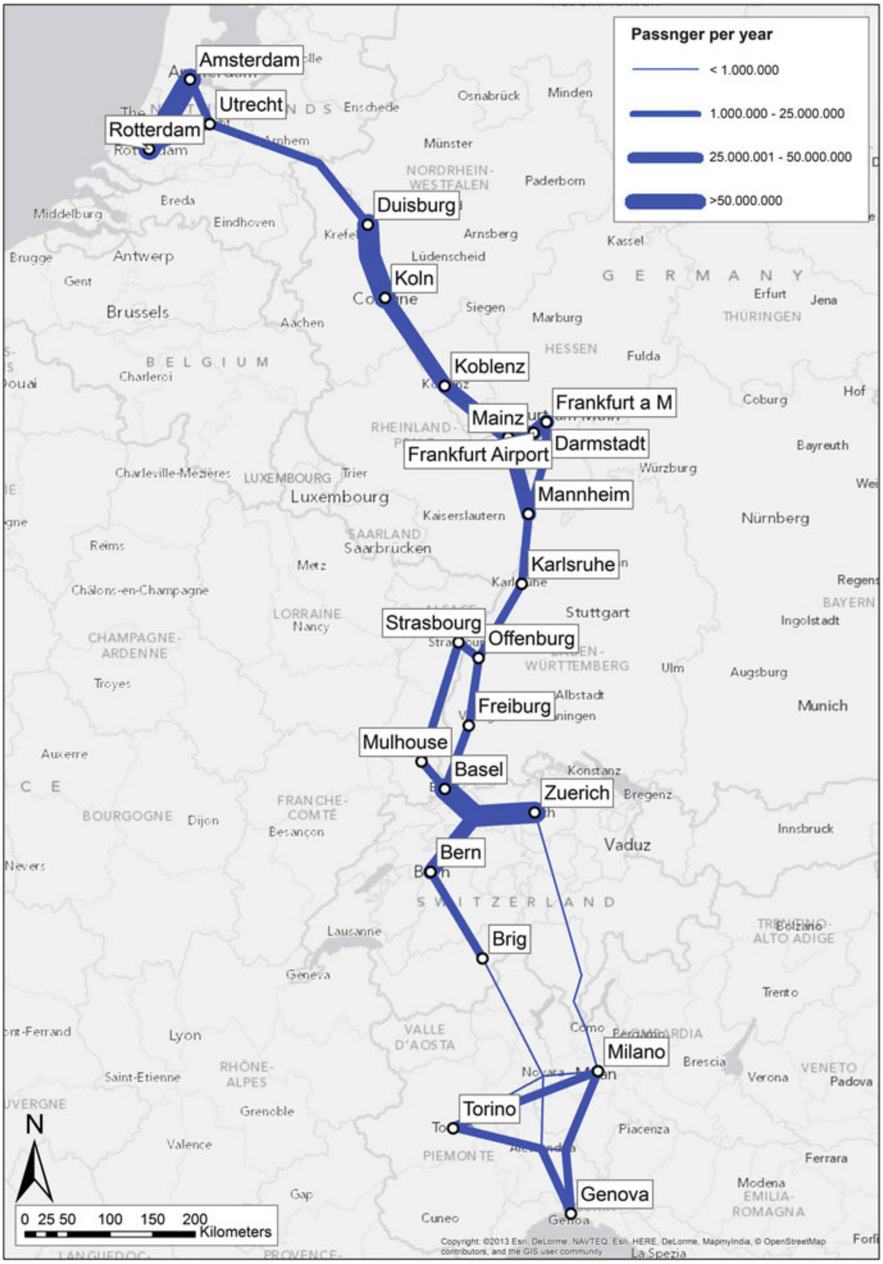


Fig. 2 Yearly interzonal mobility demand on the Rhine–Alpine Corridor for all modes of transport. *Source*: Elaborations of ETIS+ data; base map: Canvas/World_Light_Gray_Reference, Copyright: ©2013 Esri, DeLorme, NAVTEQ

The previous comments are confirmed by Fig. 2, which represents the annual interzonal mobility demand on the corridor for all the modes of transport. The figure reveals high passenger demand between Duisburg and Mannheim, and within the Netherlands and Switzerland. Lower, but still significant, demand exists for travel between the Netherlands and north-western Germany, between south-western Germany and Switzerland and within north-western Italy. Finally, demand is low between Italy and Switzerland.

4 High Speed and Long Distance Rail Services: The System along the Rhine–Alpine Corridor

Before moving to the analysis of service integration along the corridor, this section gives an overview of the rail axis between Rotterdam and Genoa. This comprises lines with different characteristics that are used by a mix of services, although mainly passenger services (Rhine–Alpine Corridor 2013). Figure 3 shows the railway lines forming the corridor and highlights those that allow trains travelling at a speed higher than 200 kph, consistent with the interest of the CODE24 project (and with some studies, see e.g., Givoni 2006). Only some sections of the corridor are equipped for trains travelling at 250 kph or more and may be considered high speed lines according to UIC (2013).

In the Netherlands, there exists a high speed line linking Amsterdam with Rotterdam and then providing an international link to Antwerp in Belgium. The rest of the network, also along the corridor, reflects the density of settlements in the country, which warranted fast services based on high frequency rather than very high speed, due to the frequent stops resulting from the settlement pattern.

Germany has both polycentric metropolitan regions and long intercity distances. There, high speed and long distance services together form the higher tier of rail connections. On the German section of the corridor, there are lines allowing speeds over 250 kph such as those between Köln and Frankfurt and between Mannheim and Stuttgart. In Switzerland, the dense railway network provides frequent integrated services not only between major cities, but also with their hinterlands. The pattern of services and lines was developed according to the Rail2000 strategy, which focused on connections and frequency.

In Italy, the area of the CODE24 project comprises the Torino–Milano high speed railway connection, whereas the corridor links between the Alpine crossings, Milano, and Genoa do not include HS lines.

The high speed lines along the corridor use conventional stations that facilitate the interchange with local services. Indeed, Italy and the Netherlands are the only corridor countries where HS trains travel on dedicated lines though, at present, they use conventional lines when approaching nodes.

The description above highlights the lack of high speed links across the borders of the corridor. This is consistent with the national focus of the original HSR

Fig. 3 Main rail lines along the corridor: *thick links* indicate lines allowing a speed over 200 kph, whereas thin links indicate *lines* with allowed speed not exceeding 200 kph. *Source*: CoDe24 Portal; base map: Google Maps, Google Inc.

network development plans, noted by Vickerman (1997), and only later expanded by a Europe-wide vision. Moreover, as mentioned above, services have a different organisation among the countries. In Germany, long distance and high speed services have similar functions and, in some cases, even services provided by local authorities cater to long distance travel (Beckers et al. 2009). The Netherlands and Switzerland have comparatively short intercity distances and national long distance services that do not rely on very high speed. In Italy, high speed services have replaced many long distance ones, which are left with a minor role, although this is only partly relevant along the corridor since, with the exception of the Milano–Torino link, it is formed by conventional lines where only intercity and regional services are provided.

It is remarkable that many HS lines have been developed to obviate capacity shortages, rather than with the single aim to provide HS links (Givoni and Banister 2012). Such a point is also noteworthy as one of the reasons that motivated the CODE24 project was to examine issues about the mix of different types of traffic and the relevance of the Rhine–Alpine Corridor for freight traffic. In fact, the corridor carries the largest logistics volume in Europe in tonnes-km (Rhine–Alpine Corridor 2013). Work to overcome capacity shortages and improve operations and interoperability between different rail services has recently been completed or is ongoing along the corridor. Projects of the former group include the Katzenberg Tunnel in Germany and the Lötschberg Tunnel in Switzerland (concerning one of the two tracks). Ongoing projects include new tracks between Karlsruhe and Basel, Emmerich and Oberhausen in Germany; the Gotthard Tunnel, and the Ceneri Tunnel in Switzerland; and enhancements on the lines between the Alps and Milano and the third Giovi line in Italy. Operations on existing and new infrastructure should also be eased and made increasingly interoperable by the deployment of the ERTMS.

5 High Speed and Long Distance Rail Services: Integration along the Rhine–Alpine Corridor

This section reports on the investigation on corridor accessibility aimed at understanding whether the entire Rhine–Alpine Corridor and, in particular, cross-border mobility, are suitably served by HS and LD trains. The analysis considered the main stations belonging to the OD pairs with highest demand (more than one million passengers). Data related to the supply of direct rail services were collected, with the support of the CODE24 partners, on a typical day (a weekday in October 2013) among those stations.

The number of services was used as a proxy of the seats provided because the number of seats of each train is not available in the train operators' publicised data and it is not easy to estimate since train capacity can vary greatly between different countries and lines.

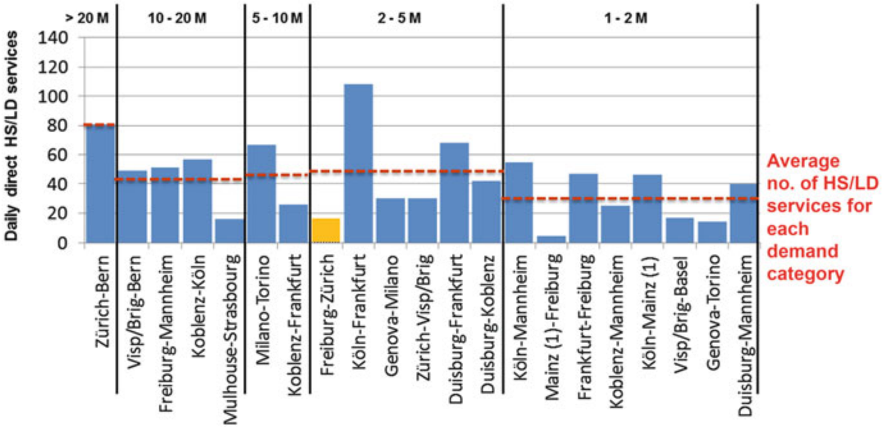


Fig. 4 Daily direct HS and LD services between ODs with a high mobility demand. *Source*: Elaborations of DB European timetables available on web. (1) The Region of Mainz, Rheinhessen-Pfalz, is also served by trains to/from Mannheim

Figure 4 shows the number of daily direct services (sum of both directions) between the most important OD pairs, grouped in five categories on the basis of the mobility demand estimated as discussed in paragraph 3 (>20 million, 10–20 million, 5–10 million, 2–5 million and 1–2 million passengers per year). For each demand category, the average number of HS/LD services is depicted by a dashed horizontal line. The only transnational OD (Freiburg-Zürich) is shown in a different colour.

The number of direct services within each demand category can vary significantly. In particular, for some ODs, a seemingly low number of direct services is provided, i.e. Mulhouse–Strasbourg, Koblenz–Frankfurt and, the only cross-border relation, Freiburg–Zürich: these could be "critical connections".

When interregional and local (IR and L) services are also included, the number of critical connections decreases. For short distance ODs (less than 200 km), in particular, IR/L trains are well integrated with HS/LD trains since they aim at serving not only the regional mobility demand, but also the medium to long distance demand that cannot be served by HS/LD services. In fact, the latter are characterised by a low number of stops in order to reduce the total travel time between the more distant stops.

However, some ODs, e.g. the only transnational OD, Freiburg–Zürich, appear critical even considering IR/L services. For those relationships, data collection was extended to include connecting services requiring transfers.

Figure 5 reports all the daily connections between Freiburg and Zürich. The graph shows direct connections on the top (eight direct services per direction with an average travel time of 1 h 54 min) whereas below are the other connections that require up to three transfers (22 connections/day: 17 with one transfer, 3 with two transfers and 2 with three transfers).

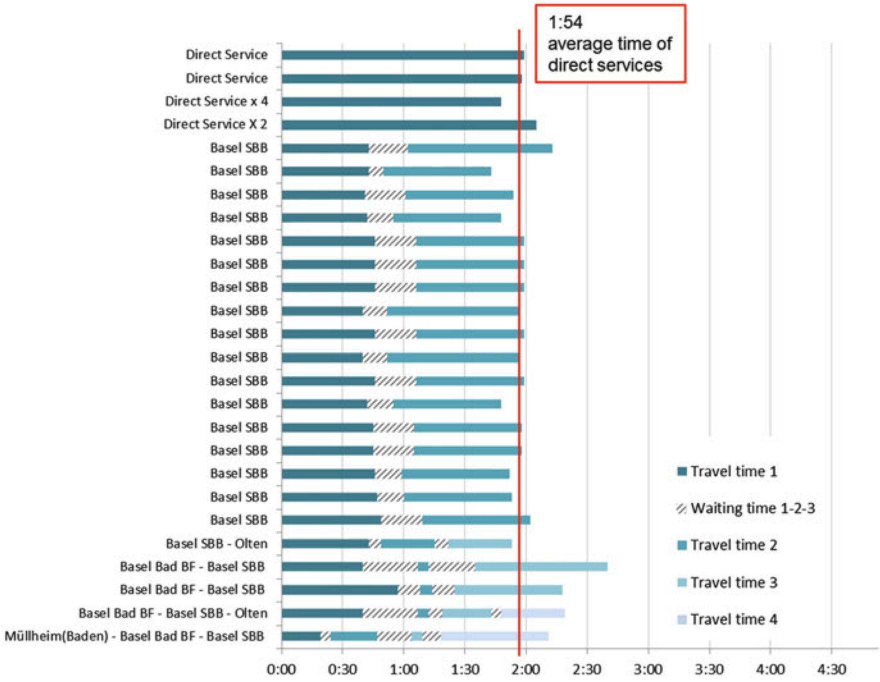


Fig. 5 Freiburg–Zürich daily connections and respective total travel time split into travel time and waiting time at the interchange stations. *Source*: Elaborations on DB European timetables available on the Internet

It is evident that connections with one transfer suitably integrate the direct services: total trip times are similar to trip times with direct services (in some cases even shorter) and the waiting times at the interchange stations are usually shorter than 20 min.

This situation recurs along the corridor. Some high-mobility ODs have few direct services compared to other relationships with a similar demand, although they are served by very good indirect connections with total travel times similar to those of direct services. A further analysis could be carried out to investigate what other factors, in addition to mobility demand, are considered in the choice between direct services and options including transfers.

The previous comments remain valid for other transnational ODs with lower demand as well (Fig. 6). The only exception is the relationship between Torino (Porta Susa station) and Brig. In that case, there is no direct service and changing trains usually requires waiting more than 30 min in Milano Centrale Station or travelling by underground between Milano Porta Garibaldi and Milano Centrale Station.

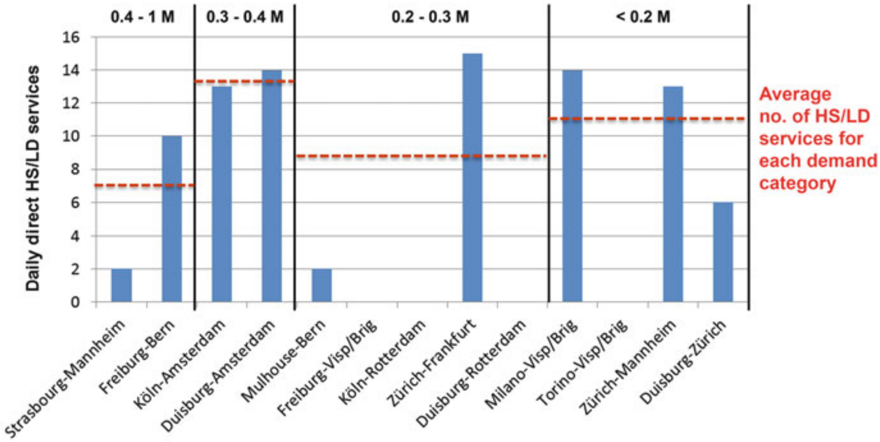


Fig. 6 Daily direct HS and LD services between transnational ODs with the highest mobility demand. *Source*: Elaborations of DB European timetables available on the Internet

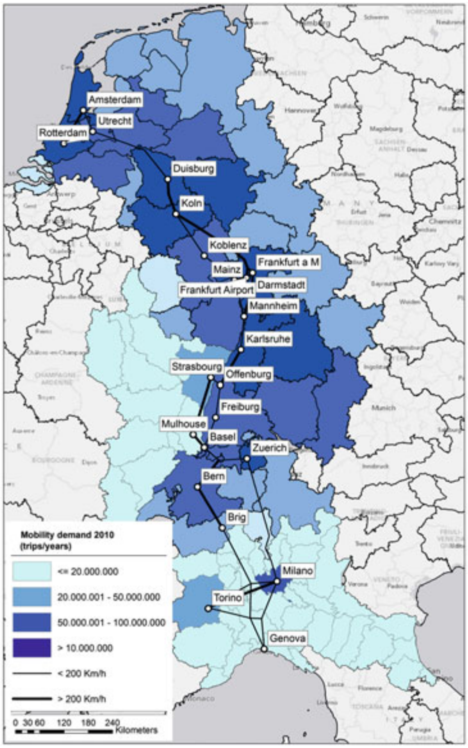
6 High Speed and Long Distance Rail Services along the Rhine–Alpine Corridor: Integration with Local Connections

Regional accessibility to HS/LD services in the main nodes along the Corridor was also investigated: the analysis focused on the connections of HS stations to their hinterland and the integration of HS/LD trains with interregional (IR) and local (L) trains.

The level of integration was analysed in terms of timetables and efficient transfer times between two different services in a node. In particular, services were defined as:

- Integrated with short transfer time, 5–15 min
- Integrated with medium transfer time, 15–30 min
- Potentially integrated when transfer time is between −5 and 5 min (negative values mean that a service arrives a few minutes after another service that it could be integrated with; in such cases small timetable shifts could increase the number of possible transfers)
- Not integrated in all other cases

On the basis of the level of mobility demand attracted and generated by the zones along the corridor (number of passengers per year using all transport modes, see Sect. 3), eight main nodes were identified for the analysis. Since some of these nodes are served by more than one HS station, the timetables of services in 14 stations (those highlighted in Fig. 7) were collected and analysed in detail for a typical time slot (8:00–10:00 am) and a typical day (a Tuesday in October 2013).



Main rail stations	
The Netherlands	Amsterdam
	Rotterdam
	Utrecht
Germany	Duisburg
	Darmstadt
	Koblenz
	Freiburg
	Offenburg
	Mainz
	Köln Hb
	Koln Messe Deutz
	Frankfurt Hbf
	Frankfurt Airport
	Mannheim
France	Strasbourg
	Mulhouse
Switzerland	Basel SBB
	Basel Bad Bhf
	Zuerich
	Visp/Brig
	Bern
Italy	Milano Centrale
	Milano P. Garibaldi
	Milano Rogoredo
	Torino Porta Nuova
	Torino Porta Susa
	Genova

Fig. 7 Main rail stations identified along the Genoa–Rotterdam Corridor on the basis of mobility demand in 2010. *Source*: Elaborations of ETIS+ data; base map: Canvas/World_Light_Gray_Reference, Copyright: ©2013 Esri, DeLorme, NAVTEQ

Starting from the arrival and departure times of the trains at the stations, transfer times for all possible service combinations were evaluated in order to assess integrations between HS/LD trains and IR/L trains serving the corridor hinterland. HS and LD services were considered as equivalent for the analysis.

This method allowed us to identify and represent, for each analysed station, all possible final destinations that can be reached arriving at that station from 8:00 to 9:00 am with a HS/LD service and transferring on a local train with an appropriate transfer time or, vice versa, all the possible locations from where one can leave with a local train in order to transfer on a HS/LD service.

Comparing some of the most important nodes along the corridor (Fig. 8), it is noticeable that in both the German and Swiss main stations, e.g. Frankfurt am Main, Köln, Zürich, HS/LD services are very well integrated with IR and L trains: the hinterland is efficiently connected and a high number of regional services (calling at many other stations along their path) are already available within 5 and 15 min transfers. The same considerations hold also for Dutch stations that were not considered in the analysis due to the very high number of LD services provided (all local trains are integrated with at least one such service). Milano Centrale,

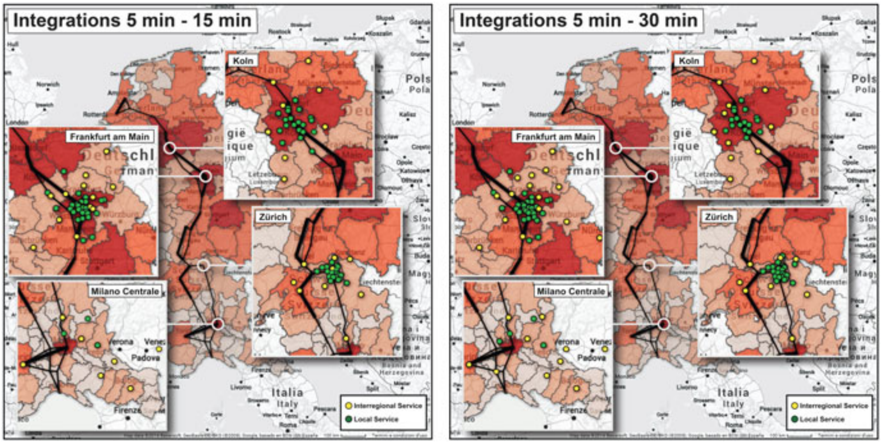


Fig. 8 Origins and destinations of IR and L trains integrated in the main corridor stations with HS/LD services having short or medium transfer times from 8:00 to 9:00 am. *Source*: Elaborations of DB European timetables; base map: Google Maps, Google Inc.

in Italy, presents a different picture: there are fewer IR/L trains integrated with a short transfer time. Their number increases with increasing transfer time (5–30 min) since 15 min is considered too short an interval to take into account the HS station size (usually large stations, sometimes with dedicated HS platforms that are not always near those used by local services) and the average boarding/disembarking time (people travelling on HS trains usually have luggage).

In terms of IR/L services provided, Milano Centrale is similar to smaller stations (Fig. 9), for example, Mannheim and Basel SBB, which provide fewer services, but are both 1-h away from a large station along the Corridor, Frankfurt and Zürich respectively. However, almost all the integrated trains in Milano are IR services, connecting the node with large cities further away and serving fewer stations in the proximity of Milano, while in Mannheim and Basel SBB more integrated local services are available.

This point is even more evident if we compare different nodes that are served by more than one HS station (Fig. 10). Two different service models for IR and L connections in such nodes can be observed. In Germany and Switzerland, the central station provides most of the IR/L services, as shown by the examples of Köln central station and Basel SBB compared with the Köln node (also served by Köln Messe Deutz) and the Basel node (also served by Basel Bad Station). In contrast, in Italy, different stations serving the same node have different functions: in the case of Milano, the Centrale Station connects the city with other important cities (providing more IR services), while Rogoredo and Garibaldi serve the hinterland (providing L trains). In such cases, it is sometimes necessary to move between two different stations in order to transfer from a local train to a HS/LD service and vice versa.

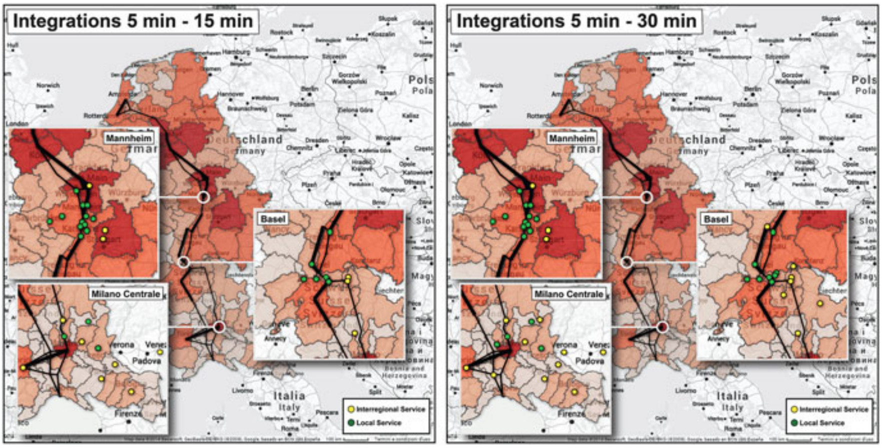


Fig. 9 Origins and destinations of IR and L trains integrated in other corridor stations with HS/LD services with short or medium transfer times from 8:00 to 9:00 am. *Source*: Elaborations of DB European timetables; base map: Google Maps, Google Inc.

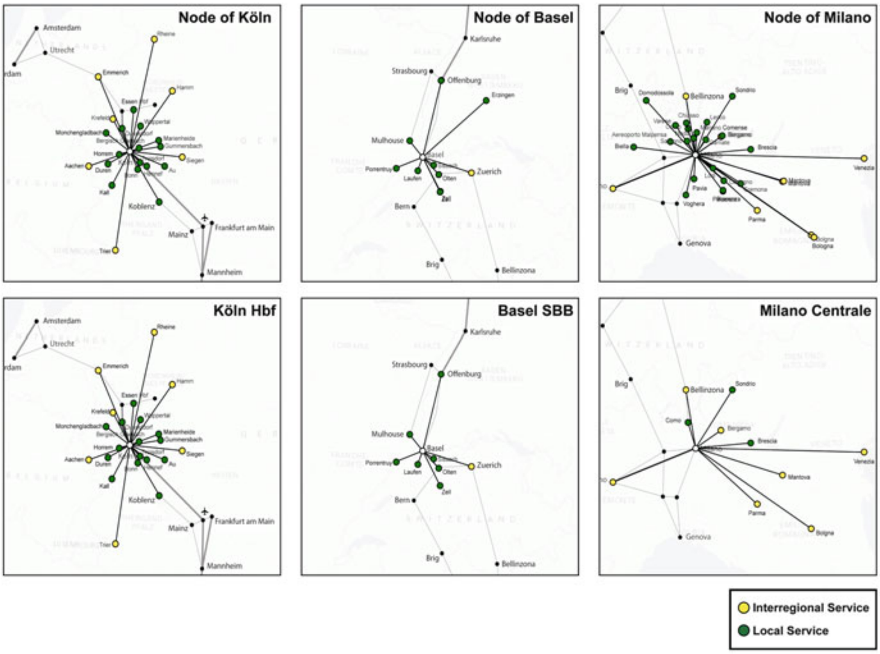


Fig. 10 Incoming integrated IR and L services in nodes served by more than one HS station and in the corresponding central station. *Source*: Elaborations of DB European timetables; base map: Google Maps, Google Inc.

The analysis showed that integrations (assessed in a typical time slot) between HS/LD trains and IR/L services in the main nodes along the Corridor perform adequately and the hinterland appears suitably connected to HS stations and transfers have short waiting times. In Italy, transfer times are usually longer than in other countries. Moreover, a different service model for IR and L connections has been observed since different HS stations serving the same node have a different function and provide either more L services or more IR services, compared with other countries where both services are usually available at the central station.

7 Conclusions and Open Issues

While the initial focus of the CODE24 project was on improving the flow of rail freight and its implications for corridor development, it was soon realised that there is a need to investigate how passenger rail services could be optimised in parallel with rail freight, and how to make the most of the opportunity provided by the increasing importance of HSR, which, on the corridor, typically shares the tracks with the other services.

A survey of experiences underlined which factors should always be in the forefront of the HSR discourse, such as the importance of average speed, rather than of maximum speed, the trade-off between speed and additional stops, which affects, in part, ridership, frequency of services and types of users expected or attracted, with the different experiences around the relevance of commuters rather than business people or people travelling for other purposes. Other elements that should be understood when considering HS and LD services are the attraction of air and car travellers as well as the shift from other non-HS rail services. Such factors have a clear commercial importance, but also significant implications for the provision of other rail services and on the transport land-use links.

A brief description of the system along the corridors showed that settlement patterns and rail service offers can be quite different from one another. The latter point recalls the initial, and current, focus on national passenger services. Furthermore, the significance of the corridor in terms of freight carried, often across borders is such that many technical efforts are underway to ensure better corridor interoperability and capacity for trains. Interestingly, in several cases, the lack of capacity was also the reason to develop HSR lines.

It appeared to the CODE24 project that one key element for exploiting railway technical capabilities, e.g. capacity and speed, for passenger transport is the integration among services. Integration is also relevant from the viewpoint of the land use/transport interaction to avoid losses in levels of service for locations not served by HS services and to ensure that the entire corridor may benefit from HS links thanks to feeder services.

The paper explored two aspects of integration: integration of services among the Rhine–Alpine Corridor nations and integration of LD and HS services with local services. The focus of the investigation was based on an assessment of the travel demand for all modes that exist along the corridor. The data presented show that the key OD pairs are national, whereas international travel demand plays a much smaller role. What is more, much passenger travel happens between zones that are less than 100 km apart. A comparison between demand and supply of HS and long distance services between the most significant OD pairs revealed that the number of direct services is not necessarily similar across ODs with a similar potential demand, although dissimilarities in supply decrease when IR/L services are also considered. Further, the investigation highlighted the important role of indirect—but connecting—services in ensuring a high level of service between important OD pairs.

The analysis of the integration between HS/LD and IR/L services focused on the availability of local connections within a given time at a selected set of stations. The results show a good integration in German and Swiss main stations in particular, with a longer transfer time in Italy. Milano experiences a different service model where three stations are served by HS services, with one right in the city centre, but not integrated with the other services and the other two benefitting from more local services. Moreover, HS trains calling at the first station do not serve the others.

The results summarised in this paper were presented during an experts' workshop held in Frankfurt in June 2014. The experts confirmed the importance of long distance services with the ensuing savings in travel time serving the backbone of the Corridor. They also agreed that, in the interest of regional accessibility, the focus should not be limited to HS and LD services. It was proposed to foster the existing multi-scale accessibility approach, which takes into consideration the numerous nodes along the corridor. This multi-scale accessibility brings a second advantage: the integration of regional feeder services in relevant regional and national transfer nodes, which results in better accessibility than focusing on high speed solutions. The fewer stops provided by the latter take the risk of losing customers "along the lines", notably when creating parallel lines, which make network accessibility for stations further away more difficult. Moreover, demand may be shifted from air towards rail, but to a lesser extent than from cars. This is justified by the density of the corridor, the polycentric character of the regions and the interregional relationships along the corridor, which again justify the multi-scale strategy.

Regular services along the corridor at intervals of 2 h may be suggested. Standardised transfer times of 15–30 min would ensure a seamless travel chain without unattractive waiting times. Additional faster services calling at fewer stations may be a top option for coping with considerable air demand levels, as found between Frankfurt and Zürich or Amsterdam, Zürich and Milano or Cologne and Zürich.

Considering this proposal, further work may include an assessment of the introduction of such services and the possible loss of customers on other trains of the proposed 2-h service structure. Another topic to investigate is whether passengers would prefer air travel within Europe if airports were more accessible and integrated. Furthermore, it would be interesting to evaluate how HSR should be part of an overall rail development strategy with the centres and their central stations as the backbone for more sustainable settlement patterns aimed at reducing the overall carbon footprint as a sum of predominantly air and car trips. This, especially, is an issue that Givoni and Dobruszkes (2013) raise in their paper on the effects of HSR.

Moreover, it would also be useful to extend the integration analysis to other factors that are as important as saving transfer time in order to improve service integration, such as:

- Service frequency, increasing the number of possible transfer choices
- Service reliability, reducing the risk of delays
- Integration of fares among the different operators, also considering interregional and local services so that it is possible to transfer to the next useful train in case of a delayed arrival in transfer nodes
- Information that allows users to share knowledge about available services
- Regulations to coordinate cooperation among both the public authorities and the operators

Further useful work on the matters discussed here would include investigations on the rationale and the effects of the choices between direct services and options including transfers, typically made by operators.

In closing, the lack of official data on passenger mobility along such an important corridor and the need to resort to modelled data should be underlined. Further work on reconstructing actual demand patterns in Europe is desirable.

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