High-Speed Rail Integration to Corridor 24 Final Report

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ROTTERDAM CODE24 CORRIDOR DEVELOPMENT GENOVA

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Preface

Many parts of the European railway network are facing difficulties in coordinating the increasing number of passenger (high-speed, long-distance and regional) and freight services, especially in high-density urban areas that share tracks. The Rhine-Alpine Corridor linking Rotterdam with Genoa is particularly concerned. Tremendous pressure because of fairly tight public budgets and limited land resources makes separation of rail traffic and the underlying development of infrastructures difficult. However, an international integrated timed transfer has the potential to guarantee regional accessibility and to overcome spatial disparities which may be underpinned with the development of pure high-speed rail focusing too much on connecting metropolises. The work is part of a specific action named as "Increasing Network Accessibility by Including High Speed Rail (HSR)" which was part of the five year EU-project CODE24 (Corridor 24 Development Rotterdam – Genoa).

The report will show that (potential) demand is generated by several stations and their hinterland along this densely populated and linked corridor and not predominantly by a few metropolises. This is in line with the literature review and the fact that 60 % of German long-distance demand arises from outside those metropolises. The report will also visualise a cross-border perspective and is therefore valuable to make a contribution for fulfilling the EU common goals and the 60 % reduction target for CO2-emissions as set in the EU White Paper on transport published in 2011.

The results of this study will help the partners of the newly founded follow-up organization "Interregional Alliance for the Rhine-Alpine Corridor EGTC" to refine a strategy established for the development of this corridor.

We hope you enjoy reading and welcome any feedback for the on-going strategy.

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Executive Summary

Why Is HS Rail Necessary for the Corridor?

Europe has witnessed an increasing number of HS (High-speed) rail operations and development at national and trans-national level. The European Union`s (EU) commitment to developing HS rail corridors has been confirmed by policies such as the Trans-European Transport Network (TEN-T) and the White Paper on Transport published 2011. The EU's key political agenda is to strengthen economic, social and territorial cohesion towards the creation of a European single market. To this end, it is important to ensure better connectivity between European regions by making them benefit from HS rail as a means to reduce travel times. To obtain effective connectivity, HS rail should be integrated into a long distance (LD) rail strategy ensuring seamless travel chains and accessibility for the cities where HS services call and for their adjacent regions. To ensure seamless connectivity for the regions HS and LD rail need to be integrated with regional services. For CODE 24, there is the need to explore better ways of maximising the benefits for passenger rail services and to cope with the capacity and operational issues related to rail freight operations.

Objective and Key Activities

The aim of Action 17 within CODE24 project is to develop guidelines for pursuing an integrated railway network along the Corridor. The Action introduced an integrated international timetable which encompasses HS rail as part of an integrative strategy including LD services, regional and local trains and rail freight transport. The specific role of HS rail in the Corridor was discussed through visualising the interconnectivity between the regions along the Corridor and the regional network accessibility around major transfer nodes (mainly the so called central stations). Three activities to achieve these goals were identified: 1) assessment of HS/LD rail integration within Corridor 24 rail services; 2) proposal of an optimal timetable following the concept of International Integrated Timed Transfer (IITT)1; and 3) EXPO Milano 2015 case study to improve Genova and Rho-Fiera connection.

Methodology

A set of new methodologies was developed to conduct the three activities. For the first activity (assessment of HS/LD rail integration), regional accessibility (timetables of different train services in selected key nodes) and corridor accessibility (connections between the main origins and destinations (OD) pairs) were visualised and investigated using a GIS based tool which shows the correlations between the collected data. For the second activity (timetable along the Corridor), potential travel time savings at main nodes and along the lines have been analysed using an IITT concept. Thirdly, the case study of EXPO Milano 2015 examined the feasibility of a dedicated shuttle train service between Genova and Rho Fiera from the perspectives of transport demand outlook and capacity. To refine preliminary findings and help in drawing final conclusions, an expert workshop was held to gain an insight from professionals in the fields of HS rail development, railway management and spatial planning.

Definition of HS Rail

Maximum speed is considered as a primary factor when discussing the quality of HS service and most commonly used by the EU or the International Union of Railways (UIC). The notion of the average speed appears more appropriate to assess the effectiveness of HS rail performance than the maximum speed. Beyond the speed element HS rail should be considered from different angles. HS rail is suitable to serve a wide range of travel purposes and to induce new travel demand as well as it can be an attractive alternative to air travel. However, there is a tendency for HS rail to divert demand from conventional rail services. It is thus important to ensure integration of HS rail into existing rail networks by improving the transfer possibility at relevant nodes. Comparison of HS services with overseas and other European countries (e.g. Spain and France) revealed the difficulty for the Rhine-Alpine Corridor to cope with both passenger and freight services in the mixed-use tracks in a trans-national setting.

Current Integration between the Corridor and Regions

Numerous factors contribute to an efficient integration of railway services such as timetable integration, service frequency, service reliability, integration of fares, information and regulation. In Action 17, integration was analysed in terms of timetables and efficient transfer time in the main nodes along the Corridor. Two aspects of integration were considered: corridor accessibility and regional accessibility. The corridor accessibility analysis aimed at assessing whether the Rhine-Alpine Corridor can be considered seamless and adequately served by the current rail services, in particular cross border services. To achieve this aim, the integration between HS and LD services for connecting the main stations along the Corridor was assessed by considering daily direct and non-direct railway services (provided in a typical weekday in October 2013) connecting the selected OD pairs (both national and international).

Regional accessibility was assessed analysing whether the main HS stations along the Corridor are adequately connected with their hinterlands. Integration between high speed/long distance (HS/LD) trains and interregional/local (IR/L) services in the main stations along the Corridor was analysed in terms of transfer times. 14 stations (i.e. nodes) along the Corridor were selected for data collection and analysis on a typical time slot (8:00-10:00 am) and a typical day (a Tuesday in October 2013).
The study highlighted the important role of indirect but well-connected services in ensuring a high level of supply between main OD pairs. In particular transnational ODs can be served by good indirect connections with similar total travel time as direct services. Connections (assessed in a typical time slot) between HS/LD trains and IR/L services in the main nodes along the Corridor perform adequately: 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 (e.g. Milano) have a different function and provide either more L or more IR services, compared with other countries where both services are usually available at the central station.

Expo Milano 2015 Case Study

The Expo 2015 case study aimed to explore ways of utilising an event opportunity for improving the integration of different types of rail services and then to identify the needs for better hinterland accessibility to the event site. The analysis was firstly developed in order to obtain a snapshot of the current situation of the accessibility to the EXPO site, by car and by train, and revealed that the overall rail reachability to the EXPO lags behind in comparison with car travel. In particular, Genova would be suffering from a poor service with respect to other Italian cities served by HS rail as well as comparing with Swiss cities which will be better connected by extra trains during the event. Therefore, the study focused on analysing the feasibility of adding new train paths from Genova to Rho-Fiera by looking in detail at the official timetable. The aim was to check whether a new direct train would be quicker than existing ones. This could occur mainly by obviating the need to change trains in Milano which is an added advantage in terms of improving accessibility to the event. However, in some cases, possible travel times of the new shuttle trains would be slightly longer than those of existing connecting trains. This owes to the constraints imposed by the very dense existing rail traffic, especially around Milano, which leaves barely any room for additional circulations. Therefore, although avoiding the need for connections in Milano, the proposed shuttle trains would meet only partially customer's requirements.

Moreover, experts consultation revealed that a new customised rail shuttle service Genova-Milano might be successful during the event but would not necessarily keep its interest and feasibility in the long term. The same consultation underlined also the need to think in terms of a wide offer of services, accessible with the same ticket, for added travelling flexibility rather than focussing on a single daily shuttle.

International Integrated Timed Transfer

The timetable exercise showed that service improvements do not really require new lines. Infrastructure upgrades and measures in the nodes are sufficient to increase the whole door-to-door travel chain. It is important to stress that the density of the Corridor, the polycentric character of the regions and the interregional relations along the Corridor again suggest to pursue with a strategy aiming at multi-scale accessibility. This means that either international demand and domestic travel needs can be satisfied. Backbone is an hourly long distance train service which serves the most relevant nodes along the Corridor and where transfer from/ to regional services and with other long distance services towards other corridors is guaranteed. Additional speeded up train services calling at fewer stations may be an on-top option to cope with considerable air demand levels as can be found between Frankfurt and Zürich or Amsterdam, Zürich and Milano or Köln and Zürich. To be competitive with such nonstop air services, train travel time should not exceed a four hour threshold. If there is a transfer for air passengers, a 2-3 hours difference between air and travel time may still be favourable for the train as the total travel time to be less than four hours. These services should be carefully designed in order to avoid demand shift from the hourly backbone services which in turn may be threatened. Caution is also necessary since there may be more air passengers if their HS rail accessibility to airport rail stations may increase.

Recommendations and Guidelines

The guidelines for a more integrated railway network should firstly ensure that the whole Corridor would benefit from HS links through the improvement of the corridor accessibility (integration of services along the corridor) and regional accessibility (integration of LD and HS services with regional and local trains) as well as the application of an international integrated timed transfer (IITT). Then, strategies for travel time savings for long-distance journeys need to be designed with reference to customers' requirements. In fact, it is most unlikely that people would travel by train on the entire route between Rotterdam and Genova. In this context, multi-scale accessibility would be an appropriate concept which takes into consideration the numerous nodes along the Corridor rather than focuses on HS services with fewer stops. It is very important to establish a future corridor vision of passenger train services which can liaise with catalyst events for the purpose of inducing new rail demand (e.g. Expo Milano 2015). The forecast of future demand of train users plays a key role in developing a vision, and thus better cooperation with network operators is of paramount importance to unlock the current limited accessibility to railway data.

Finally, the following points are key recommendations for improving passenger train networks in a holistic way.

- Seamless passenger travel chain: harmonising cross-border with national services
- Interoperability of train and track usage to improve direct cross-border services
- Good hinterland accessibility through integration of national and regional services
- IITT as the right approach to be pursued, possibly requiring a further feasibility study on timetable, hinterland access and demand potential along the Corridor
- Nodes optimisation by improving track and train operability, reliability, timetable coordination and by achieving harmonised transfer times (e.g. 15 minutes, ideally 00/30 to 15/45)
- Exploring the necessity and feasibility of "trains on-top" which means extra trains in addition to the ordinary long distance train services of the IITT-scheme
- Integrated timetabling, ticketing, and information
- Better information (incl. real-time) on train, fares and timetable and on facilities in the station from the (international and vulnerable) customer's perspective
- Better integration with other transport modes and services: e. g. pedestrians, bicycle (parking and rental systems), car sharing, car parking, long distance bus services and local public transport (i.e. tramway, underground or bus)
- Improving the surrounding areas of the station through better urban design and area-based regeneration
- Improving the accessibility to transport relevant demand data

1 Introduction

Over the last two decades the total length of High-Speed (HS) rail lines has nearly tripled at European level. In 2012, the European HS rail network reached 6,870 km[1] in seven countries (i.e. Belgium, Germany, France, Italy, the Netherlands, Spain and the United Kingdom, UK), and carried 110.35 billion passenger kilometres (pkm, data for 2011) (European Commission, 2014a). European Union (EU) has been effectively using the concept of Trans-European Transport Network (TEN-T) to link all HS lines on the continent into a proper integrated European HS network (European Commission, 2010: 6). EU commitment to revitalise the railway sector for improving the flow of goods and passengers has been highlighted through the TEN-T policy, as a key driver for the single market projects.

TEN-T Guidelines have identified the comprehensive network which is to outline plans for rail, road, inland waterway, combined transport, airport and port networks. It comprises 138,072 km of comprehensive railway network, of which 68,915 km are related to core network railway lines (European Commission, 2014b). According to the Green Paper (CEC, 2009:5) nearly a third of the comprehensive railway lines are HS rail, and the majority of the remaining links to be completed were related to HS rail. It is evident that focus of the priority railway projects was primarily placed on the development of a pan-European HS rail network.

Corridor 24 (i.e. Rhine-Alpine Corridor as part of the core corridor network which contains nine corridors, Figure 1) goes through five of the seven countries which are operating HS rail, and has been served by different train products such as German ICE, Benelux/French Thalys, French TGV, and Italian AV. They are offering cross-border connections such as the Netherlands and Germany by Thalys, Germany and Switzerland by ICE, and France and Switzerland by TGV.

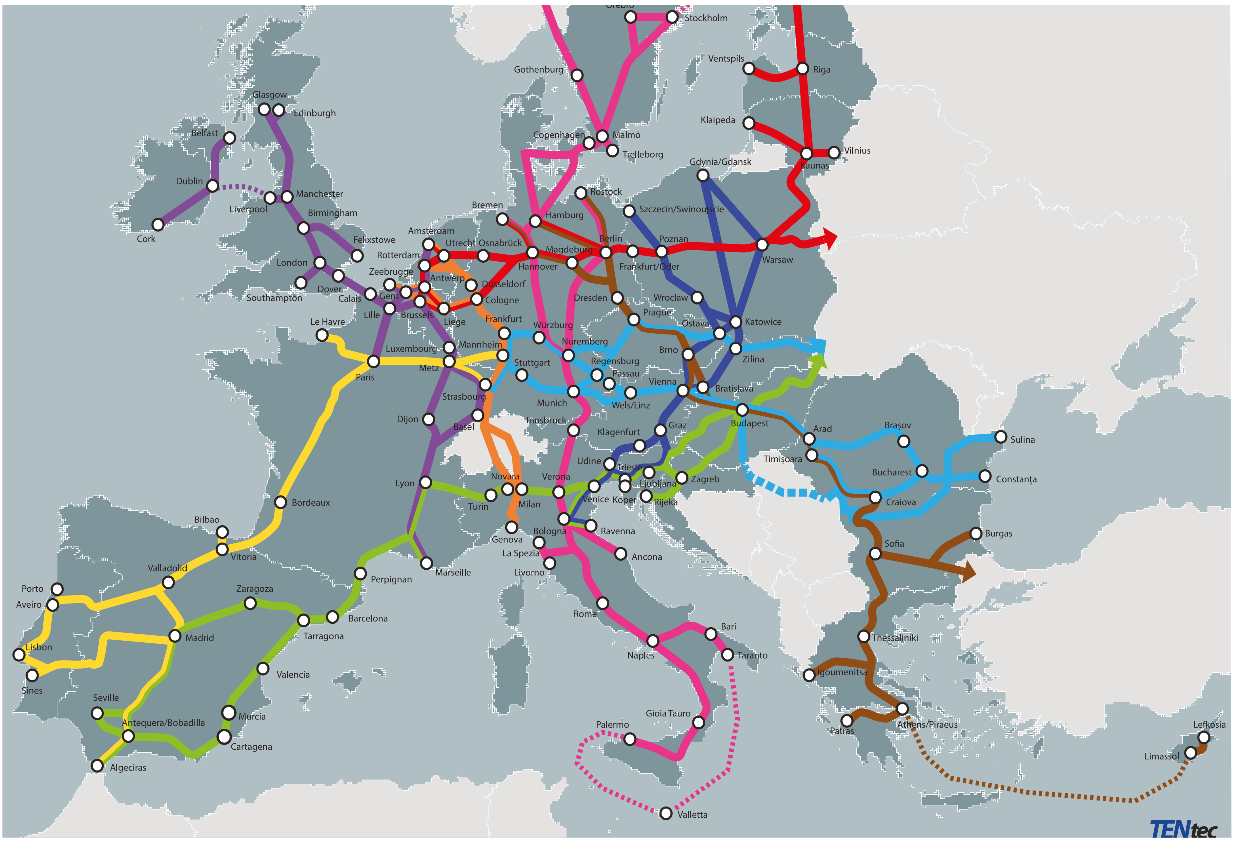


Figure 1. Rhine-Alpine Corridor (Orange colour) of TEN-T Core Network Corridors

Source: TEN-T Core Network Corridors (Regulation(EU)No1316/2013O.J.L348-20/12/2013)

However, concerning the HS rail operation at corridor-wide level, further improvement has been under discussion and further studies are required. Key challenges for HS rail and long distance (LD) rail services along the Corridor are to improve their service reliability and frequency. Given its important function as a rail freight corridor (NEA, University of Leeds, PWC, and Significance, 2010), there are a number of complex issues in mixed-use railway infrastructure such as the coordination with different train services. Nevertheless, new infrastructure, namely the construction of dedicated HS lines, is difficult to envisage due to limited financial and spatial resources, and thus better use of existing rail tracks is necessary for easing congestion of existing lines.

An investigation of capacity reserves is required from the perspective of HS rail to identify reserves of existing railway tracks with reference to conditions such as block distance and safety equipment, differences in speed between train categories, national regulations, and service hours of terminals and tracks.

CODE24 (Corridor 24 Development Rotterdam-Genoa) is a strategic trans-national initiative in the framework of the INTERREG IVB NWE Programme of the EU. The project ran from 2010 to 2014 and the partnership consists of 18 members including regional and local authorities, the ports of Rotterdam and Genova, research institutes, infrastructure and logistics consulting companies from the Netherlands, Germany, France, Switzerland and Italy (Figure 2). The project has identified several rail capacity bottlenecks to coordinate passenger and freight services which share the same railway tracks on a majority of routes. Although the initial focus of the CODE24 project has been placed on improving the flow of rail freight and its implications for corridor development, there is a need for exploring better ways of maximising HS rail and LD rail services in parallel with rail freight and regional and local train services, given the increasing importance of promoting HS rail at European trans-national level. In this respect, Action 17 was launched in April 2013, as one of actions by the CODE24 initiative, to discuss passenger rail development with a particular emphasis on HS rail provision along the Corridor.
The Action 17 team consists of members from Autorità Portuale di Genova, ETH Zürich, ILS, Verband Region Rhein-Neckar, Regionalverband FrankfurtRheinMain, SiTI and Uniontrasporti. Details of the members and their responsibilities for the action are listed in Chapter 10.

1.1 Action 17 – Objectives

Action 17 aims to develop guidelines for pursuing an integrated railway network along the Corridor through the introduction of an integrated international timetable which encompasses HS rail as part of long-distance services, regional trains and freight transport. In order to identify the specific role of HS rail in Corridor 24, the following objectives have been set up:

- To stress the importance of passenger HS rail network in Europe and Corridor 24;
- To visualise passenger rail transport that operates in response to the concept of an International Integrated Timed Transfer (IITT)[2];
- To improve the interconnectivity between regions along the Corridor and the regional network accessibility around major transfer nodes.

In response to these objectives, three activities have been carried out to visualise the current state of passenger rail services of selected nodes (i.e. key stations along Corridor 24) as well as the interconnectivity between the main nodes:

1. Assessment of HS/LD rail integration within Corridor 24 railway services;
2. Proposal for a systematic timetable (IITT);
3. EXPO 2015 case study: Genova and Rho-Fiera connection.

1.2 Methodologies for the Three Activities

Methodologies for conducting the three activities have been developed and refined through several discussions undertaken among the Action 17 members. The first activity (Assessment of HS/LD train integration within Corridor 24 railway services) has taken into account two levels of accessibilities. Timetables of different train services in selected key nodes have been analysed to assess 'regional accessibility'. Subsequently, in order to identify the Corridor accessibility, connections between the

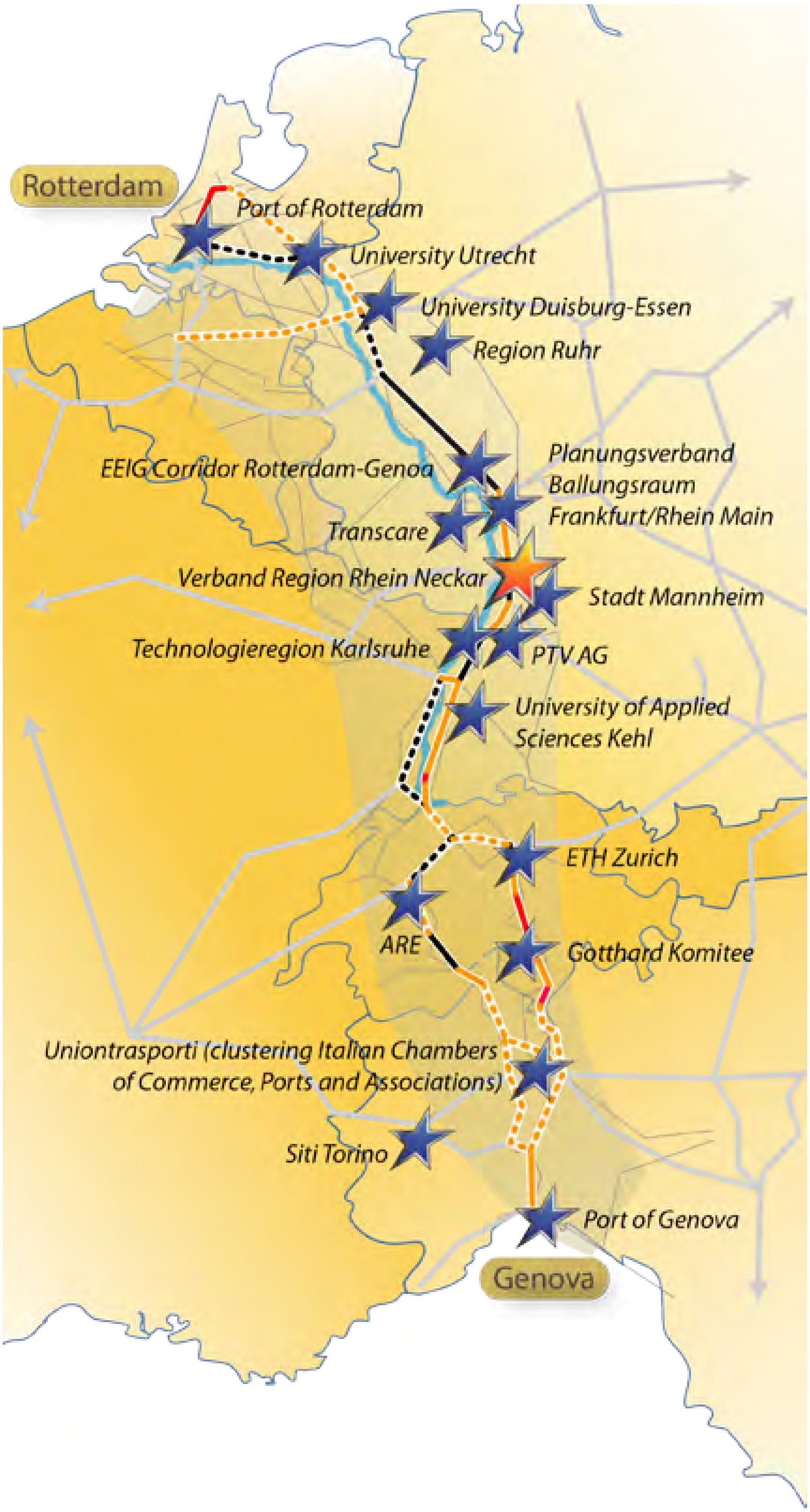


Figure 2. CODE24 Partnership
Source: ETH Zürich and CODE24, 2013

main origins and destinations (OD) pairs along the Corridor have been examined with reference to passenger flows for NUTS 3 zones. For the second activity (Proposal for a systematic timetable), existing train timetables for the services along the Corridor Rotterdam-Genova have been analysed in order to discuss potential travel time savings at main nodes and to explore the feasibility of applying an IITT concept. This concept showed good practice in Switzerland, most parts of Germany and even more recently in France and Italy. Finally, the EXPO 2015 in Milano has been selected as a specific case study to explore the feasibility of a special train service between Genova and Rho-Fiera (rail station for EXPO area) by analysing the accessibility to the fair, a graphical train timetable and preliminary demand estimation for train services.
In order to discuss preliminary findings of the three activities, an expert workshop was held in Frankfurt am Main on 12 June 2014. The workshop has provided a useful opportunity to test methodologies and preliminary results with experts in the fields of HS rail development, transport and spatial planning as well as railway management and research.

1.3 Structure of the Report

This final report is organised for describing the process and outcomes of Action 17 activities. It starts with a literature review on HS rail experiences in Europe and overseas and throws light into the relevance of HS rail operation to Corridor 24 (Chapter 2). Then the two activities are described in detail: Assessment of HS/LD rail integration (Chapter 3) and EXPO 2015 case study (Chapter 4). In each activity the scope and objectives and background information are firstly presented. Subsequently, the report explains the detailed process of developing methodologies used for the activity and results, and suggests some proposals for future improvement areas concerning the integration of HS rail to Corridor 24. Following the explanation of the two activities, Chapter 5 provides a short summary of the expert workshop.

Chapter 6 contains the proposal for a systematic timetable including insights gained during the expert workshop. The report concludes by highlighting important factors in the integration of HS rail with existing railway network of Corridor 24 and suggesting guidelines for future improvement areas (Chapter 7). The report contains rich material on the analyses made during the project phase. In order to keep it readable, some detailed illustrations have been enclosed in an annex to this report which can be accessed online via www.code-24.eu or www.egtc-rhine-alpine.eu.

2 High-Speed Rail Framework in Europe and Overseas

This chapter aims at providing an overview of HS rail in Europe and overseas. Furthermore, some empirical evidence is necessary to better appraise the suitability of HS rail along the Rhine-Alpine Corridor.

2.1 High-Speed Rail – Definiton, Strengths and Weaknesses

The following content is drawn from a literature review issued in a document for CODE24 and published partly (Arnone et al., 2015). HS rail is in many cases focused on passenger related LD rail services with an operating maximum speed of 250 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). UIC (International Union of Railways) refers to this but uses for its inventory a minimum of 250 kph (UIC, 2014). HS rail can be considered from different angles. Givoni (2006: 609) provides a broader definition of highs-speed rail: "…high capacity and frequency railway services achieving an average speed of over 200 kph." Table 1 summarises the average and maximum speed of HS rail between relevant cities.

It confirms to a certain extent that, with a maximum speed of 270 kph, the Tokyo-Osaka line attains a

Table 1. Comparison of HS Rail Lines: Speed, Distance

Origin-Destination	Distance (km)	Travel Time (h)	Average Speed (kph)	Maximum Speed (kph)
Köln – Frankfurt	179	1.05	170.48	300
Brussel – 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	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: Guirao 2013, Germanwatch 2013

higher average speed than Germany's fastest line Köln-Frankfurt with a maximum of 300 kph. On the Milano-Roma line the effect of additional stops can be observed. Overall, the notion of the average speed appears more appropriate to assess the effectiveness of rail performance than the maximum speed.
It becomes apparent that designing HS rail for maximum speed may reduce the number of stations served and thus require larger stations headways. 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). Ureña et al. (2009) raise further awareness for so-called intermediate stations such as Zaragoza, Lleida and Tarragona on the Madrid-Barcelona line or Córdoba on the Madrid-Seville line as generator of relevant amounts of ridership. In the Madrid-Barcelona case only 50% of demand is between both metropolises. Thus, a trade-off between speed/ travel time and potential ridership generated is required (Givoni, 2006). Vickerman (2013) discusses the potential of HS rail to generate demand among commuters as it is the case for the Javelin HS train - allowing daily commuting from Kent to London - and for the French TGV in the Nord-Pas de Calais region. Rebmann (2011) considers commuting as the less important trip purpose for long-distance travelling. Therefore, a frequency of every four hours appears to be sufficient in order to bundle these groups who undertake mostly planned trips. Analyses from the Rome-Naples 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). Besides trip purpose, the modal shift effect for HS rail needs to be assessed. Shifting demand from air to HS rail is one aspect. This is confirmed by the substantial shift in the Paris-Lyon line and the Madrid-Sevilla line attained three years after their release in 1981 respectively in 1991 (Givoni, 2006). In the Spanish case the market share of air travel was reduced from 40% to 13% while train ridership rose from 16% to 51%. Referring to Paris-Lyon, the share of air was reduced from 31% to 7% and HS rail increased from 40% to 72% (Table 2). It should be noted that in both cases overall amount of trips increased within the three years observed: 37% in the Paris-Lyon case and 35% with respect to the Madrid-Sevilla line (Givoni, 2006). Givoni and Dobruszkes (2013) stress the modal shift effect from air to rail while referring to HS rail services such as London-Paris/Brussels or lines in China, Taiwan or South Korea. Dobruszkes (2011) raises the awareness for the supply side since he observes an overall increase in air traffic in Europe though HS rail is successful on some connections. The substitution effect on car appears less evident, first because figures are not often available and second, because a HS rail network with fewer stations may require more car use to get to the stations (Givoni and Dobruszkes 2013). Nonetheless, the car is an important competitor for HS rail, especially for shorter distances. For the Barcelona-Madrid HS rail line, opened in 2007, a survey carried out in 2009 reveals that 44% of the customers used the car before shifting to rail, 8% used the bus, 16% made their trip by plane and another 23% "moved" from other conventional trains to HS rail. The remaining 10% can be considered as induced traffic (Frontier Economics et al., 2011).

Table 2. Mode Shift Effects of HS Rail 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 Whole Italian Travel Market

Mode	2009 (Million trips)	2009 (Share,%)	2013 (Million trips)	2013 (Share,%)	2013-2009 (abs.)	2013-2009 (%)
Car	38.7	57.3	31.4	45.2	-7.3	-19.0
Air	7.1	10.5	5.0	5.0	-2.1	-29.0
HS rail	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	69.6	100	2.0	3.0

Source: Cascetta and Coppola 2014

A before-after study in Italy made by Cascetta and Coppola (2014) shows evidence that HS rail can gain market shares also from the air segment which was reduced by 29% in relative terms, and from the car which reduced by 19% in relative terms but starting from a higher level before and thus more evident in absolute terms. HS rail increased by 81% from 2009 to 2013, but conventional trains ("Intercity") lost about 52% of its users within three years (Table 3). This latter case and the Madrid-Barcelona case mentioned above reveal another aspect: the loss of customers for conventional rail. Dobruszkes and Givoni (2013) report up to 94% of users in the case of Madrid-Sevilla that no longer use conventional trains once HS rail has 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 the aircraft, 16% from the car and bus, and 6% new -induced- demand) (Sands, 1993b, quoted by Givoni 2006).

In view of this, it should be discussed at which costs rail infrastructure is designed to deliver air substitution if, on the other hand, the land-use transport nexus may be threatened. The emergence of new stations at the edge of towns or "in the greenfields", also qualified as "TGV-generation stations", which 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, rail as backbone for urban and regional development loses overall quality if a loss in conventional rail service may occur. 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, HS rail is suitable to serve a wide range of purposes and is able to shift demand from other modes, especially if considering air as the sole competing mode or neglecting the induced traffic and cannibalising effect on conventional rail.

Another issue is how new dedicated lines are used. An inquiry made by UIC in 2009 revealed that almost none of the lines fully use the available capacity (Table 4). Based on the assumption that HS rail trains can operate with a five minutes headway, up to twelve trains could run in each direction every hour. Even if it is every ten minutes, there could still be six trains running in each direction. The highest capacity use on the Paris-Lyon line appears to have attained a saturation with 13 trains per hour so that

Table 4. Number of Trains per Hour, Cross-Sectional

Line (section)	HS train type	HS trains per hour
Paris-Lyon (Moisnay-Pasilly)	TGV	13
Berlin-Hannover	ICE 1+2	4
Köln-Frankfurt	ICE 3	10
Hannover-Fulda	ICE 1+2	7
Karlsruhe-Basel	ICE1+3, TGV	4
Mannheim-Stuttgart (east branch)	ICE1-3, ICE-T, TGV	6
Milano-Roma	„Frecciarossa" ETR 500	4
Roma-Napoli	„Frecciarossa" ETR 500	2
Madrid-Barcelona	AVE, ALVIA, AVANT	6
Madrid-Córdoba	AVE, AVANT, ALTARIA	9
Madrid-Valladolid	AVE, ALVIA, AVANT	4
Tokyo-Mishima „Nozomi"	„Nozomi" Super express	9
Tokyo-Mishima „Hikari"	„Hikari" Express	2
Tokyo-Mishima „Kodama"	„Kodama" Ordinary	3

Source: UIC, 2009, authors' adaptation

an additional parallel HS rail line is required since additional trains are needed in the future (Andersen, 2010). On the Frankfurt-Köln line, there are up to four trains operating in each direction per hour (UIC 2013). Nonetheless, it is often argued that "… capacity continues to be the main reason to construct high-speed lines, while the gain in speed will be relatively small, e.g. on the Rome to Naples line Givoni (2006: 600)."

The current debate on the implementation of HS rail in the United Kingdom is based on the necessity of promoting rail as an alternative to the increased congestion on the motorway and the domestic air travel producing evitable amounts of carbon emissions and to increase capacity on the network (Greengauge21, 2007).
As a summary, the following table puts together the main findings which are used for the work done within the project.

2.2 Overseas High-Speed Rail Experiences

This section introduces HS rail operations beyond the European context. Among six countries operating HS rail outside Europe (China, Taiwan, Japan, South Korea, Turkey, U.S.), two distinctive cases have been selected for the review: 1) Japanese Shinkansen and 2) U.S. HS rail network development. The Japanese Shinkansen is the first HS rail operation in the world with 51 years of operation history; the development of European HS rail has largely borrowed the idea of Shinkansen model. Secondly, the development of HS rail network in U.S. seems to be an interesting case for European counterparts since they aim to establish a trans-American railway network integrating HS rail which have been promoted by the America 2050 policy. The U.S. approach resembles pan-European HS rail network supported by the TEN-T policy. In the following, HS rail operation in the both countries is discussed.

Table 5. Summary of Main Findings

Issue	Findings
Maximum speed often not sufficient	Italy: 300 kph (maximum); ø 140-177 kph (average) Spain: max 310-320 kph; ø 177/168 kph Spain: max 240-260 kph; ø 169 kph Japan: max 270 kph; ø 212 kph France: max 300 kph; ø 218 kph
Users' Profile	Car considerable part: e.g. Italy, partly France and Spain Air especially where long-distances > 200 km Shift from conventional rail and thus reduction of services Not Only business, also leisure, commuting Not only big city – big city trips – intermediate cities important
Network/Capacity	(new/HS rail) Stations to be integrated into a city/existing rail network Stations headway below 200 km Stations in the greenfield doubtfully successful Network effect to be considered/integration with regional hinterland/catchment area Capacity of HS rail lines not fully utilised

Source: Authors' elaboration based on previous findings

2.2.1 Japanese Railway Development and the Shinkansen Corridor

The success of Japanese railway development has been widely remarked with reference to the Shinkansen, which is the world's first full-scale HS train system that began in 1964, in coincidence with the Tokyo Olympic Games. The Shinkansen (literally 'new trunk line') has been recognised not only as merely the 'bullet train' and a means of travelling at high-speed and on time between major cities, but also as a potent symbol of Japan's post-war development (Hood, 2010). Up to date some 2,388 km of high-speed dedicated lines have been completed in Japan (Japan's MLIT, 2010; Figure 3). The success of the Shinkansen went on to strongly influence the opening of the French TGV in 1981, followed by the Italian Direttissima in 1988, the German ICE in 1991, the Spanish AVE in 1992, and Eurostar in 1994 (Nakagawa and Hatoko, 2007).

The Shinkansen system is undoubtedly the world's leader in terms of volume, safety and punctuality (Smith, 2003) and most publicity on the Shinkansen system tends to be centred on the Tokaido line (literally 'east coast road'), between Tokyo and Osaka. This is the first phase of the Shinkansen project to be completed (515 km) by constructing a dedicated line and it is one of the largest and most stable transport corridors in the world; carrying approxi mately 410,000 passengers per day with 320 daily services (Ogawa et al., 2008). This corridor has a catchment population of almost 55 million (40% of the total Japanese population) and serves a region producing 49% of national GDP (Smith, 2003). This high concentration of population is characteristic for Japan which is a mountainous country consisting of four main islands. Less than one fifth of the land is suitable for development and agriculture and the majority of the population lives in cities along the Pacific coast. The Tokaido corridor

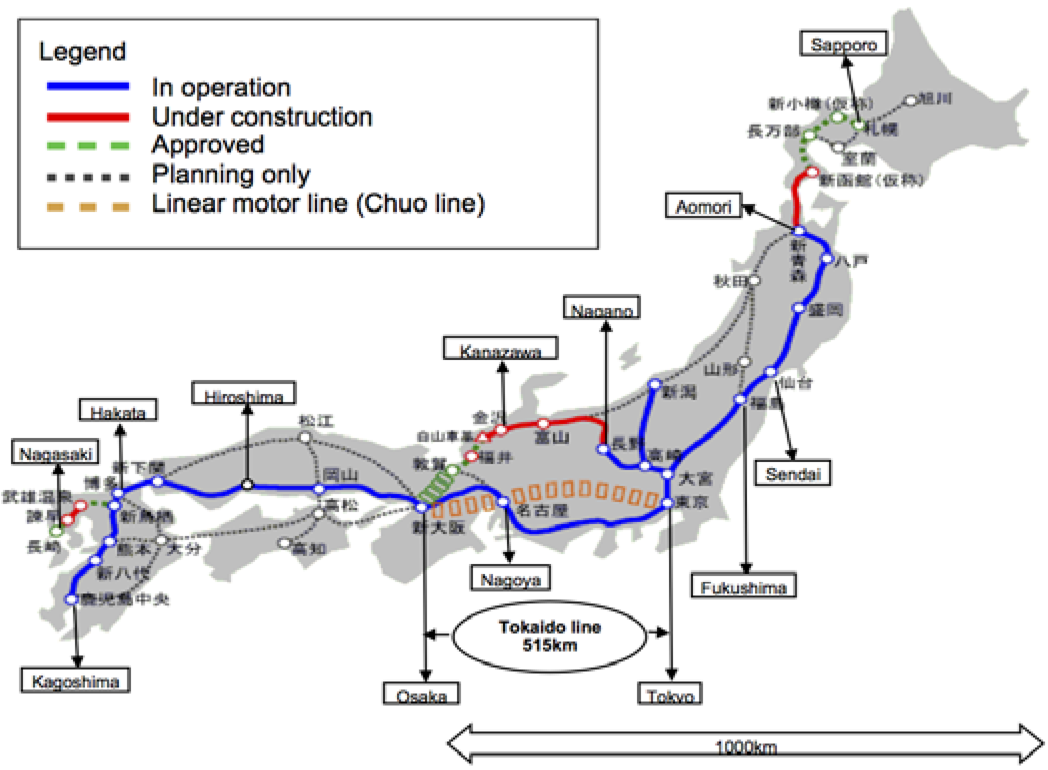


Figure 3. Shinkansen Network

Source: JRTT, 2012, English translation and information of Tokaido line are added by Otsuka provides the backbone of the Japanese economy and it is undoubtedly the most important route in the country when it comes to the future expansion of passenger and freight rail services.

The Tokaido Shinkansen is the most heavily scheduled HS rail service in the world (Ogawa et al, 2008) and there is no leeway for adopting further trains at the moment. To ease its capacity limit, two alternative Shinkansen routes are to be introduced: the Hokuriku line which is already under construction and the so-called Chuo line which has been recently granted a planning permission by the Central Government with plans to open in 2027 (Asahi Shinbun, 2014). The Chuo line will be ultra-high-speed being powered by linier motors and will link Tokyo with Osaka in just 1 hour (Nakagawa and Hatoko, 2007; Figure 3).

To sum up, it is clear that the Japanese railway has so far largely prioritised passenger trains with an emphasis on the development of HS rail corridors with a dedicated line all over the country, while rail freight service has been neglected and relied on limited slots available on the conventional lines.

2.2.2 U.S. Railway Development and the Acela Line (Northeast Corridor)

The U.S. railway development shows a contrasting insight from its Japanese counterpart. Brown (2010: 55) stated that "America is an absurdly backward country when it comes to passenger trains" and it is no doubt to say their priority has traditionally been placed on the development of freight rail over passenger service. Most of passenger rail services are operating on freight 'rights-of-way' in the U.S., and this situation makes it difficult for passenger trains to achieve a higher speed and to increase their capacity (Todorovich et al, 2011).

Until recently HS rail in the U.S. has been limited to the Acela express on the Northeast corridor, where Amtrak began the service in 2000 connecting the 728 km between Boston and Washington D.C. through New York City, Philadelphia and Baltimore. This corridor is the most heavily used rail line in the U.S., carrying approximately 250 million passengers per year by both the conventional and Acela lines (Todorovich et al, 2011). Approximately 52 million people are currently living in these regions and an additional 18 million inhabitants have been estimated by 2050 (Woods and Poole Economics, 2010). The Northeast 'megaregions' (the concept is defined below) have 18% of the total U.S. population and represent 20% of national GDP (Chen, 2010). Due to the high population density and the growing travel demand between these megacities, major railways, highways and airports are now reaching their capacity limit. The investment in HS rail service can be considered as an effective tool for increasing accessibility and stimulating economic activities along the corridor (Chen, 2010; Ross, 2011). However, the performance of the Acela express has lagged behind comparing to other HS rail services in the world. The Acela express uses a tilting train running over nineteenth-century tracks and achieving a maximum speed of 150 miles per hour (Hall, 2011). The lack of a dedicated track and complicated railway ownership are the key causes for lower rates of on-time performance (punctuality), capacity and frequency. Freight operation and conventional intercity rail and commuter rail services have greatly impacted the performance of the Acela express, and in fact freight railways accounted for over 2.8 million of Amtrak's 3 million delay minutes in 2003 (Chen, 2010).

While Japan's Tokaido Shinkansen can carry more than 1,300 passengers per train travelling at over 250kph and operating on 5-10 minute headways, Acela train accommodates only 300 passengers operating on 60 minute headways at average speeds of less than 130 kph (Todorovich et al, 2011: 41).

In 2009, the Obama administration announced the allocation of $US 8 billion of federal funding for kick-starting HS rail projects. In the same year the Federal Railroad Administration launched the HS Intercity Passenger Rail Programme, which is designed to connect communities end-to-end through the construction of an efficient network of passenger rail corridors (Ross, 2011). In parallel with the recent federal government efforts, a new national planning initiative, America 2050 should be mentioned. The initiative was launched in 2005 and has identified eleven megaregions where most of the population growth by mid-century will take place in the U.S (Regional Plan Association, 2013). The ten new HS rail corridors designated by the Obama Government all traverse the megaregions, and HS rail would therefore become a promising transportation mode for relieving the future congestion and improving inter-megacity connections (Chen, 2010).

For the improvement of passenger trains a variety of operational models have been introduced, ranging from dedicated line to track shared by conventional trains. The U.S. approach is a contrasting case to the Japanese Shinkansen model, which applied a standardised development process for the last five decades, predominantly based on HS running on a new dedicated line. The vision of the latest U.S. railway development aims at 'tiered passenger rail corridors' that take into account the different markets and geographic contexts found throughout the United States. The corridors have been divided into the four tiers: 'Core Express Corridors', 'Regional Corridors', 'Emerging/Feeder Routes' and 'Community Connections' (U.S. DOT, 2010: 10). The initial phase of the HS rail development has been planned on the Northeast and California corridors (Figure 4). In 2008 California received a federal grant to create a 'Core Express Corridor' connecting major cities which aims at reaching the top speeds of 350 kph on new, dedicated lines. The existing Acela line falls into the category of 'Regional Corridors' running on dedicated and mixed tracks with frequent 140-200 kph service, and new proposals have been drawn up to upgrade the line to the Core Express standard (Todorovich et al, 2011).

Although the strong national government leadership and some financial incentives for the HS rail development are now in place, several state governors cancelled rail projects in 2011, which resulted in Congress to appropriate no funding for HS rail projects (Todorovich et al, 2011). In the face of the severe economic downturn, the HS rail's high investment costs have been questioned since it is difficult to justify the full range of accessibility and economic benefits to local communities along the new HS line.

HS rail is still a new notion for U.S. railway industry, which has a strong tradition of investing in the

Figure 4. A Phasing Plan for HS rail in U.S.

Source: Regional Plan Association, 2013, name of the major cities are added by Otsuka freight market. Railway industries have invested the highest percentages of the revenues in freight railways to maintain the state of good infrastructure and add more capacity to their system. (U.S. DOT, 2010). It is therefore most likely this trend will continue and the development of HS rail corridors in U.S. will face a number of difficulties in obtaining supports from both business and local communities.

2.3 European High-Speed Rail Network – Past and Future

In Europe, the very early concepts for high-speed rail development started in the 1970s and 1980s and were limited to national boundaries (Vickerman, 1997). However at this time an extensive network of cross-border EC-services, already connected cities and regions. The HS rail concepts focused on capacity increase on critical network segments such as in France or on the provision of faster connections to remote areas which is pertinent again to France and Spain. Germany developed ICE-lines in order to gain travel time (Vickerman, 1997).

A European network has been developed later. First examples include the lines between Paris, Brussel/Bruxelles, London, Amsterdam and Köln followed by extensions of the French network to the east. French TGV operates abroad in neighbouring countries since the late eighties. In Italy, HS rail was designed predominantly in order to increase capacity to provide more train services (Givoni, 2006). Today, the Spanish HS rail network comprises of 2,515 km according to the UIC-standard (UIC, 2014). The first

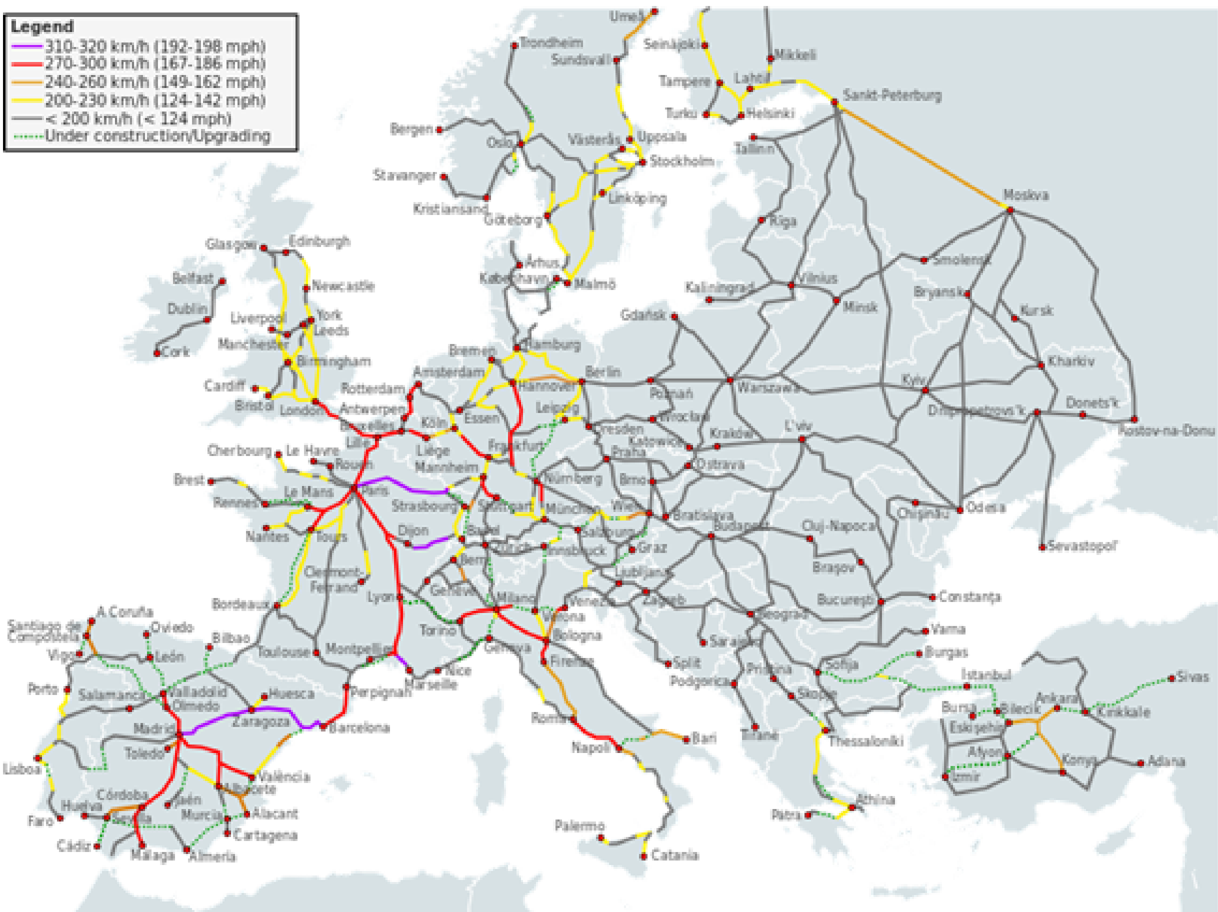


Figure 5. Trans-European High-Speed Network

Source: http://en.wikipedia.org/wiki/High-speed_rail_in_Europe, User: Bernese media and RScheiber and others, accessed 9 February 2015 line was the Madrid-Sevilla axis opened in 1992. In terms of integration it has to be noted that the HS rail network uses the standard 1,435 mm gauge thus allowing cross-border services to France. However, the remaining conventional rail network is mainly in broad gauge of 1,688 mm width. The Spanish HS rail network AVE is running centred towards Madrid. Only few lines bypass the Spanish capital (Guirao, 2013). In Spain HS rail dedicated lines are jointly used by the AVE-trains and "slower" conventional trains (Vickerman, 1997).

In Sweden, tilting trains have been used in order to achieve an operating speed of up to 200 kph which was considered sufficient in order to satisfy the needs for fast connections according to the network company (Vickerman, 1997). In the United Kingdom insufficient capacity on the rail network was even a reason against the development of HS rail in the 1970s and 1980s (Givoni, 2006). In 2011, official statistics defined a 6,879 km network comprising lines allowing a maximum speed of 250 kph and more (European Union, 2013). However, a closer

Table 6. HS Network and Extensions in Europe (km) - Lines with Maximum Speed ≥ 250 kph

	Existing (Sept 2014)	**Under construction**	**Planned (fixed)**	**Planned (long-term)**
Austria	48	0	201	
Belgium	209	0	0	
France	2,036	757	50	5,200
Germany	1,352	446	0	324
Italy	923	125		221
Netherlands	120			
Poland				712
Portugal				1,006
Russia			3,150	
Spain	2,515	1,308		1,702
Sweden				750
Switzerland	35	107		
United Kingdom	113		543	

Source: UIC, 2014

look at Figure 5 reveals that – according to the EU-definition of HS rail provided above – the network is a lot larger if considering lines with 200 kph and more.

UIC has an extensive overview of HS rail infrastructure used and planned in the world but only considering lines enabling trains with a maximum speed of 250 kph and more (UIC, 2014). According to this narrow definition, Spain has the largest network with 2,515 km leaving France behind with a 2,036 km network length, followed by Germany with 1,352 and Italy with 923 km (UIC, 2014, Table 6).

For the EU the issue of HS rail is a relevant ingredient to fulfil the EU main objectives including the smooth functioning of the internal market and the strengthening of economic, social and territorial cohesion which are set out in the Europe 2020 Strategy and the White Paper „Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system". The EU stresses the necessity to make better connections with HS lines and favours the creation of new development areas around newly created stations in the outskirts as one vital option (European Commission, 2010). The EU further pursues the development of HS rail in its Trans-European Transport Network (TEN-T) concept in order to achieve the common market goal and better connectivity. Resulting from this, operational concepts and services offered by the passenger operators should focus on better interconnections and network interoperability while using resources efficiently. In the perspective of the authors, this may lead to the concentration of services linking mainly metropolises and the creation of new stations along the HS rail lines but with less rail interconnectivity with conventional services.

It is clear that the development of HS rail has been promoted in European countries with the necessity to the increase of capacity and speed, which will continue to be on the political agenda to ensure better connectivity between European regions. The systems vary from country to country and major investments have been made in Spain and France. However integration in terms of track type, transfer at nodes, timetable still cannot be ignored.

Table 6 reveals the ongoing development of the HS rail network in France, Spain, Germany, Italy and Switzerland though in the latter case this refers mainly to the Gotthard and Ceneri tunnels under construction. In the near future, Russia has ambitious plans to deploy a network of 3,150 km. Britain foresees the so called HS rail line 2, linking London with Birmingham, Manchester, Liverpool and the Scottish metropolises Glasgow and Edinburgh (Martínez Sánchez-Mateos and Givoni, 2012).

Though average speed is a more suitable criterion to assess long-distance services of the Corridor, the network using the concept of maximum speed is

Frankfurt Hbf is one relevant node with many Cross-border train services.

Table 7. Characteristics of Line Segments along the Corridor - Maximum Speed ≥ 200 kph

	Category (max speed in kph)	Length (in km)	Existing (1), Under construction (2), Planned (3)
Utrecht-Oberhausen	200	156	1
Duisburg-Köln	200	64	3
Köln-Frankfurt	300	177	1
Frankfurt-Mannheim	200	80	1
Mannheim-Karlsruhe	250	70	1
Karlsruhe-Offenburg	250	75	1
Offenburg-Basel	250	107	1,3
Lötschberg-Tunnel	250	37	1
Gotthard-Tunnel	250	57	2
Genova-Milano (Terzo Valico)	300	54	2
Milano-Torino	300	125	1

Source: CODE24 Corridor-Infosystem (http://code24.ethz.ch/ accessed 26 January 2015), DB-Leaflets "Ihr Reiseplan" (available on board the IC-/ICE-trains)

first presented. Lines are categorised according to their maximum speed of 300 kph, 250 kph and 200 kph. Table 7 gives an overview of existing and planned lines.

The rail network enables seamless cross-border travel though there are no direct trains along the entire Corridor 24. There are regular EC-trains from Switzerland to Italy and at least hourly ICE-/IC-services from Switzerland to Germany via Basel and Schaffhausen heading towards Hamburg, Berlin and Köln along the upper Rhine-axis and respectively to Stuttgart. Between Germany and the Netherlands, five ICE-trains connect Amsterdam and Utrecht with Köln, Frankfurt and even one train runs down to Basel SBB station. Between Germany and France there are joint TGV-/ICE-services mostly linking to Paris with Freiburg, Strasbourg, Karlsruhe, Stuttgart, Mannheim and Frankfurt. One service runs from Frankfurt to Marseille calling at Manheim, Karlsruhe, Baden-Baden, Strasbourg and Mulhouse. Lastly, there is a long history of linking Swiss and French cities. Relevant to the Corridor are trains from Zürich to Paris and Lyon calling at Basel and Mulhouse. A schematic overview of the daily supply and reflection on the improvements to be made will be provided in Chapter 6. Given the expected infrastructure extensions and in view of the plans provided by train operators, some changes in the supply structure can be expected in the future, notably once the Gotthard and Ceneri Tunnel will be fully operating. An inventory has been made by ETH Zürich and is visualised hereafter (Figure 8).

2.4 High-Speed Traffic Trends in the Last Ten Years

According to European statistics, 110 billion passenger kilometres had been counted which included all train types capable to run with 200 kph. Existing Eurostat data shows that HS rail performance had been increasing in some European countries until 2011, notably in France with a steady increase in HS rail demand which has been more than doubled since the nineties. Germany sees a similar development though at a lower level. HS rail demand grew more substantianly in Spain since 2007 when the Madrid-Barcelona line started operation and subsequently other segments have been opened. Similarly, Italian HS rail performance has increased steadily until 2011 (Figure 6 and Figure 7). Concerning the latter, studies from Cascetta and Coppola (2014) indicate that more demand effects can be perceived. It was in 2009 when the Italian incumbent Trenitalia reinforced its HS rail activity with the line Torino-Salerno (calling

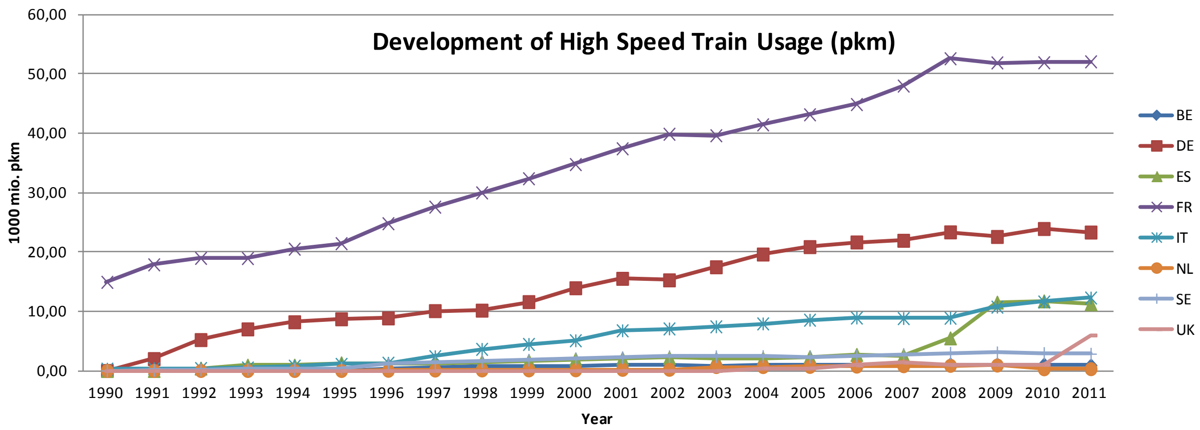


Figure 6. HS Rail Passenger Demand in some European Countries

Source: Adapted from European Union 2013, http://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2013_en.htm, accessed 4 November 2014

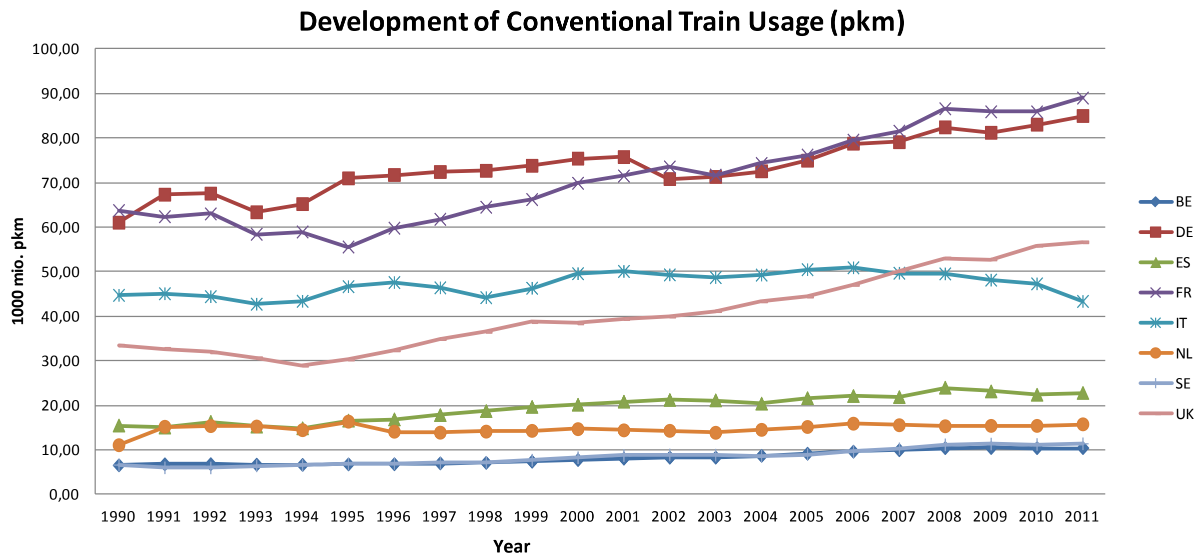


Figure 7. Passenger Demand for Conventional Train in some European Countries

Source: Adapted from European Union 2013, http://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2013_en.htm, accessed 4 November 2014

amongst other in Milano, Bologna and Roma) and then in 2012 the competitor NTV started operation though at a lower level given the fewer services (Cascetta and Coppola, 2014). The demand level for the United Kingdom and Sweden is quite low and remains unchanged over the years since there have not been newly implemented HS rail lines and thus services. While HS rail usage increased, conventional train services decreased or stagnated in some countries over the years.

A reduction in demand performance is true for Italy and Spain, but partly in the Netherlands if considering the last ten years. Conventional rail demand decreased in France and Germany in the early nineties and continued in Germany at the beginning of the millennium (Figure 7).

Figure 8. Rhine-Alpine-Corridor Infrastructures and Potential Upgrades
Source: ETH Zürich for CODE24

3 Current Integration between Corridor and Regional Services

3.1 Mobility Demand

The Rhine-Alpine Corridor covers some of the most important economic regions in Europe. Its catchment area includes 70 million inhabitants. Surprisingly, 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 NUTS 2 regions are available for 2005 and 2010, but several OD-pairs 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[3], 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 NUTS 3 zones, only using data coming from official statistics.

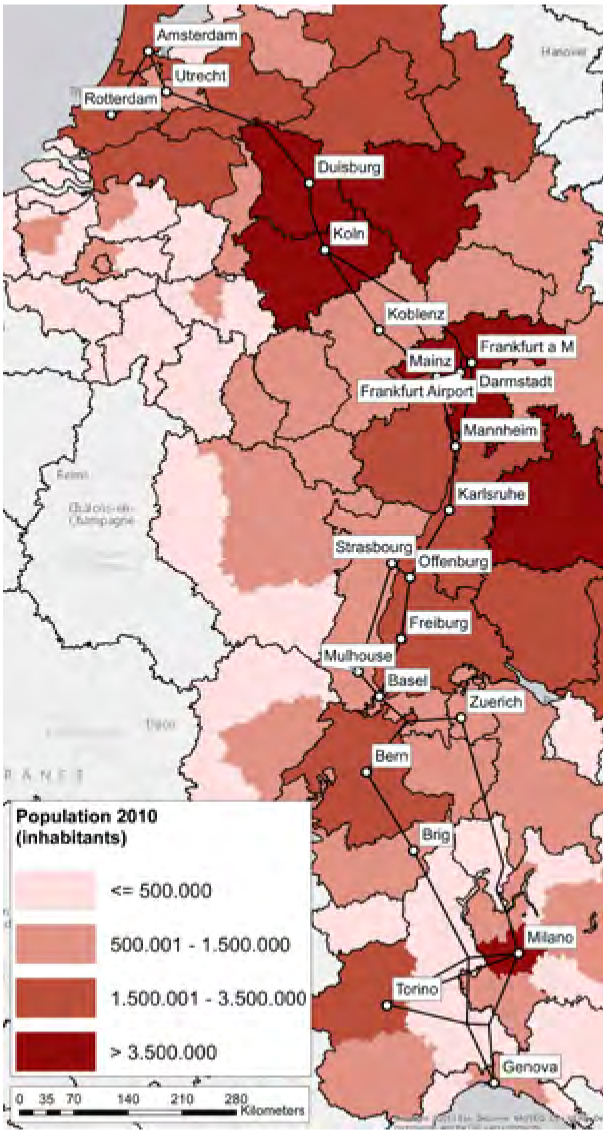


Figure 9. Map of the Zones Identified along the Corridor on the Basis of Their Population

Source: SiTI elaborations of Eurostat data; base map: Google Maps, Google Inc.

However, the ETIS+ project[4] 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 sets are useful to provide an overview on the Corridor mobility and identify the main OD relations. Therefore, the Rhine-Alpine Corridor catchment 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 (Figure 9). The zones correspond to provinces (NUTS 3) in Italy and France whereas in Germany, Switzerland and the Netherlands the zones correspond to regions (NUTS 2). Only zones along the Corridor were considered, e.g. the Bavarian 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 the 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.

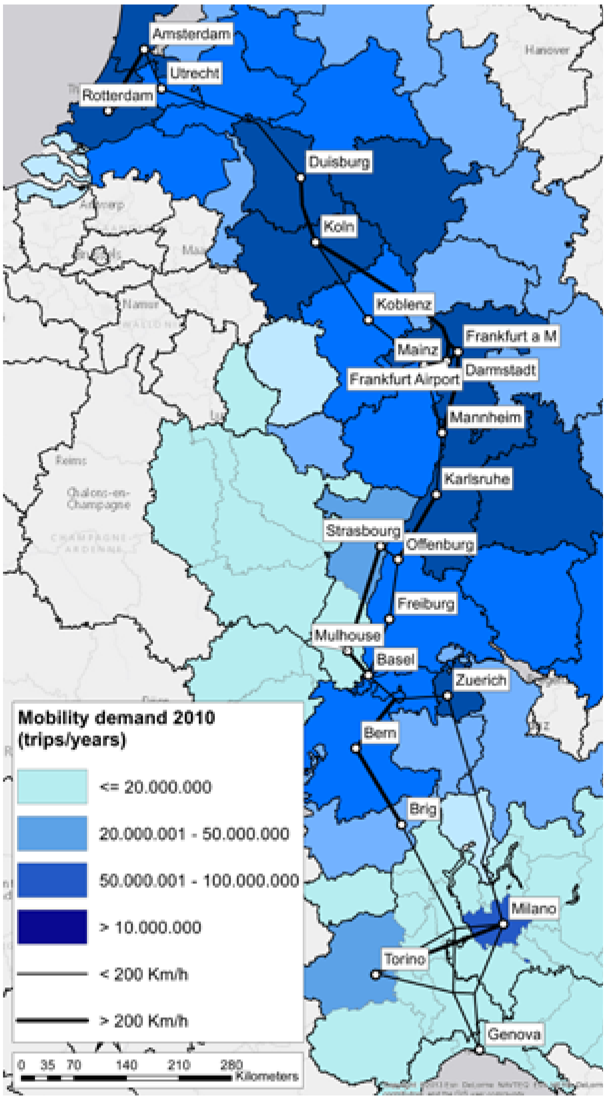


Figure 10. Number of Trips Generated and Attracted in 2010 by the Zones along the Corridor and Main Rail Stations Identified on the Basis of the Mobility Demand
Source: SiTI elaborations of ETIS+ data; base map: Google Maps, Google Inc.

3.1.1 Main Mobility Nodes

The analysis of the number of trips generated and attracted in 2010 by each of the identified zones, shows that the areas interested by the highest mobility demand (more than 50 thousands trips per year) are all crossed by the railway Corridor Rotterdam-Genoa and endowed with at least an important HS station (Figure 10).

Interzonal mobility demand proves to be generally proportional to the zone population, so the main mobility nodes in the study area correspond to the zones that have the highest number of inhabitants. However, there are also few exceptions such as the zones of Mannheim, Karlsruhe or Zürich which present a higher mobility/population ratio: these zones are located on important junctions between different Corridors in Europe and represent very important transfer points. On the other hand, other zones, like Milano for example, show a lower mobility/population ratio, probably due to the fact that in such areas intrazonal mobility demand (not considered in this analysis) is even more predominant than in other zones.

3.1.2 Main Mobility Relations

The ODs with the highest passenger mobility (relationships with more than five million passengers per year) are represented in Figure 11 on the left. The most relevant OD relations are at the national level: five large passenger demand clusters (indicated with circles in Figure 11 on the left) can be identified:

- The Netherlands;
- North-West Germany;
- Central/Southern West Germany;
- Switzerland;
- 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 trips between different countries are fewer than trips limited to domestic relations (Figure 11 on the right).

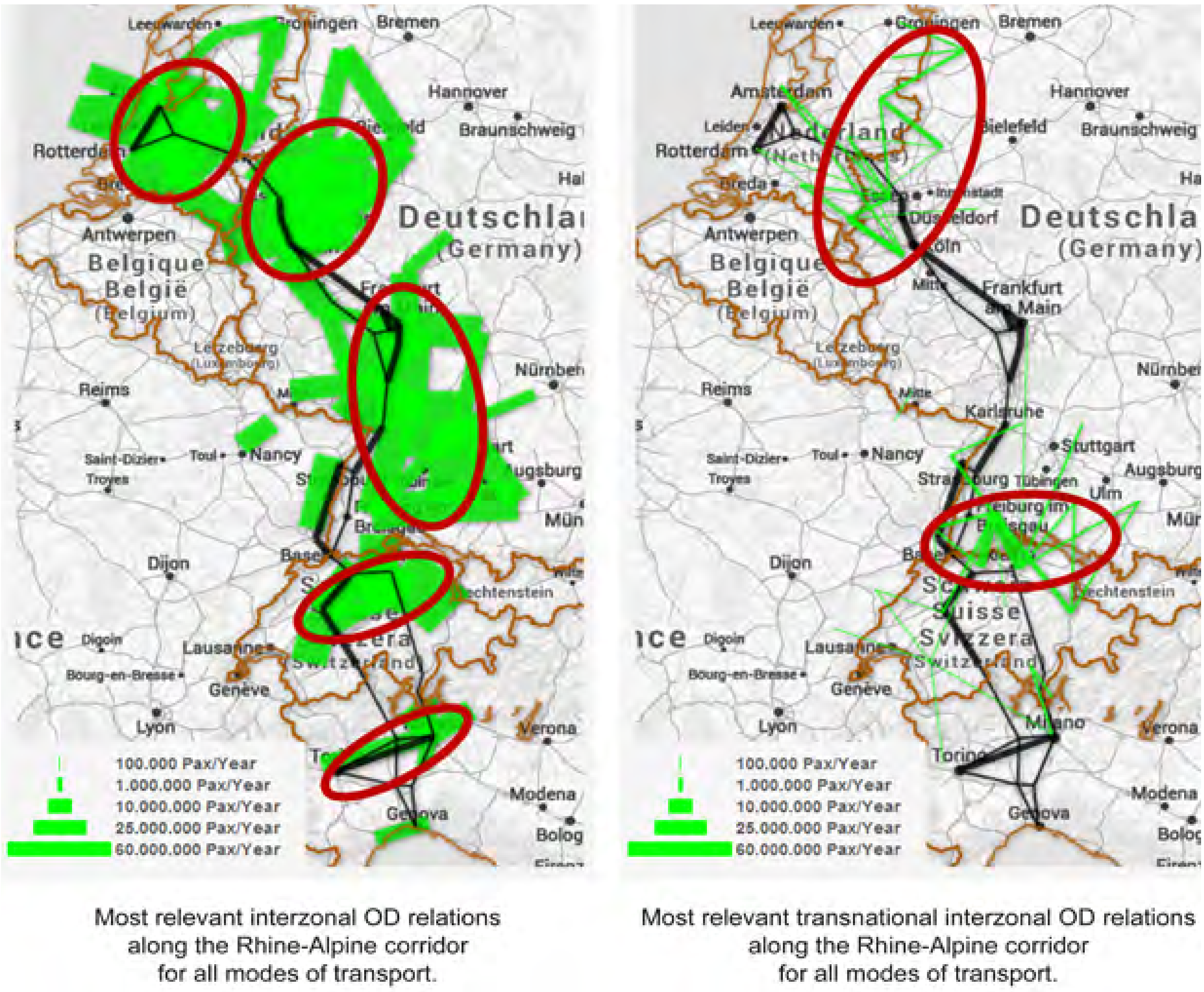


Figure 11. Most Relevant Interzonal and Transnational OD Relations
Source: SiTI elaborations of ETIS+ data; base map: Google Maps, Google Inc.

These transnational ODs are always characterised by less than 0.5 million passengers per year. Two main cross-border relations can be identified: one between Northern Germany and the Netherlands and another between Southern Germany and Switzerland. The relations between France-Germany, France-Switzerland and Italy-Switzerland appear to be less significant.

The previous comments are confirmed by Figure 12, which represents the annual interzonal mobility demand on the Corridor for all the modes of transport. The figure reveals high passenger demand

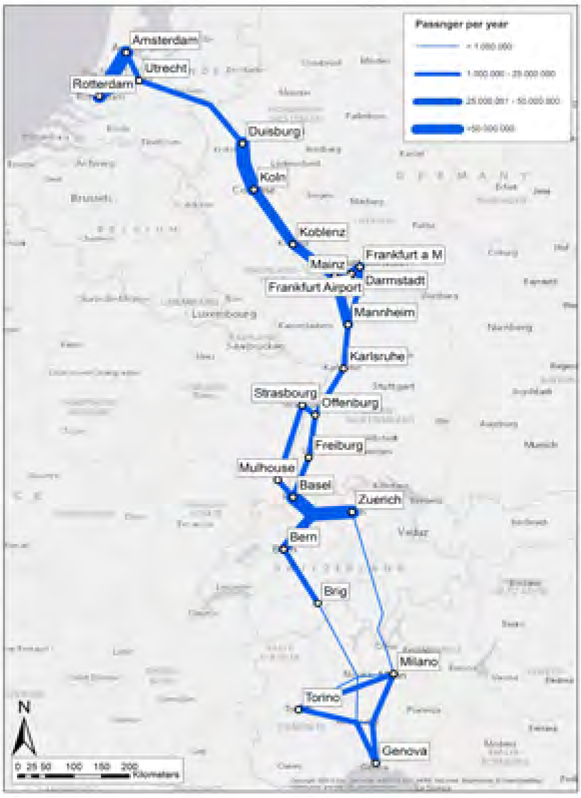


Figure 12. Yearly Interzonal Mobility Demand on the Rhine-Alpine Corridor for All Modes of Transport
Source: SiTI elaborations of ETIS+ data; base map: Canvas/World_Light_Gray_Reference, Copyright: ©2013 Esri, DeLorme, NAVTEQ

between Duisburg and Mannheim, and within the Netherlands and Switzerland. Lower, but still significant, demand exists for travels 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.

3.2 Railway Services Integration

Numerous factors contribute to an efficient integration of railway services, for example:

- Timetable integration for efficient transfer times between different services in the nodes;
- Integration of fares (especially when different operators offer services: the ticketing system needs to be regulated and extended also to interregional and local services so that it is possible to transfer to the next useful train in case of delayed arrival in transfer nodes);
- Information that allows users to share knowledge about available services and connections (e.g. costs, timetables, stops);
- Regulations to coordinate cooperation among both the public authorities and the operators;
- Service reliability that reduces the risk of missing the connection in case of delays.

In the following analysis integration was evaluated only in terms of timetables and efficient transfer times in the main nodes along the Corridor in order to investigate how to exploit the travel time benefits that planned improvements along the railway network will bring.

In order to assess the level of integration of the railway services along the Rhine-Alpine Corridor, two types of integration have been considered:

- Integration between high-speed (HS) and long distance (LD) services to connect the main stations along the Corridor, which was defined as corridor accessibility;
- Integration between high-speed and long distance (HS/LD) and interregional and local (I/L) services to connect the main stations along the Corridor with their hinterland, which was defined as regional accessibility.

The corridor accessibility analysis is aimed at assessing whether the Rhine-Alpine Corridor can be considered seamless and if the current rail services along the Corridor, in particular, cross-border services provided through HS/LD trains, serve adequately the national and transnational demand and are competitive with other transport modes (car and plane). Planned upgrades and improvements of the railway line will further reduce current travel times. If not wasted with long waiting times in the interchange stations, this could be used to capture new demand from other modes and to serve new OD pairs.

The efficiency of HS/LD services connecting the main nodes along the Corridor can also be evaluated according to the volumes of satisfied passengers.

In order to assess whether the main HS stations are adequately connected with their hinterlands and are able to attract and efficiently serve the local demand, regional accessibility has been analysed.

3.2.1 Methodology and Data Visualization

Each of the raised issues was analysed with a different methodology, as summarized in Figure 13.

The *corridor accessibility* analysis considered the main demand flows, connecting stations more than 100 km apart along the railway axis: for each OD pair (both national and international) showing high mobility demand (more than 5 million passengers) data related to the supply of direct rail services on a typical day (a weekday in October 2013) were collected. Data on daily direct services were also collected for other international OD pairs with lower demand; in case of lacking direct services or few direct services, non-direct railway connections were analysed.
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' published data and it is not easy to estimate since train capacity can vary greatly between different countries and lines.
Finally, the analysis considered transnational OD pairs for which train could become competitive against air transport, following the forecasted improvements on the network. Data on their current daily connections were collected and analysed in order to understand how to maximise the benefits achieved with the railway improvements.

Regional accessibility to HS and LD services in the main nodes along the Corridor was also investigated: the analysis focused on the

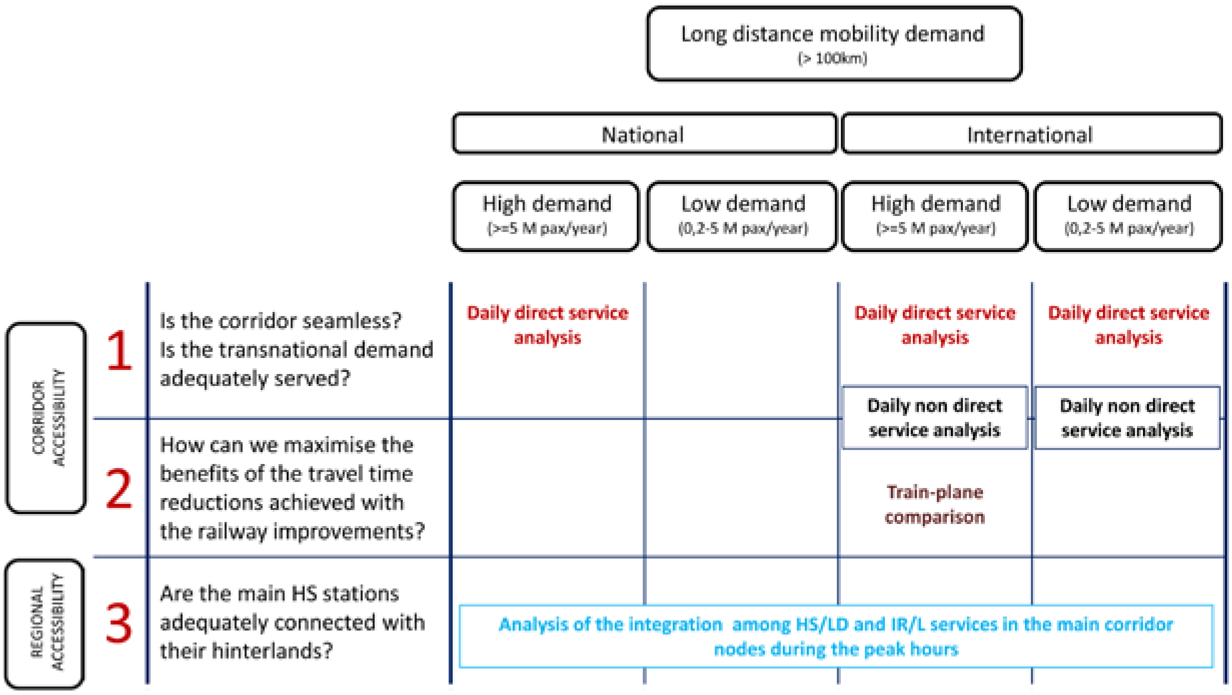


Figure 13. Summary of the Methodologies Used to Assess the Integration of Railway Services along Corridor Genoa - Rotterdam
Source: SiTI, 2014

Table 8. List of Railway Services Included in the Four Different Service Categories Considered for the Analysis

ICE	InterCityExpress	1	High-Speed (HS)
AV	Alta Velocità		
TGV	Train à Grande Vitesse		
THA	Thalys		
FYRA	FYRA		
EC	EuroCity	2	Long Distance (LD)
IC	InterCity		
CNL	City Night Line		
EN	Euro Night		
IR	Interregionale	3	Interregional (IR)
RE	RegionalExpress		
RB	RegionalBahn	4	Local (L)
S	Stadtschnellbahn		
Sp	NS Sprinter Lighttrain		
R	Regionale		

Source: SiTI, 2014

connections of HS stations to their hinterland and the integration of HS/LD trains with interregional (IR) and local (L) trains.

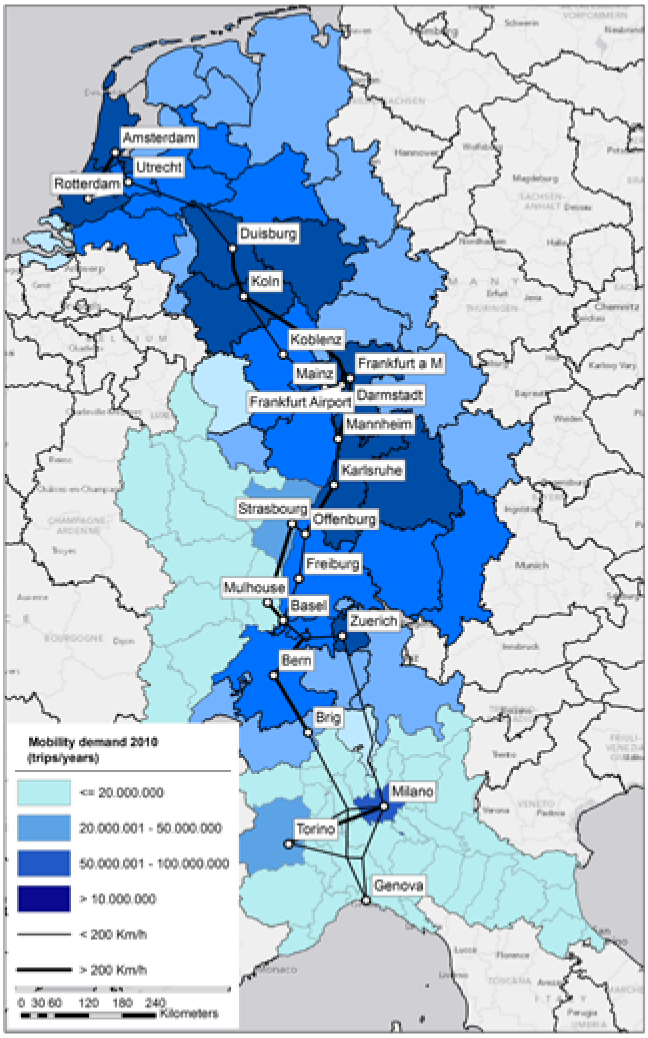
Service categories were defined mainly on the basis of train speed as Table 8 shows.

As mentioned before, 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 to 15 minutes;
- Integrated with medium transfer time, 15 to 30 minutes;
- Potentially integrated when transfer time is between -5 min and 5 min (negative values mean that a service arrives a few minutes after another service that 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), 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 Figure 14) 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).

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.
The collected data were initially used to provide effective representations of the provided railway services and preliminary comparisons of the main HS stations along the Corridor. In particular, two types of data visualization were produced with reference to the railway traffic in the peak hour of the morning (8.00-9.00 am):



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

Figure 14. Main Rail Stations Identified along the Genoa - Rotterdam Corridor on the Basis of Mobility Demand in 2010
Source: SiTI elaborations of ETIS+ data; base map: Canvas/World_Light_Gray_Reference, Copyright: ©2013 Esri, DeLorme, NAVTEQ

- Station clocks: clock representations of the arrival and departure times of different types of trains in the main stations along the Corridor from 8.00 to 9.00 am;
- Schemes of HS/LD services in the nodes: schematic representation of the main nodes along the Corridor with HS/LD services arriving and departing from 8.00 to 9.00 am and their main direction.

Comparing station clocks of different nodes (Figure 15), even if they refer only to the peak hour services, three different service models for long distance connections can be observed:

- In Germany and Switzerland HS and LD trains provide a similar service and are used to connect similar OD pairs: sometimes the same ODs are connected by both HS and LD trains during the day thus providing hourly services with a different quality and level of service (different number of stops, speeds, etc.);
- In Italy HS services are replacing LD services;
- In the Netherlands there are more LD than HS services also due to the shorter distances between the main cities of the Country (although Amsterdam and Rotterdam have more international HS services than Utrecht).

These considerations led the authors to account LD and HS trains as equivalent services in the following accessibility analysis.

From this preliminary assessment some significant differences among the railway nodes came up. For example the comparison of Milano and Frankfurt nodes showed that during the peak hour (8.00-9.00 am) they're both served by a similar number of HS/ LD direct trains; in particular 9 HS and 3 LD direct services are provided in Frankfurt am Main and 11 HS and 2 LD trains in Milano Centrale station. However, in Frankfurt am Main (Figure 16) 11 services out of 12 travel from/to stations along the Corridor, and 3 of them are international services (going to Paris, Interlaken and Wien). In Milano

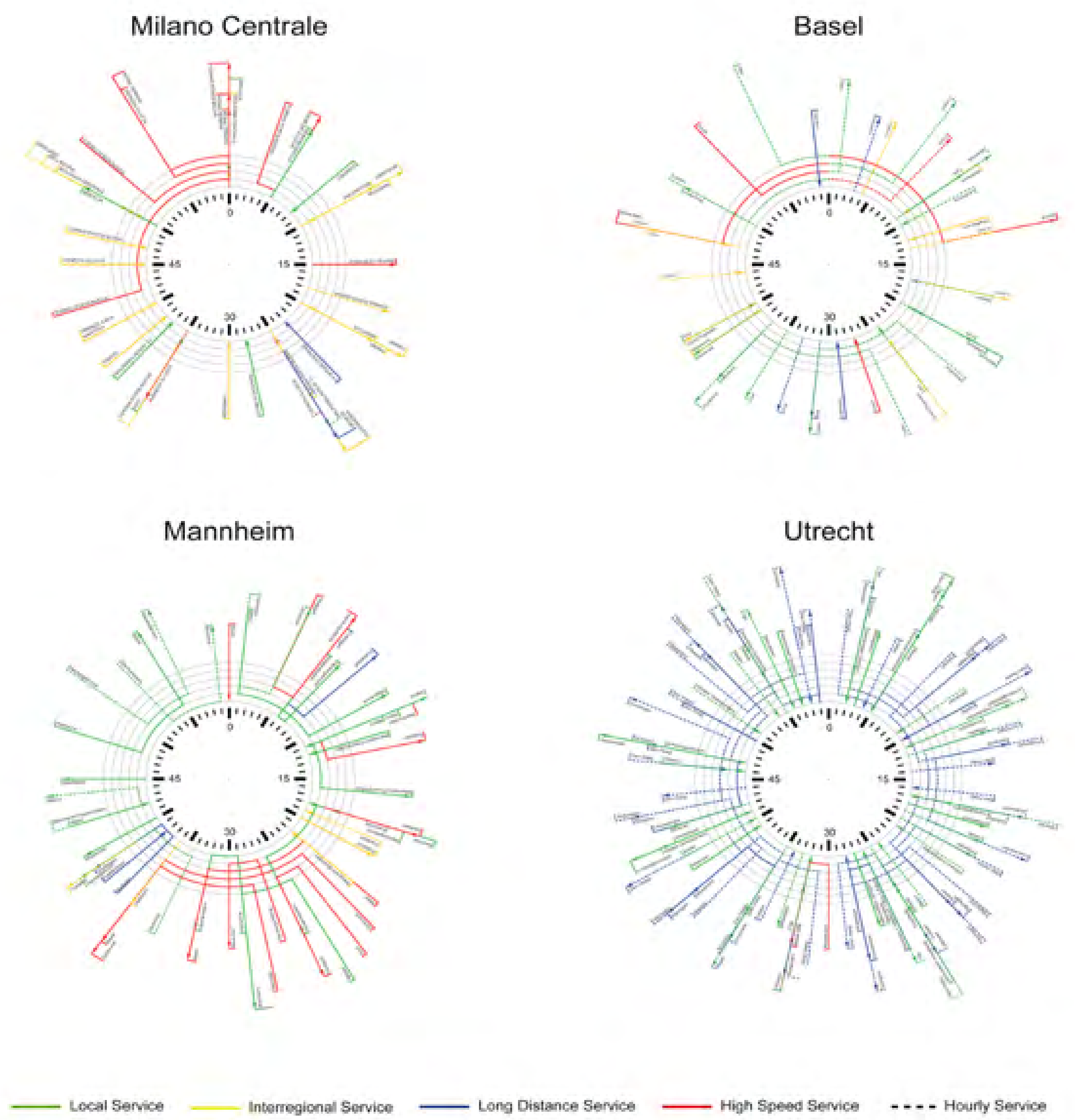


Figure 15. Station Clocks Representing the Arrival and Departure Times of Trains During the Time Slot 8.00-9.00 am in 4 Main Stations along the Corridor
Source: SiTI elaborations of DB European timetables available on http://www.bahn.de/p_en/view/index.shtml (accessed October 2013)

Centrale (Figure 17) only 3 direct services out of 13 connect the Italian node to stations along the Corridor, and all of them are LD trains: 2 coming from Genova and 1 going to Brig and Geneve. All the HS trains are national connections from/to Torino, Venice and Southern Italy. The train going to Geneve is also the only international service.

Looking also at the IR and L services, represented in Figure 18, a great disparity can be noticed between the two stations: while in the peak hour Frankfurt am Main is very well connected to his hinterland by interregional (26 trains) and local trains (82 services), Milano Centrale provides 19 interregional and only 8 local trains (local trains in the node of Milano are mostly provided by other HS stations such as Milano Porta Garibaldi and Milano Rogoredo, as it will be explained in Section 3.2.3).

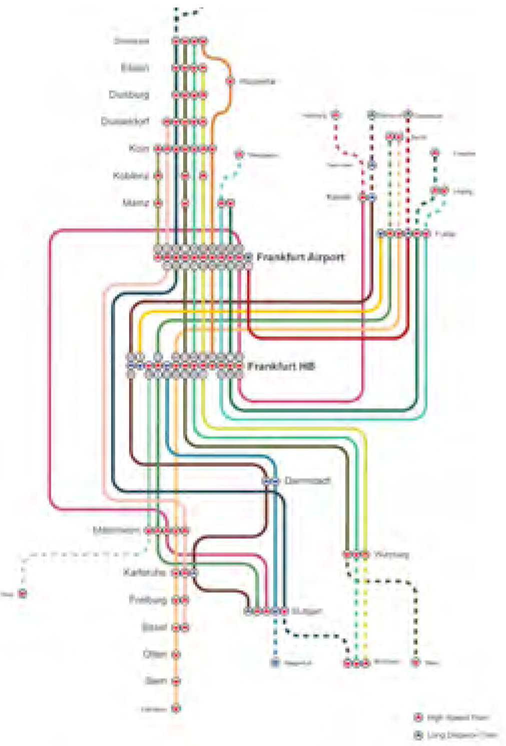


Figure 16. HS and LD Railway Services Arriving and Departing in the Node of Frankfurt from 8.00 to 9.00 am

Source: SiTI elaborations of DB European timetables available on http://www.bahn.de/p_en/view/index.shtml (accessed October 2013)

It is worth to notice that such analysis is still partial since it takes into consideration only a 1 hour time slot (8.00-9.00 am): it is known for instance that LD services from Milano Centrale to Zürich are departing only after 9.00. More in depth assessments are then needed and some had already been carried out taking into account, for example, daily connections.

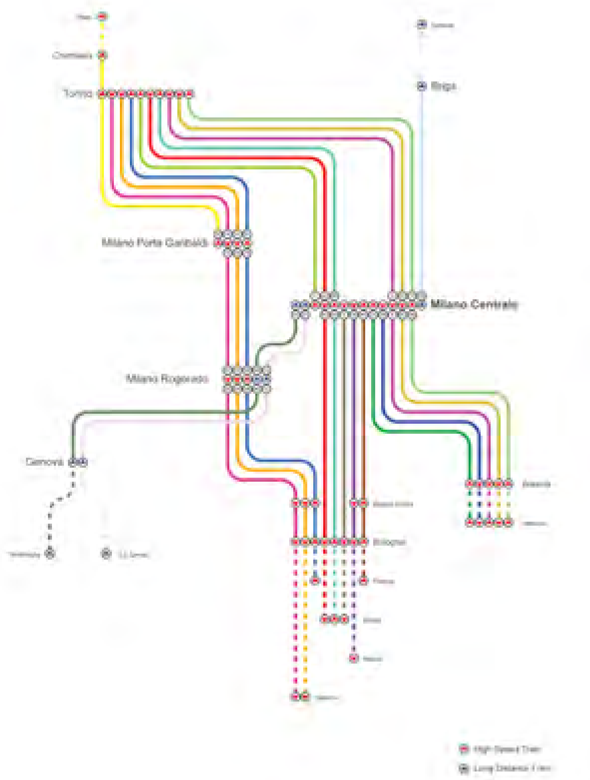


Figure 17. HS and LD Railway Services Arriving and Departing in the Node of Milano from 8.00 to 9.00 am

Source: SiTI elaborations of DB European timetables available on http://www.bahn.de/p_en/view/index.shtml (accessed October 2013)

The service representations for each of the selected nodes along the Corridor are available in an annex to this report which can be accessed online via www.code-24.eu or www.egtc-rhine-alpine.eu.

In order to facilitate data exploration and readability, a GIS-based tool was developed. Such tool is useful for showing the correlations between collected data and for comparing different nodes along the Corridor. The tool is a web-based interactive visual tool, which works on geo-referenced dynamic maps, currently created with free Web GIS applications.

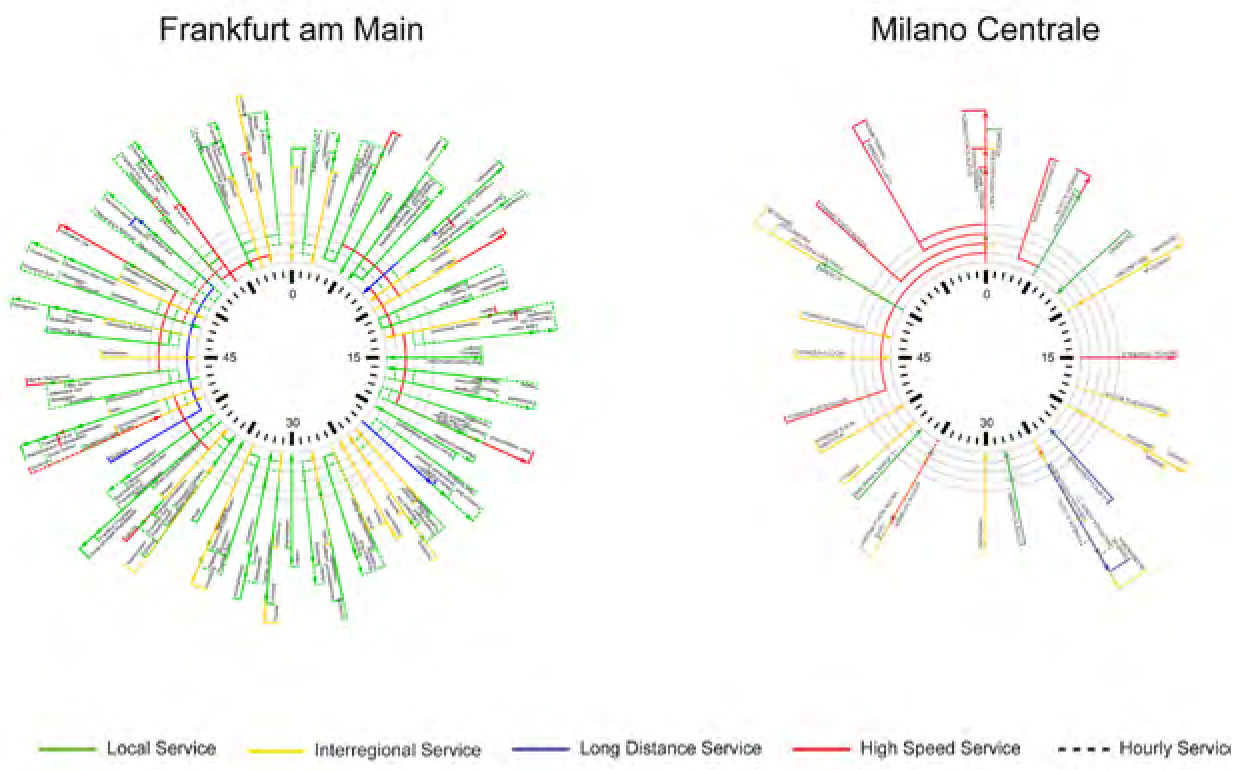


Figure 18. Station Clocks of Frankfurt am Main Hbf and Milano Centrale
Source: SiTI elaborations of DB European timetables available on http://www.bahn.de/p_en/view/index.shtml (accessed October 2013)

It displays data on a map and offers the possibility to select and filter data by single attributes (e.g. by node, or by type of service offered in the nodes), allowing users to interact readily with large databases and customise the visualisation of information. Some examples of the possible visualizations are shown in Section 3.2.3.

3.2.2 Corridor Accessibility: Integration among Corridor Services

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.
Figure 19 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 above (> 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 compared with a high mobility demand, i.e. Mulhouse-Strasbourg, Koblenz-Frankfurt and, the only cross-border relation, Freiburg-Zürich: these

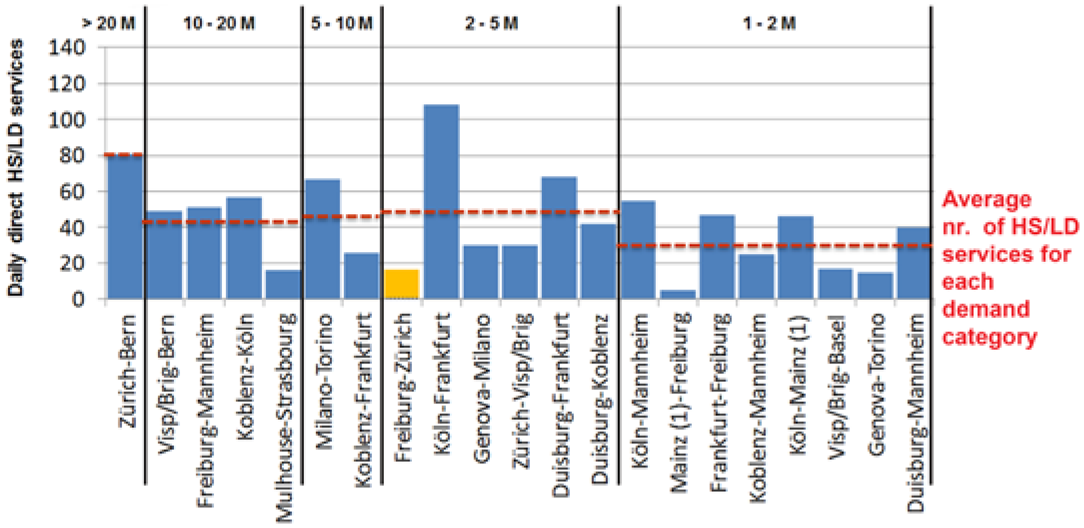


Figure 19. Daily Direct HS and LD Services between ODs with a High Mobility Demand.

(1) The Region of Mainz, Rheinhessen-Pfalz, is also served by trains to/from Mannheim

Source: SiTI elaborations of DB European timetables available on http://www.bahn.de/p_en/view/index.shtml (accessed December 2013)

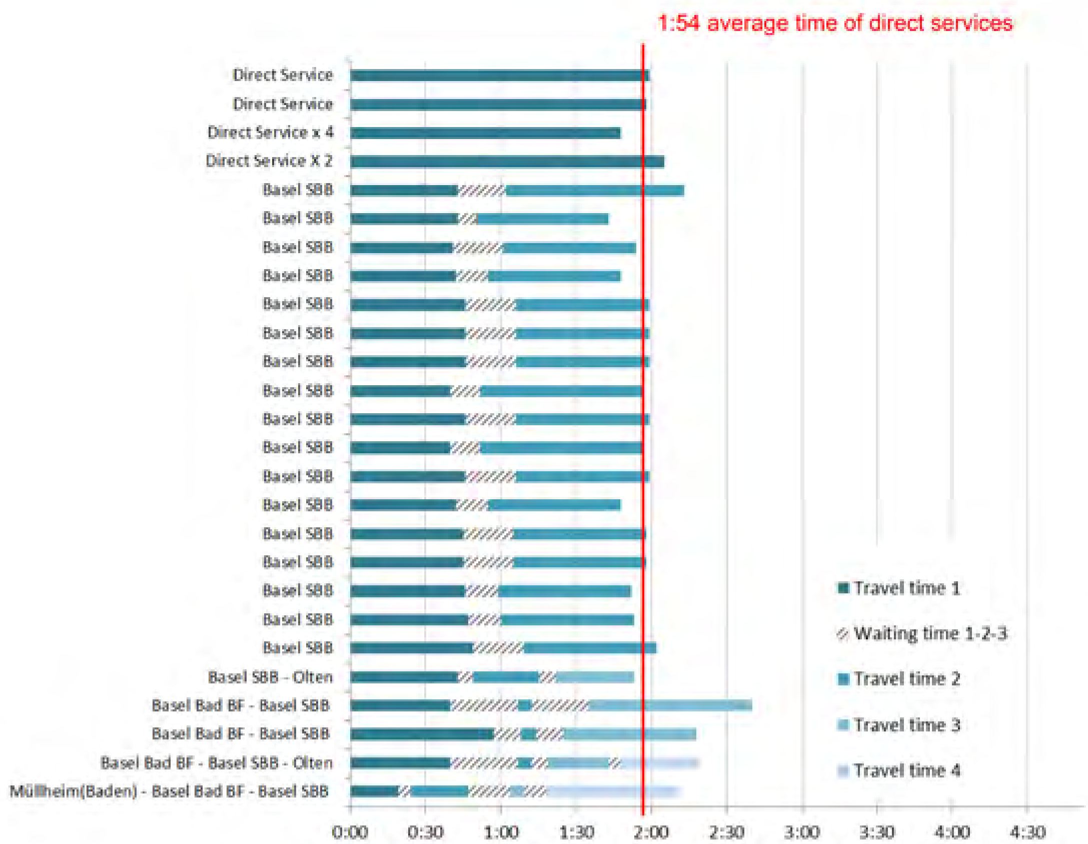


Figure 20. Freiburg-Zürich Daily Connections and Respective Total Travel Time Split in Travel Time and Waiting Time at the Interchange Stations

Source: SiTI elaborations of DB European timetables available on http://www.bahn.de/p_en/view/index.shtml (accessed December 2013)

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-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 relations, data collection was extended to include connecting services requiring transfers.

Figure 20 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 1h 54m) and below is the connections that require up to three transfers (22 connections per day: 17 with one transfer, 3 with two transfers and 2 with three transfers).

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 relations 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 when choosing between direct services and options including transfers.

This comment remains valid for other transnational ODs with lower demand as well (Figure 21).

The only exception is the relation between Torino (Porta Susa station) and Brig (Figure 22). In that case

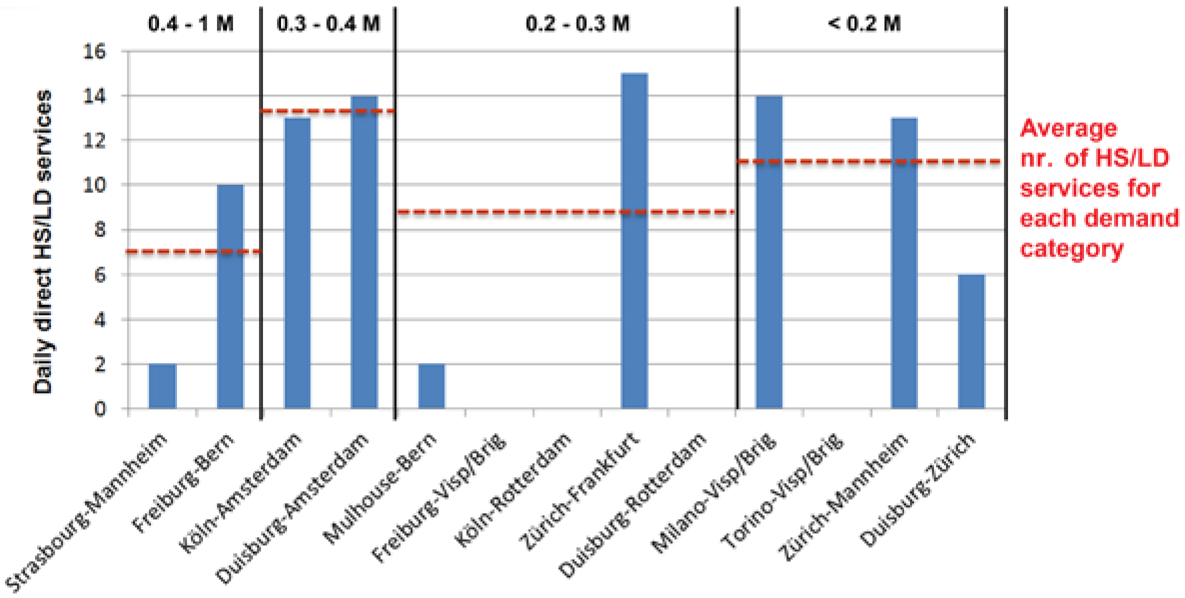


Figure 21. Daily Direct HS and LD Services between Transnational ODs with the Highest Mobility Demand
Source: SiTI elaborations of DB European timetables available on http://www.bahn.de/p_en/view/index.shtml (accessed December 2013)

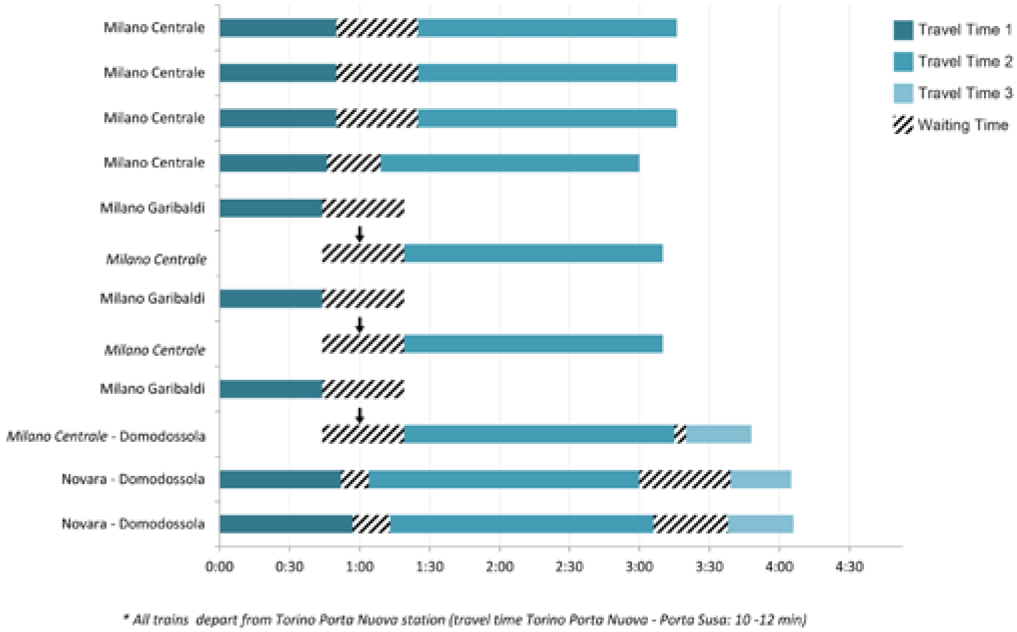


Figure 22. Torino-Brig Daily Connections and Respective Total Travel Time Split in Travel Time and Waiting Time at the Interchange Stations
Source: SiTI elaborations based on DB European timetables available on www.bahn.de

there is no direct service and changing trains usually requires waiting more than 30 minutes in Milano Centrale Station or travelling by underground between Milano Porta Garibaldi and Milano Centrale Station.

Another aspect considered in the analysis was the competitiveness between air and train travel modes serving transnational connections along the Corridor.

With the improvements on the railway network (i.e. Gotthard tunnel, Karlsruhe-Basel upgrades, etc.) travel times of direct services will reduce significantly in the coming years, for example in 2020:

- Milano-Zürich will be connected in almost 3 hours instead of the current 3 hours and 41 minutes (- 19%);
- Zürich-Frankfurt travel time will reduce of half an hour (from 3 hours and 40 minutes to 3 hours and 10 minutes, - 14%).

These improvements could allow the railway services to capture passengers from other transport modes, both cars and planes; in particular, trains could compete with air transport on medium to

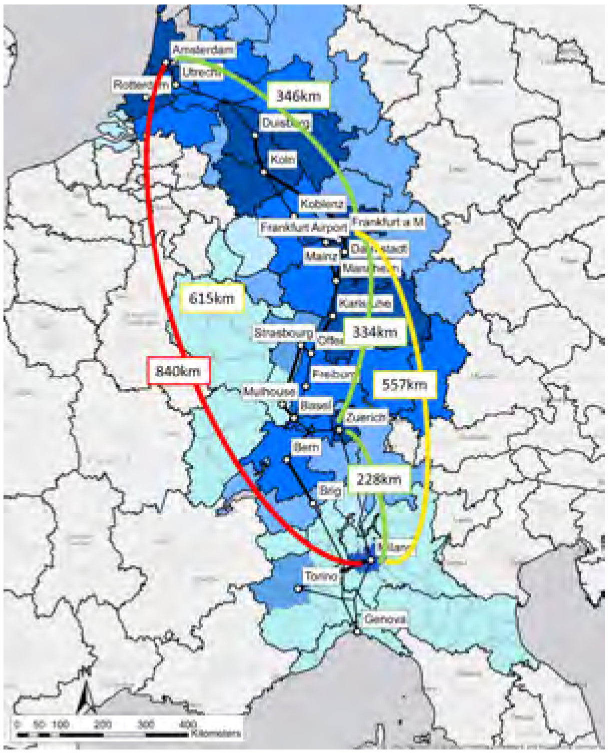


Figure 23. Air Distances between Some of the Most Important Nodes along the Corridor
Source: Distances according to http://www.worldatlas.com/travelaids/flight_distance.htm

long distance connections (Figure 23). In order to assess this issue, some of the OD couples along the Corridor showing the highest levels of air passengers per year (Figure 24) were analysed and current daily services provided by both train and plane on these ODs were compared.

On the basis of the literature[5], trains were considered competitive with planes if their travel time (including possible transfers in the stations) does not exceed by more than 2-3 hours the air travel time on the same OD (travelling by plane is indeed very fast but travel times from/to the airport and waiting times in the airport can never be avoided and thus extend the total travel time).

Figure 25 shows daily railway connections between Frankfurt and Zürich on a typical day (a weekday in October 2013): at present, the cities are linked by 2 direct railway services plus 27 non-direct trains (16 with 1 transfer, 7 with 2 transfers and 1 with 3 transfers). The average travel time for direct services is between 4 and 5 hours and most of the connections with transfers are already well integrated with waiting times usually lower than 20 minutes and trip times similar to direct trip times. After fundamental improvements to the railway network the train travel time will further decrease of almost 1 hour.

A railway connection served in 3 hours and 10 minutes (or a similar time for non-direct services) could certainly be competitive with air trips that usually last 1 hour and 10 minutes (to which travel times to/from the airport, frequently located outside the city centre and waiting times in the airport should be added). Besides travel time, other important factors that may lead passengers to choose the train instead of the airplane are the cost and the service frequency. For this OD couple both cost and frequency are very competitive (90 - 110 € for trains instead of 450 – 500 € for planes and 29

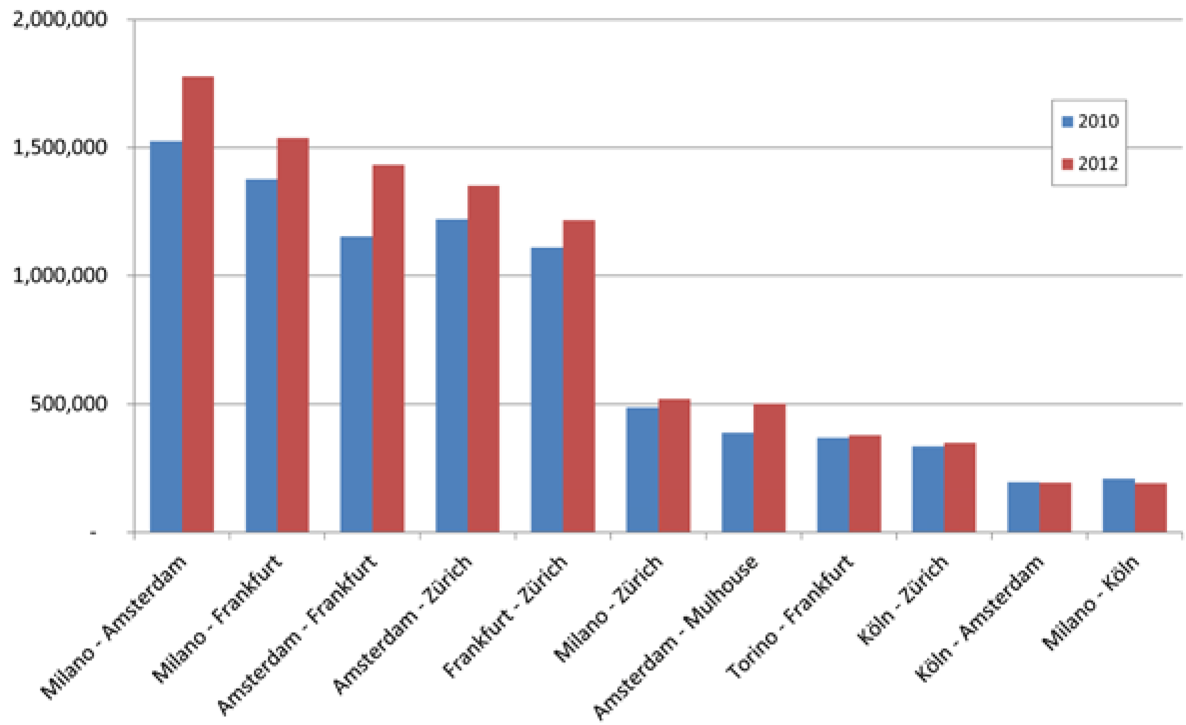


Figure 24. Passengers per Year (Including Transfers in Airports) between some of the Most Important Nodes along the Corridor
Source: SiTI elaborations based on Eurostat data

Figure 25. Railway Daily Services between Frankfurt and Zürich.
Source: SiTI elaborations of DB European timetables available on http://www.bahn.de/p_en/view/index.shtml (accessed December 2013)

daily connections by trains compared to 10 direct connections by air).

Train competitiveness is even more evident when the OD couple includes a location that is not served by an airport, such as in the case of the Mannheim – Zürich connection. Moving by train between Mannheim and Zürich is already competitive at present, even without any network improvement, since trains are frequent (7 direct connections, 15 with 1 transfer and 1 with 2 transfers), non-direct services are well integrated and travel, both with direct and non-direct trains, takes on average almost 3 hours and 30 minutes (Figure 26). The same OD couple can be covered by the air mode leaving from Frankfurt airport and using the services just described for the Frankfurt – Zürich connection, but in this case the total travel time needs to take into account the longer connecting times to reach the airport of Frankfurt from Mannheim.

On the other hand, competition fails for more distant OD couples, such as, for example, Amsterdam – Zürich. On this link daily train services are frequent (1 direct service plus 21 non-direct trains, 7 with 1 transfer, 10 with 2 transfers and 4

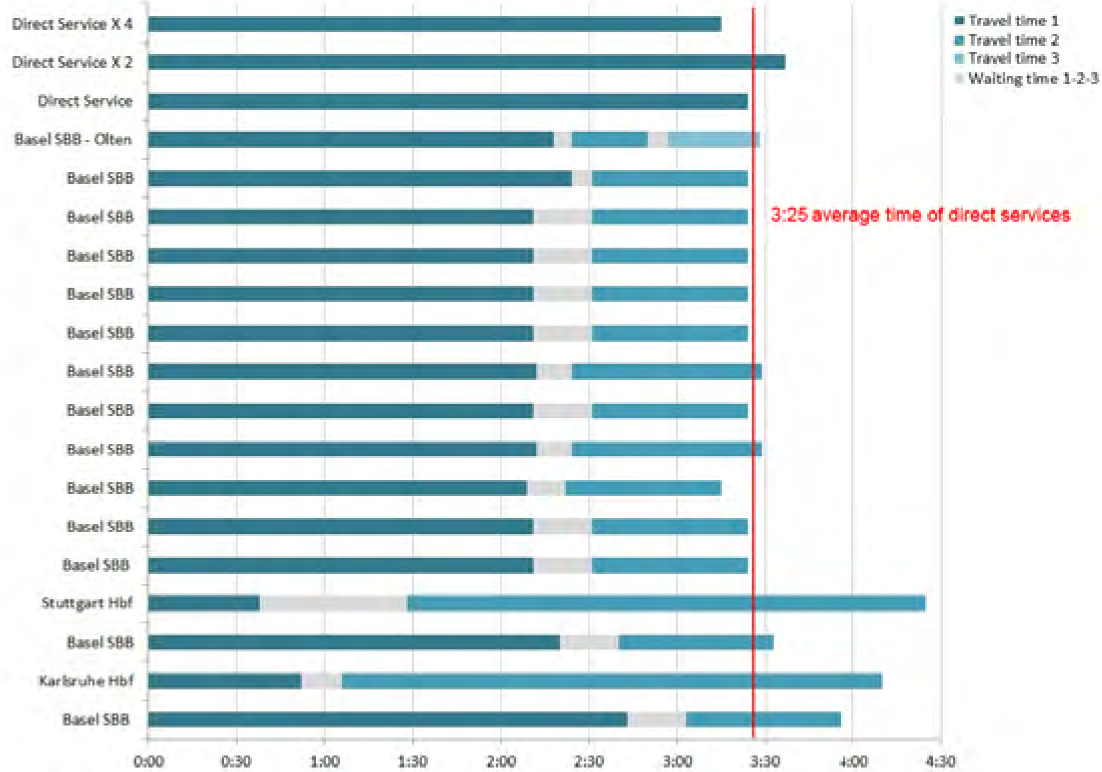


Figure 26. Railway Daily Services between Mannheim and Zürich

Source: SiTI elaborations of DB European timetables available on http://www.bahn.de/p_en/view/index.shtml (accessed December 2013)

Figure 27. Railway Daily Services between Amsterdam and Zürich

Source: SiTI elaborations of DB European timetables available on http://www.bahn.de/p_en/view/index.shtml (accessed December 2013)

with 3 transfers), as shown in Figure 27. However, the trip time is very long (12 hours for the direct train while the non-direct connections are faster but still take between 8 and 10 hours) if compared with air trip time (1 hour and 30 minutes). Even after basic improvements on the network trip time will reduce to 6 hours and 45 minutes but will still remain too long to compete with the air mode.

3.2.3 Regional Accessibility: Integration between Corridor and Regional Services

The regional accessibility assessment method allowed us to identify and represent, for each analysed station, all possible final destinations that can be reached arriving in 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 (Figure 28) 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 minute 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, 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 minutes) since 15 minutes 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

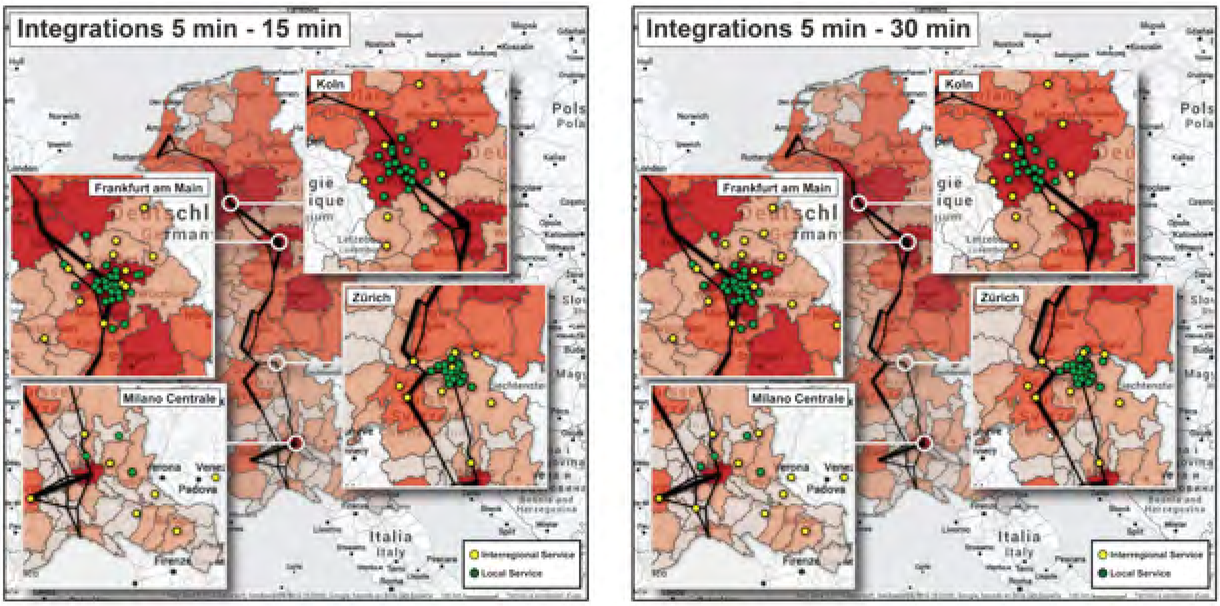


Figure 28. Origins and Destinations of IR and L Trains Integrated in the Main Corridor Stations with HS/LD Services Having Short or Medium Transfer Times from 8:00 to 9:00 am

Source: SiTI elaborations of DB European timetables available on http://www.bahn.de/p_en/view/index.shtml (accessed October 2013); base map: Google Maps, Google Inc.

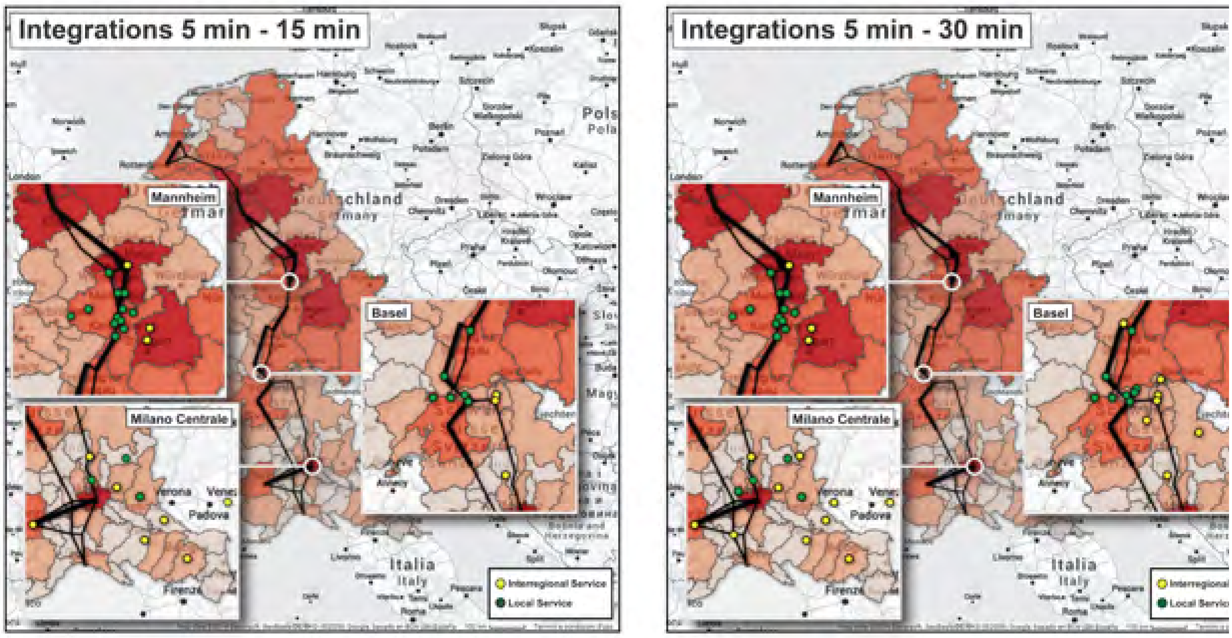


Figure 29. Origins and Destinations of IR and L Trains Integrated in Other Corridor Stations with HS/LD Services with Short or Medium Transfer Times from 8:00 to 9:00 am

Source: SiTI elaborations of DB European timetables available on http://www.bahn.de/p_en/view/index.shtml (accessed October 2013); base map: Google Maps, Google Inc.

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 (Figure 29), for example, Mannheim and Basel SBB, which provide fewer services, but are both one-hour 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 comparing different nodes that are served by more than one HS station (Figure 30). 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 Koln 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 Central Station (Milano Centrale) 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.

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, 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.

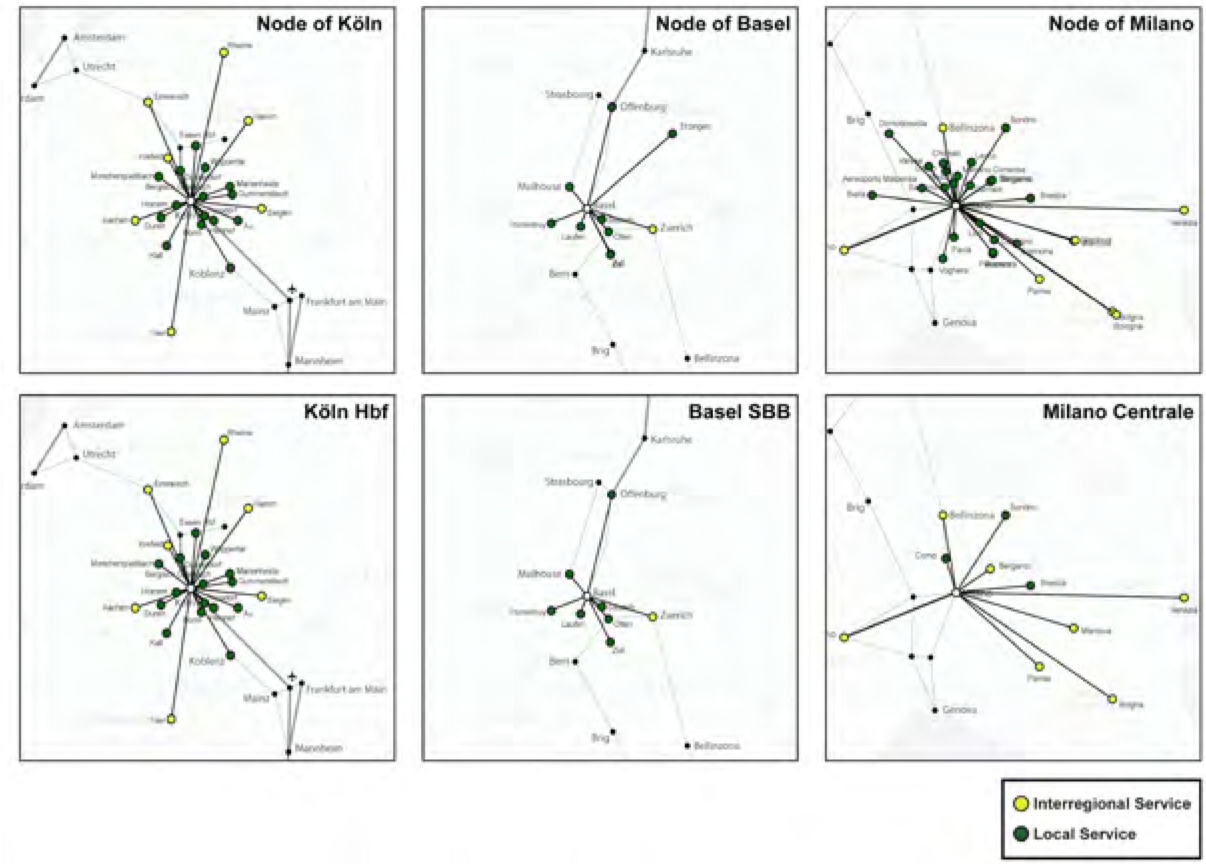


Figure 30. Incoming Integrated IR and L Services in Nodes Served by More than One HS Station and in the Correspondent Central Station
Source: SiTI elaborations of DB European timetables available on http://www.bahn.de/p_en/view/index.shtml (accessed October 2013); base map: Google Maps, Google Inc.

3.3 Does Transport Supply Meet Mobility Needs?

The CODE24 project focussed on one key element to exploit rail technical capabilities for passenger transport: the integration among services in terms of timetables and transfer times. 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.

Two aspects of integration were explored: integration of services among the Corridor (to provide corridor accessibility) and integration of long-distance and HS services with local ones (to provide regional accessibility).

The first focus of the investigation was based on an existing assessment of the travel demand, by all modes, along the Corridor. The data presented show that the key OD pairs are national (relations with more than 5 million passengers per year), whereas international travel demand plays a much smaller role. Five big passenger demand clusters can be identified at national level: the Netherlands; North-West Germany; Central/Southern West Germany; Switzerland and the Piedmont-Lombardy axis in Italy. What is more, much passenger travel happens between zones that are less than 100 km apart. However also transnational demand (which is

particularly significant between Southern Germany and Switzerland and Northern Germany and the Netherlands) should be served properly.
The number of HS and LD direct services connecting the most significant OD pairs, in terms of transport demand, is not necessarily similar between ODs with similar demand levels. However, dissimilarities in supply reduce when also IR/L direct services are considered. Further, the investigation highlighted the important role of indirect but connecting services in ensuring a high level of supply between important OD pairs. In particular transnational ODs have few direct services but they are served by very good indirect connections with similar total travel times.

Different train *service models* for HS and LD connections were observed: in Germany and Switzerland HS and LD trains provide a similar service and are used to connect similar OD pairs with a different quality and level of service (different number of stops, speeds, etc.) while in Italy HS services are increasingly replacing LD services.

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 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.

Good connections between HS and local trains in the main HS stations along the Corridor are also a key element in providing railway services competitive with the air mode and for capturing potential air travellers. If railway services are frequent with short to medium transfer times in the main HS nodes, the total travel time from an origin to a destination, can be reduced significantly and become shorter than the total travel time needed to connect the same OD pair by plane (often due to the longer distances needed on average to reach airports and to the less frequent air services).

However, it is important to emphasise that other factors could be even more important than saving transfer time in the transfer nodes in order to realize an efficient integration, such as:

- Service frequency, increasing the number of possible transfer choices;
- Service reliability;
- Integration of fares;
- Information;
- Regulations.

4 EXPO Milano 2015 Case Study

The EXPO2015 event has been selected as a specific case study for Action 17 in order to identify the needs for better hinterland accessibility and foster the integration between different types of railway services.

The EXPO2015 venue is located north-west of Milano and the event will be held for six months from May to October 2015, attracting approximately 20 million visitors (about 70 % from Italy), that will mean about 24 million visits (GfK Eurisko, 2013). Concerning the split of visitors' travel mode (last mile), it is estimated that 32 % of the visitors will arrive by rail, 25 % by underground, 20 % by car, 19 % by bus, and 4 % by taxi (Regione Lombardia 2014). Substantial investment will be undertaken with a positive impact on the Italian national economy: from 2012 to 2020 the EXPO is expected to bring 23.6 billion euro in additional GDP, with 191,000 people directly or indirectly involved. Tourism is certainly one of the market sectors that will witness the greatest benefits, estimated at 4.5 billion euro of added value. These forecast figures (SDA Bocconi, 2014) are among the main reasons that make the EXPO site interesting for an analysis of long-distance train services along the Genova-Rotterdam Corridor using the idea of integrating High-Speed Rail as an option.

Figure 31. Rail stations considered in Milano city
Source: Uniontrasporti, 2014

4.1 Accessibility to and from the EXPO Centre (Modal Split)

The concept of accessibility is widely recognised as difficult to define, since in analysing the accessibility to a node, it is possible to follow different methodological approaches, and differently interpretable according to specific scenarios.
The current accessibility to the EXPO area has been analysed by evaluating the available daily connections, by rail and road, within different thresholds of time and distance (i.e. within 3 hours and 500 km, or 1 hour and 30 minutes) in order to depict the so called catchment areas.

Then, it was possible to schematize the basins of reference, in terms of population and bed places[6 7] reachable within those ranges of time and distance. The objective was to compare rail and road modes and identify weaknesses and needs for a better accessibility to EXPO fair. The delineation of the current state is the starting point to conclude with drawing up a new hypothetical passenger railway service as test for improving accessibility of some areas.
Regarding the relevance of the nodes connected to Rho-Fiera, it depends on their distance, their demographic size and their tourism attractiveness (in terms of accommodation facilities) that somehow

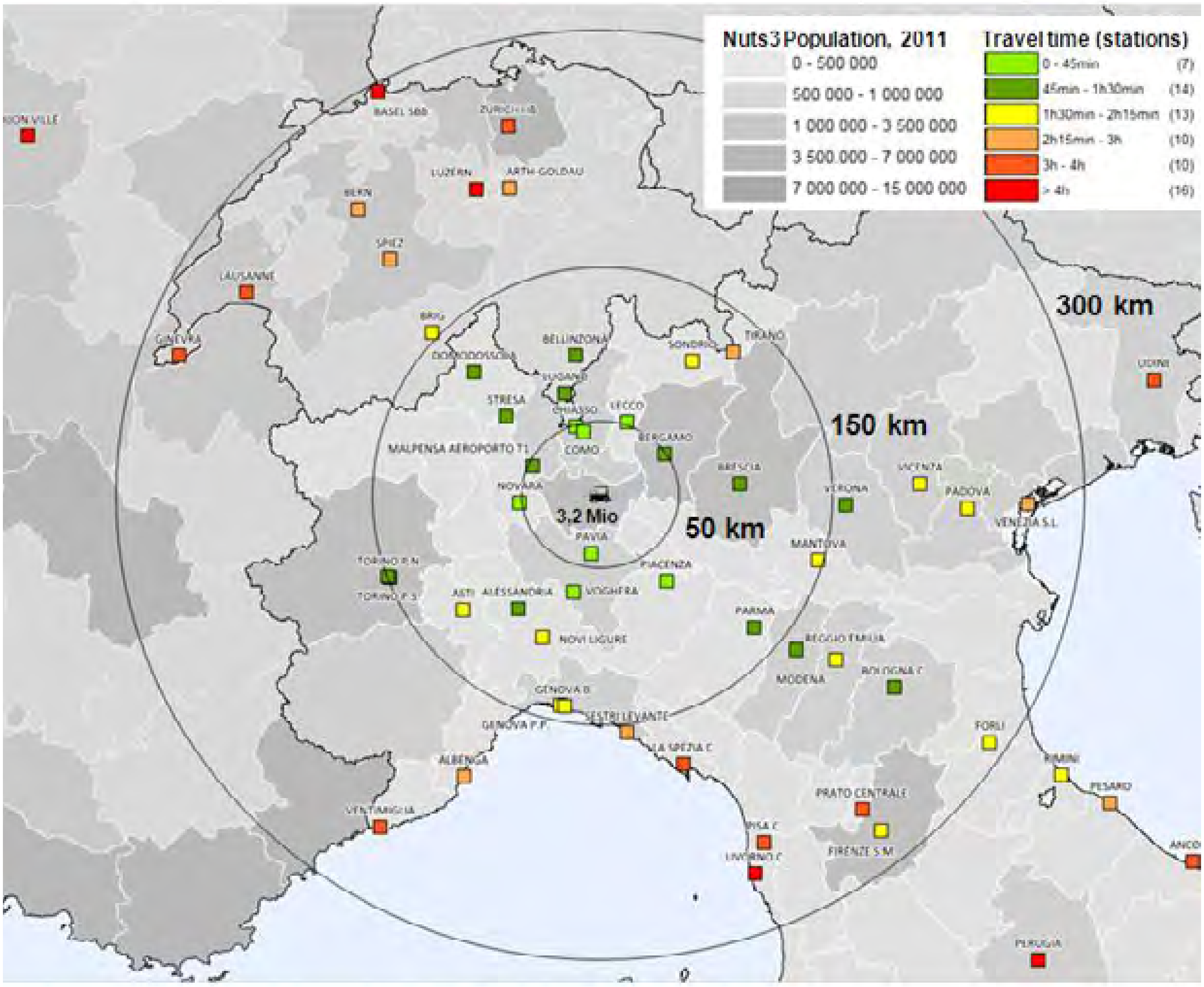


Figure 32. Rail Accessibility to Milano Rho-Fiera as "Unified" Station and NUTS 3 Population
Source: Uniontrasporti, 2014

refer to the size of the metropolitan area. The population is the variable which most significantly affects the amount of passengers flow to/from a city and thus can be considered as a good proxy of GDP. These associations cannot be neglected in view of the considerations of the final outputs. In fact, the evaluation of the connections of a node should also take into account the context of needs/ opportunities generated by the concerned territory.

On the rail side, the following schematic stages synthesize the procedure to assess the rail catchment area:

- Selection of crucial rail stations in Milano as demand attractor points (Figure 31);
- Computation of the main destinations reachable without transfer (as an index of the quantity of services)[8];
- Computation of daily frequencies and travel times of the connections (as index of quality of service)[9];
- Matching the above accessibility information with population and accommodations availability (NUTS 3 territorial segmentation);
- Definition of the basins of destinations for each Milano station with reference to a scale

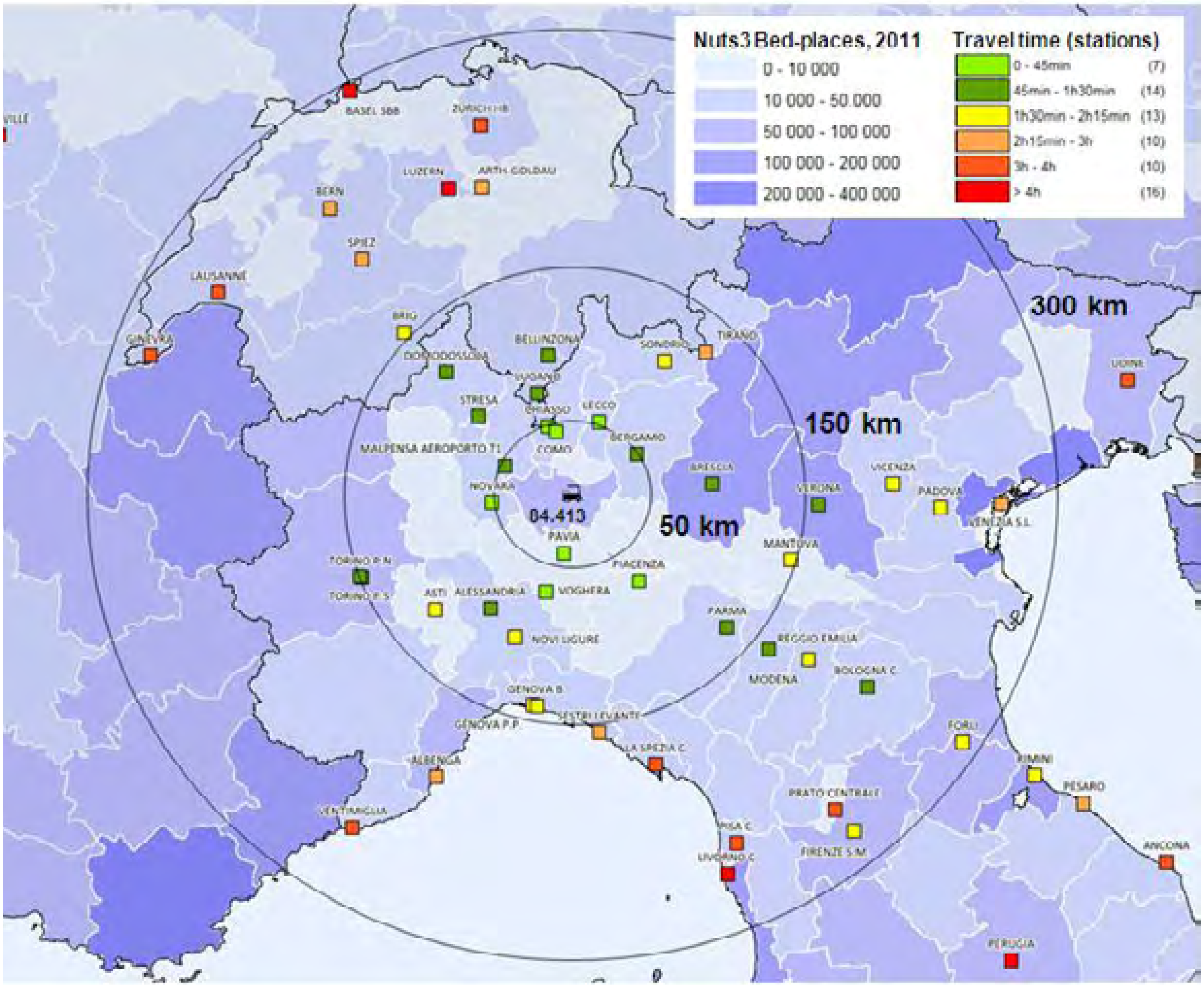


Figure 33. Rail Accessibility to Milano Rho-Fiera as "Unified" Station and NUTS 3 Bed places
Source: Uniontrasporti, 2014

Table 9. Milano Rho-Fiera Integrated Basin, Distance and Population at NUTS 3 Level

RHO-FIERA integrated	POPULATION (NUTS 3 level)					
	> 1 000 000		500 000 - 1 000 000		100 000 - 500 000	
DISTANCE	Destination	T/d	Destination	T/d	Destination	T/d
< 50 km	**Pioltello Limito *** **Rho *** **Treviglio ***	**72** **74** **46**	Besana Como S.Giovanni **Gallarate *** Malpensa Aeroporto T1 Pavia Saronno Seveso **Varese ***	18 15 **40** 26 35 31 26 **33**	**Chiasso** Lecco Lodi **Novara ***	**14** 17 84 **51**
50 - 150 km	Bergamo Brescia Chivasso **Torino Lingotto *** **Torino Porta Nuova **** Torino Porta Susa	19 38 3 **1** **20** 18	Genova B. Genova P.P. Luino Stradella Voghera	14 22 4 13 31	Alessandria Arona Arquata Scrivia Asti **Bellinzona** **Brig** Cremona **Domodossola *** **Lugano** Novi Ligure Parma Piacenza Sondrio Stresa Tirano	6 13 8 1 **7** **7** 4 **5** **7** 3 25 27 10 11 8
150 - 300 km	Firenze S.M. **Zürich HB**	21 **6**	**Bern** Bologna Centrale **Lausanne** Padova Reggio Emilia Sestri Levante **Spiez** **Venezia Santa Lucia *** Verona Porta Nuova Vicenza	**3** 45 **4** 21 13 9 **3** **1** 37 22	Albenga **Arth-Goldau** **Basel SBB** **Chambéry** Forlì **Genève** La Spezia Centrale Livorno Centrale **Luzern** Mantova Modena Pisa Centrale Prato Centrale Ventimiglia	8 **7** **3** **3** 6 **4** 10 8 **1** 10 24 9 3 7
300 - 500 km			**Dijon Ville** Perugia Udine	**1** 1 2	Ancona Pesaro Rimini Terni Trieste Centrale	3 11 12 1 4

T/d = Trains per day; Stations outside Italian borders are in green

Total Destinations: 75 - Total Connections (T/d): 1 230

* Direct connection (10)

** To reach Torino P.N. time is saved with exchange in Milano P. Garibaldi station (9 trains per day) Source: Uniontrasporti, 2014

Soure: Uniontrasporti, 2014

of ranges (in terms of population/ bed places - distance/travel time).

Four rail stations have been considered as demand attractor points in Milano city: three are the High-Speed Rail stations in Milano (Milano Centrale, Porta Garibaldi and Rogoredo) and one is the station immediately next to EXPO area (Rho-Fiera).

In the first part of the analysis, the four stations have been analysed individually through the above mentioned procedure: four catchment areas have been defined containing the daily destinations reachable, without transfer, from those stations of Milano and in specific ranges of time and distance. Subsequently, the outcomes were merged so that the four stations composed, together, one

Table 11. Milano Rho-Fiera Integrated Basin, Travel Time and Population at NUTS 3 Level

RHO-FIERA integrated		**POPULATION (NUTS 3 level)**					
		> 1 000 000		500 000 - 1 000 000		100 000 - 500 000	
		Destination	T/d	Destination	T/d	Destination	T/d
TIME	45 min	**Pioltello Limito ***	**72**	**Gallarate ***	**40**	**Novara ***	**51**
		Rho *	**74**	Como S.Giovanni	15		
				Pavia	35		
	45 min - 1h 30 min	Brescia	38	Besana	18	Arona	13
		Bergamo	19	Bologna Centrale	45	**Chiasso**	**14**
		Torino Porta Nuova **	**20**	Malpensa Aeroporto T1	26	**Domodossola ***	**5**
		Torino Porta Susa	18	Reggio Emilia	13	Lecco	17
		Treviglio *	**46**	**Varese ***	**33**	Lodi	84
				Voghera	31	**Lugano**	**7**
				Verona Porta Nuova	37	Parma	25
						Piacenza	27
						Stresa	11
	1h 30 min - 2h 15 min	Chivasso	3	Genova B.	14	Alessandria	6
		Firenze S.M.	21	Genova P.P.	22	Arquata Scrivia	8
		Torino Lingotto *	**1**	Luino	4	Asti	1
				Saronno	31	**Bellinzona**	**7**
				Seveso	26	**Brig**	**7**
				Stradella	13	Cremona	4
				Vicenza	22	Forlì	6
						Mantova	10
						Modena	24
						Novi Ligure	3
						Sondrio	10
	2h 15 min - 3 h			Padova	21	Pesaro	11
				Sestri Levante	9	Rimini	12
				Spiez	**3**	Tirano	8
				Venezia Santa Lucia *	**1**		

T/d = Trains per day; Stations outside Italian borders are in green

Total Destinations: 55 - Total Connections (T/d): 1 142

Source: Uniontrasporti, 2014

* Direct connection (10)

** To reach Torino P.N. time is saved with exchange in Milano P.Garibaldi station (9 trains per day)

Table 12. Milano Rho-Fiera Integrated Basin, Travel Time and Bed places at NUTS 3 Level

RHO-FIERA integrated	BED-PLACES (NUTS 3 level)					
	> 100 000		50 000 - 100 000		1 000 - 50 000	
TIME	Destination	T/d	Destination	T/d	Destination	T/d
45 min			**Pioltello Limito ***	**72**	Como S.Giovanni	**15**
			Rho *	**74**	Gallarate *	**40**
					Novara *	**51**
					Pavia	**35**
45 min - 1h 30 min	Brescia	38	**Torino Porta Nuova ****	**20**	Arona	13
	Verona Porta Nuova	37	Torino Porta Susa	18	Bergamo	19
					Besana	18
					Bologna Centrale	45
					Chiasso	**14**
					Domodossola *	**5**
					Lecco	17
					Lodi	84
					Lugano	**7**
					Malpensa Aeroporto T1	26
					Parma	25
					Piacenza	27
					Reggio Emilia	13
					Stresa	11
					Treviglio *	**46**
					Varese *	**33**
					Voghera	31
1h 30 min - 2h 15 min			Chivasso	3	Alessandria	6
			Firenze S.M.	21	Arquata Scrivia	8
			Forlì	6	Asti	1
			Torino Lingotto *	**1**	**Bellinzona**	**7**
					Brig	**7**
					Cremona	4
					Genova B.	14
					Genova P.P.	22
					Luino	4
					Mantova	10
					Modena	24
					Novi Ligure	3
					Saronno	31
					Seveso	26
					Sondrio	10
					Stradella	13
					Vicenza	22
2h 15 min - 3 h	Rimini	12			Padova	21
	Venezia Santa Lucia *	**1**			Pesaro	11
					Sestri Levante	9
					Spiez	**3**
					Tirano	8

T/d = Trains per day; Stations outside Italian borders are in green

Total Destinations: 55 - Total Connections (T/d): 1 142

* Direct connection (10)

** To reach Torino P.N. time is saved with exchange in Milano P.Garibaldi station (9 trains per day)

Source: Uniontrasporti, 2014

"single station" of access to Rho-Fiera. In other terms, all the connections of the four stations were aggregated together. In this procedure, the overlappings were avoided taking into account the minimum travel time of connection to Rho-Fiera. In this way, the catchment area was defined for Rho-Fiera considering the four stations of Milano simultaneously. This enlarged catchment area hereafter will be named as "integrated basin" of Rho-Fiera. This procedure was necessary in order to be able to compare the railway accessibility to road accessibility, as it will be clearer in the end. In this report, only the main outputs of the integrated basin of Rho-Fiera are reported.

Two illustrations (Figure 32, Figure 33) show the position of the main destinations reachable from Rho-Fiera, as designed before, the travel times ranges and the distribution of population or bed places at NUTS 3 territorial level. Travel times are spaced every 45 minutes and the more they increase the more the station colour goes towards red. The population size is coloured in shades of grey so that the higher is the more the grey becomes dark (Figure 32). With the same logic, the spread of bed places is coloured in shades of violet (Figure 33). Population and bed places figures refer to 2011, as this is the latest annual data published by Eurostat[10] at the state of data collection. Just as data

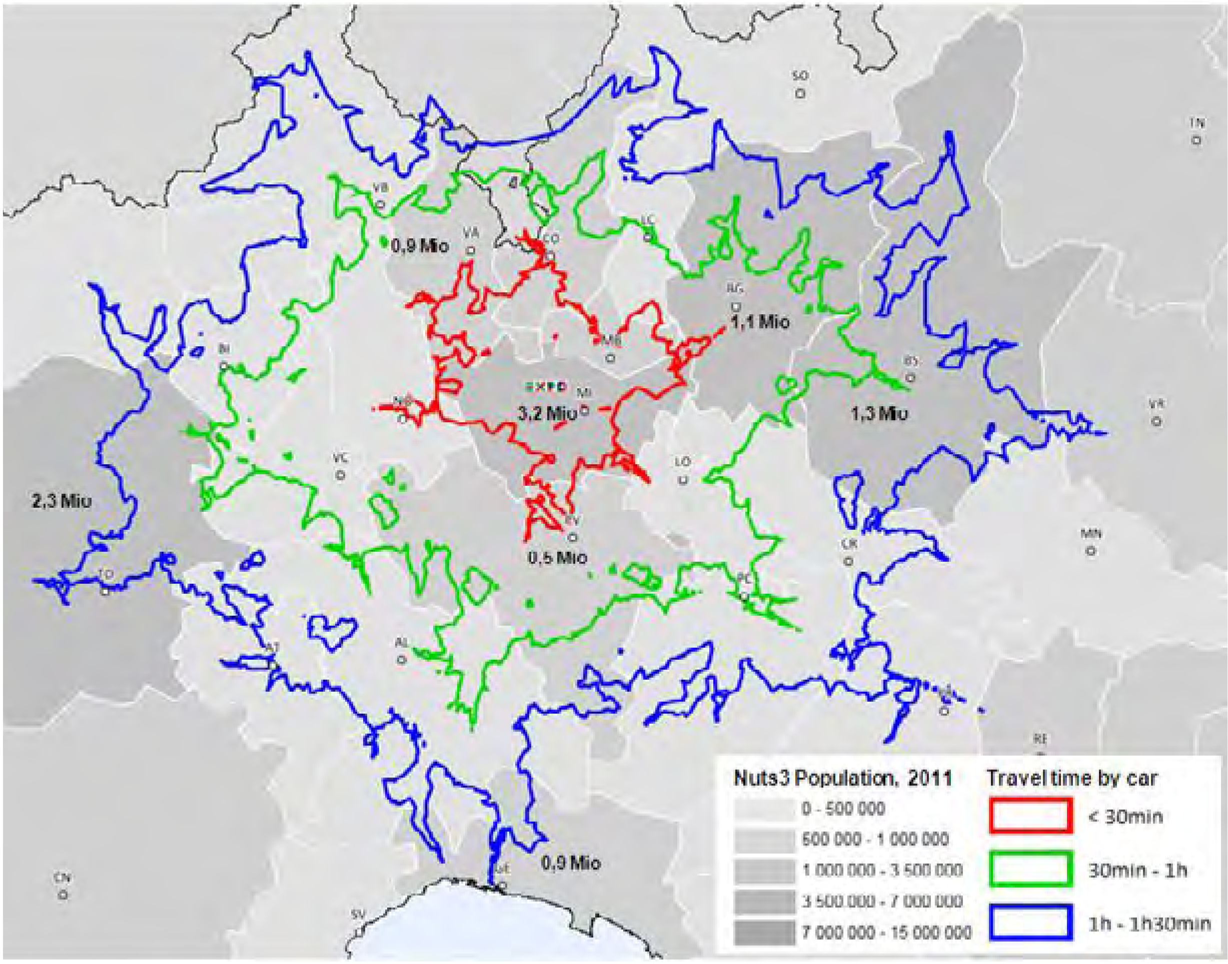


Figure 34. Road Accessibility to EXPO and Population at NUTS 3 Level – 90 Minutes
Source: Uniontrasporti, 2014

Table 13. Road Accessibility to EXPO and Population at NUTS 3 Level – 90 Minutes

EXPO CENTER	**POPULATION (NUTS 3 level)**								
	> 1 000 000			500 000 - 1 000 000			100 000 - 500 000		
	NUTS 3 Destination	Munic.	sqKm	NUTS 3 Destination	Munic.	sqKm	NUTS 3 Destination	Munic.	sqKm
TIME – **30 min**	ITC46 - Bergamo ITC4C - Milano	2 94	11 1,070	ITC42 - Como ITC4D - Monza e della Brianza ITC48 - Pavia ITC41 - Varese	31 35 6 34	182 288 87 282	ITC43 - Lecco ITC15 - Novara	4 1	23 18
TIME – **60 min**	ITC46 - Bergamo ITC47 - Brescia ITC4C - Milano ITC11 - Torino	145 15 40 1	1,219 205 506 12	ITC42 - Como ITC4D - Monza e della Brianza ITC48 - Pavia ITC41 - Varese	76 20 134 91	503 117 1,999 752	ITC18 - Alessandria ITC13 - Biella ITC4A - Cremona ITC43 - Lecco ITC49 - Lodi ITC15 - Novara ITH51 - Piacenza ITC14 - Verbano- Cusio-Ossola ITC12 - Vercelli	11 22 25 50 52 81 2 6 38	308 289 249 258 677 1,252 162 97 770
TIME – **90 min**	ITC46 - Bergamo ITC47 - Brescia ITC11 - Torino	87 102 95	1,145 2,100 1,144	ITC42 - Como ITC33 - Genova ITC48 - Pavia ITC41 - Varese ITH31 - Verona	45 8 45 14 2	441 218 727 137 53	ITC18 - Alessandria ITC20 - Aosta ITC17 - Asti ITC13 - Biella ITC4A - Cremona ITC43 - Lecco ITC49 - Lodi ITC4B - Mantova ITC15 - Novara ITH51 - Piacenza ITH52 - Parma ITC44 - Sondrio ITC14 - Verbano- Cusio-Ossola ITC12 - Vercelli	119 7 29 56 53 21 9 1 6 30 3 5 47 30	1,998 145 318 576 878 345 106 42 71 1,223 165 54 978 804

Source: Uniontrasporti, 2014

of reference, in that year, the province of Milano registered a population of 3.2 million inhabitants and about 84,400 available bed places.

Three tables (Table 9, Table 11, Table 12) schematize the basins of destinations for Rho-Fiera as described before, so with reference to a scale of ranges of the following variables: distance and population, travel time and population, travel time and bed places. It should be noted that aerial distance is used, while travel time is the minimum between observed data. The tables can be read as matrixes divided into cells that contain a set of destinations. In this sense, they allow to obtain an easy-reading representation of the clusters of destinations characterized by a size of population (or bed places) and a dimension of travel time (or spatial distance) needed to reach the EXPO fair.

The illustrations immediately reveal a snapshot of the current scenario: localization, travel time spent and size of destinations. At the same time, the tables, referred to the illustrations, define a set of clusters (basins) through specific limits of time, population dimension, distance, etc. The definition of the basins of destinations for each station

Table 14. Road Accessibility to EXPO and Bed places at NUTS 3 Level – 90 Minutes

EXPO CENTER		BED-PLACES (NUTS 3 level)								
		> 100 000			50 000 - 100 000			1 000 - 50 000		
		NUTS 3 Destination	Munic.	sqKm	NUTS 3 Destination	Munic.	sqKm	NUTS 3 Destination	Munic.	sqKm
TIME	**30 min**				ITC4C - Milano	94	1,070	TC46 - Bergamo ITC42 - Como ITC43 - Lecco IITC4D - Monza e della Brianza ITC15 - Novara ITC48 - Pavia ITC41 - Varese	2 31 4 35 1 6 34	11 182 23 288 18 87 282
	60 min	ITC47 - Brescia	15	205	ITC4C - Milano ITC11 - Torino	40 1	506 12	ITC18 - Alessandria ITC46 - Bergamo ITC13 - Biella ITC42 - Como ITC4A - Cremona ITC43 - Lecco ITC49 - Lodi ITC4D - Monza e della Brianza ITC15 - Novara ITC48 - Pavia ITH51 - Piacenza ITC41 - Varese ITC14 - Verbano-Cusio-Ossola ITC12 - Vercelli	11 145 22 76 25 50 52 20 81 134 2 91 6 38	308 1,219 289 503 249 258 677 117 1,252 1,999 162 752 97 770
	90 min	ITC47 - Brescia ITH31 - Verona	102 2	2.100 53	ITC20 - Aosta ITC11 - Torino	7 95	145 1,144	ITC18 - Alessandria ITC17 - Asti ITC46 - Bergamo ITC13 - Biella ITC42 - Como ITC4A - Cremona ITC33 - Genova ITC43 - Lecco ITC49 - Lodi ITC4B - Mantova ITC15 - Novara ITH52 - Parma ITC48 - Pavia ITH51 - Piacenza ITC44 - Sondrio ITC41 - Varese ITC14 - Verbano-Cusio-Ossola ITC12 - Vercelli	119 29 87 56 45 53 8 21 9 1 6 3 45 30 5 14 47 30	1,998 318 1,145 576 441 878 218 345 106 42 71 165 727 1,223 54 137 978 804

Source: Uniontrasporti, 2014

of Milano allows to establish a hierarchy of the destinations reachable from Milano.

This definition was developed with reference to the following specifications:

- A minimum and a maximum threshold of demographic size and touristic capacity, assumed as being significant for the importance of the destination;
- A minimum and a maximum threshold of distance and travel time from the node, within which the realization of a high-speed railway service could be interesting.

The so defined Milano Rho-Fiera "integrated" basin contemplates, in total, 75 destinations (14 of them located also in France and Switzerland) and 1,230 connections inside 500 km of radius, but 20 of those destinations are not reachable within 3 hours of travel time, that means 1,142 connections in that time range (comparing Table 9 with Table 11, Table 12). Considering a time interval of 1 hour and 30 minutes from Rho-Fiera station[11], 27 rail stations can be reached (Table 10): seven of them are reachable through direct connection, while the other connections imply an exchange in the stations of Milano Rogoredo, Milano Centrale or Milano Porta Garibaldi.

Table 10. Comparison between Rail Basins in 1h and 30 Minutes

Stations of Milano	**Destinations in 1h 30"**		**Connections in 1h 30"**	
	National	International	National	International
Centrale	20	3	493	28
Rogoredo	15	-	400	-
Porta Garibaldi	13	1	223	28
Rho-Fiera	7	-	321	-
Rho-Fiera integrated	25	2	813	21

Source: Uniontrasporti, 2014

Concerning accessibility by road[12], the catchment area has been defined in terms of isochrones within 1 hour and 30 minutes and considering the move with private vehicles from each municipality towards Rho-Fiera site. This evaluation was developed using ChronoMap[13] tool and considering standard speed limits allowed on roads (without congestion) as shown in the following pictures (where intervals of 30 minutes of travel times are represented with lines coloured red, green and blue) with reference to population and bed places spread, as developed for the railway side (Figure 34, Figure 35).

In the tables (Table 13, Table 14), a detailed snapshot of the composition of the road basins are proposed: for each range of travel time and with reference to the size of NUTS 3 regions, in terms of population and bed places, it is specified the municipalities that belong to those ranges of travel time spent and population/bed places. For example, 207 municipalities are reachable within 30 minutes by car from Rho-Fiera site; of those, 96 municipalities belong to two provinces that count more than 1 million inhabitants, Bergamo (2 municipalities reached) and Milano (94 municipalities reached).

In total, about 2,000 municipalities, 11 million inhabitants and 400 thousands bed places can be "caught", by car, within 90 minutes of travel time from the EXPO venue.

Finally, the information concerning both rail and road accessibility, within 90 minutes of travel time, have been matched together in order to highlight lack of connections and or discrepancy between the territories that compose the Rho-Fiera basin and those outside this basin.

The following illustration (Figure 36) shows clearly that car is more competitive than train, in terms of travel time, especially if considering those locations that are not served by High-Speed Rail services (the nodes in grey) or otherwise, that there is not a good connection with Rho-Fiera in terms of rail level of services.

The overall railway reachability of the EXPO fair does not reveal excellent performance in comparison with car travel. Considering both frequency and travel time, the most efficient connections to Rho-Fiera are the stations of Lodi, Rho, Pioltello Limito, Novara, Treviglio, Bologna Centrale and Gallarate, all served by more than 40 trains per day and with a travel time not exceeding 90 minutes. Particularly

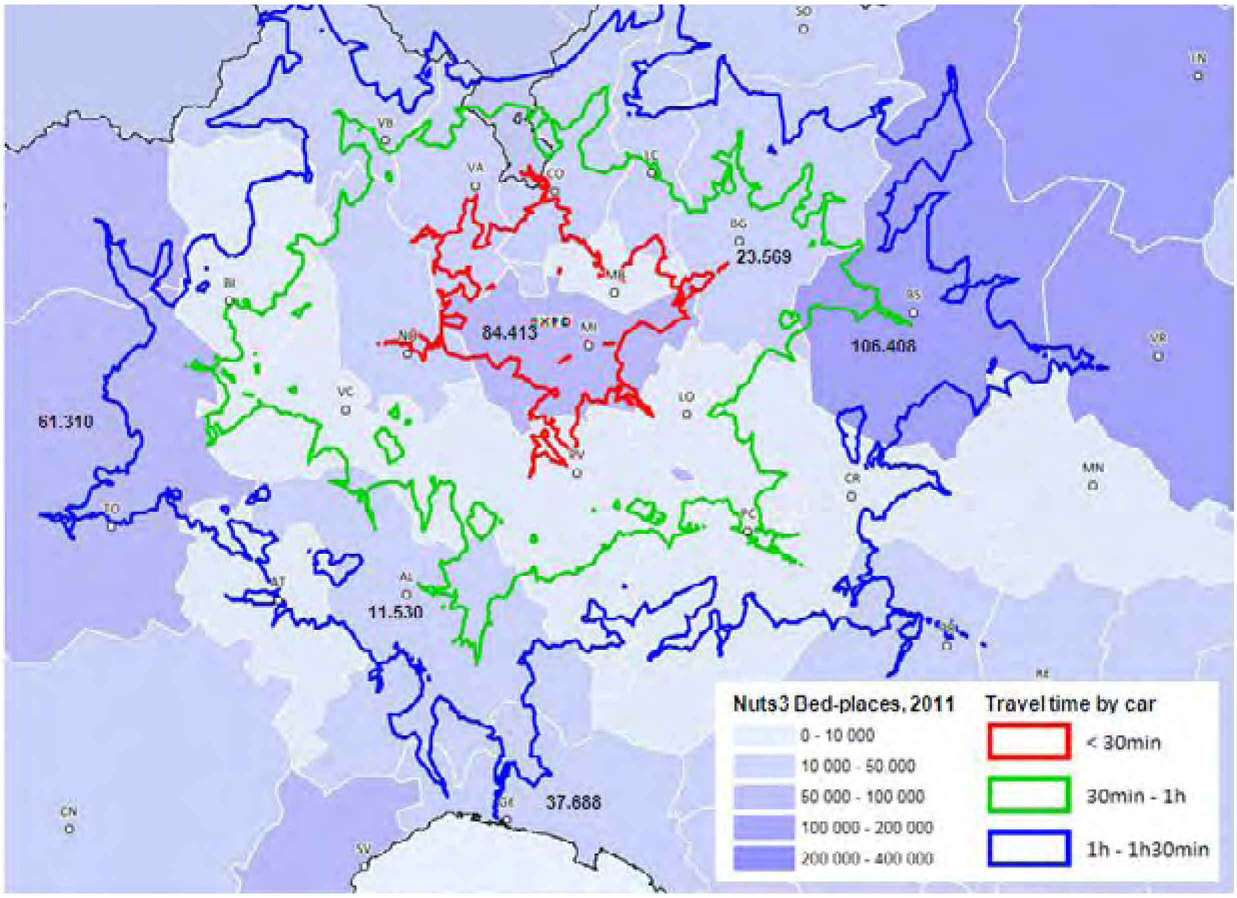


Figure 35. Road Accessibility to EXPO and Bed places at NUTS 3 Level – 90 Minutes
Source: Uniontrasporti, 2014

negative performances are recorded for the stations of Chivasso, Torino Lingotto, Genova Piazza Principe, Genova Brignole, Luino, Stradella, Alessandria, Arquata Scrivia, Asti, Bellinzona, Brig, Cremona, Novi Ligure, Sondrio and Tirano whose distance from Rho-Fiera is between 50 and 150 km, but the travel time is more than 90 minutes.These stations are overtaken by other better performing stations that are physically farther from Rho-Fiera (more than 150 km), but served by faster rail connections (travel times between 45 and 90 minutes), such as the stations of Bologna Centrale, Reggio Emilia and Verona Porta Nuova.

The situation of the Genova node is particularly emblematic if compared to that of Bologna Centrale, because they also have a comparable size of their territories (they belong to the same ranges of population and bed places).

In general, it is an evidence that Genova comes up with a lacking and disadvantaged service with respect to other Italian cities facilitated with HS rail services. However, it cannot be ignored that the port of Genova, together with the Alps, are the two main land-gateways for EXPO international visitors coming from the South and from the North

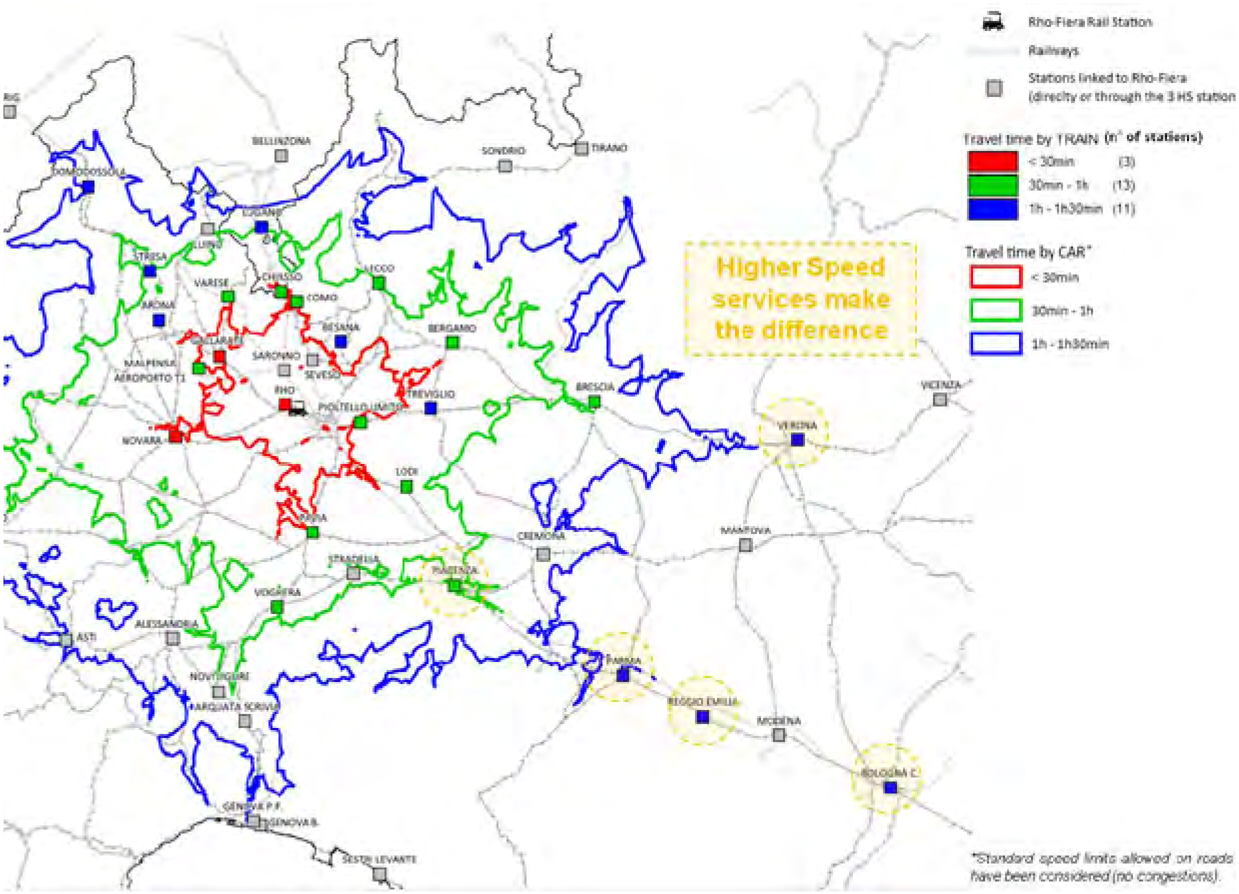


Figure 36. Accessibility to EXPO Road vs Rail – 90 Minutes
Source: Uniontrasporti, 2014

respectively. Nevertheless, Trenitalia's plans for the EXPO event seem to be more oriented to strengthen high-speed services, eventually increasing the number of stops at the station of Milano Rho-Fiera, and north side access to EXPO (from Switzerland, in cooperation with SBB), rather than improving the connections to Genova.

Extra services for visitors coming from Switzerland are planned by SBB in cooperation with Trenitalia: they are planning to offer 2,500 extra seats per day during the EXPO event, and the EC trains on the route of Simplon, Genève-Milano and Basel-Milano, will also stop at Milano Rho-Fiera station. Improved connections with Genova remain an open question.

4.2 Methods to Estimate Railway Capacity

Railways are made up of several interconnected facilities such as lines, stations, junctions, stabling yards, freight terminals, and marshalling yards. The capacity of each of those elements may be described as the maximum number of trains which may use each element during a given time. This further requires a choice of the time over which capacity is discussed, e. g. one hour, one day, one week and of the quality level with which trains use the facility, e. g. what is the maximum delay allowed. All those elements are working together to provide the infrastructure to operate train services so the actual capacity is defined by the appropriate combination of the capacities of the elements. Railways are complex and interconnected systems. The work in this part of Action 17 focuses on line capacity, and so will this section of the report. Looking at line capacity means focusing on a part of the overall picture and this is an approximation that is acknowledged.

Moreover the railway line capacity depends on the viewpoint considered. For instance it is possible to:

- Discuss a line that may carry on average 210 trains/day in either direction and in certain conditions;
- Look at the availability of a path at a given time of a day, which is what is required when forming a timetable.

This section discusses and applies the first approach. The second approach, which turns out to be more appropriate for the EXPO case study, is employed in Section 4.3.

It should be noted that the International Union of Railways (UIC) has only one standard for the evaluation of railway capacity consumption, the UIC 406-1 leaflet, which is reviewed at the end of Section 4.2.2 and is not for the evaluation of railway capacity per se. Indeed the UIC 406 states that "…capacity as such does not exist. Railway infrastructure capacity depends on the way it is utilised". The same UIC Leaflet notes that "A unique, true definition of capacity is impossible". Those guidelines therefore focus on providing a method to evaluate capacity consumption. There is indeed a large body of research that, starting several decades ago, tries to quantify capacity on railway lines based on several assumptions and levels of realism. Kontaxi and Ricci (2010) conducted a survey of such methods and concluded that no less than forty analytical methods have been developed since the 1950s, some being developments of previous ones. The same authors note that different methods provide different results, sometimes remarkably different results.

As the aim is to characterise a relatively simple but useful method to quantify railway capacity, this section will review a selection of methods and suggest the use of one, which is sensitive to several factors influencing capacity. The method is then applied and tested on a part of a line on the Corridor.

Notwithstanding, the difficulties mentioned above about defining railway capacity, for the purpose of this work, railway line capacity is defined as: the maximum number of trains that may be operated using a defined part of the infrastructure during a defined time period.

Figure 37. Elements Composing a Railway System
Source: SiTI, 2014

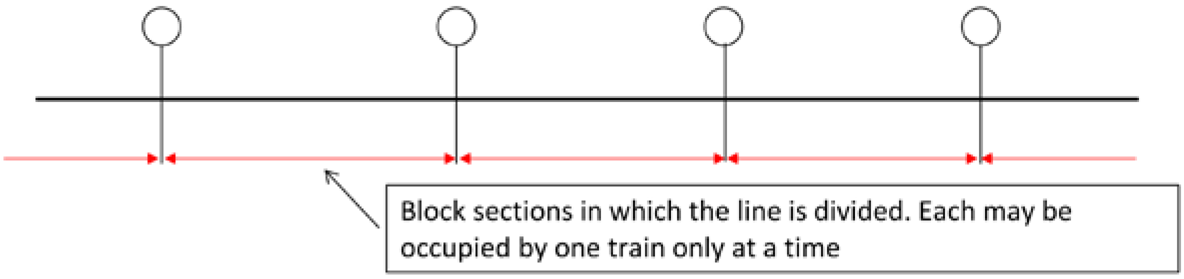


Figure 38. Railway Line Divided in Block Section. Each Block Section is Delimited by Signals (Sketched as circles on their posts)
Source: SiTI, 2014

There are however different capacities that may be characterised and the key distinction is between theoretical capacity and practical capacity. Theoretical capacity is an ideal reference figure representing the number of trains - often identical trains - that could be operated running at the minimum theoretical distance between each other and in unperturbed operations. Practical capacity is a more realistic reference figure that accounts for the differences among train types, and for the actual operating conditions, including possible disruptions.

To illustrate what line capacity may depend upon, the following section reports some simple examples of effects that different operating conditions may have on it and concludes with a list of the items that should be accounted for to obtain the practical capacity.

A selection of methods to evaluate capacity space is described in the ensuing section while the closing part of this section reports an application calculation for the Genova-Milano corridor.

4.2.1 A Set of Examples to Illustrate what Railway Line Capacity Depends upon

Line capacity is firstly about train separation. Trains running on a line must travel at a distance from each other that is both safe and efficient. Safety is the prime interest in rail operation procedures and demands that the following train can stop safely without reaching the previous one standing along the line. Efficiency demands that the progression of each train on a line is not influenced by those of the previous ones. Both conditions are ensured by block systems (see the sketch in Figure 38). Railway lines are divided into block sections that are stretches of track clearly marked by lineside signals. Each block section may be occupied by one train at a time only.

Main line trains are operated by drivers whose actions are supervised by on-board equipment. The driver sets the speed of the train knowing all necessary information about the service, the train, the infrastructure, and the operation of the infrastructure. The on-board equipment has the same information that the driver needs to know and acts only when required (e. g. to pre-warn the driver that the train is beginning to travel faster than allowed) or to stop the train if the driver does not amend any incorrect action (continuing the previous example, in case the driver fails to slow down and comply with the speed limit along a stretch of line). The driver of each train and the supervising on-board equipment are informed of whether the train may proceed into the next section and at what speed by devices along the line – on conventional railways lines – or by radio signals – on railway lines equipped with ERTMS level 2. Devices used on conventional railway lines are optical signals, colour coded lights primarily, and balises or coded currents in the tracks or other line side equipment whose codes may be read by antennas carried by trains and displayed on the trains' dashboards. Conventional signalling systems – different by country – and ERTMS level 1 all have lights and an automated line-train communication system working together. Starting from ERTMS level 2 (the most advanced version of ERTMS currently in operation) line side light signals are no longer required and communication between the block system, each train, and its driver is carried out by radio.

The illustration of signalling is developed for the purpose of understanding the railway line capacity by referring to conventional signalling systems and to one of the tracks of a double track line and its one-way operation. In this example, line side signals alternatively show three aspects (colours) and therefore alternatively give three different instructions to drivers. They may be summarised as follows: green for "proceed", red for "stop before this signal"; yellow for "proceed but next signal is red: slow down to be able to stop before next signal".

Consider Figure 39 where an orange train follows a blue train. Since no two trains may occupy the same block section and knowing that the course of each train should not be influenced by that of the preceding one, for safe and efficient operation the orange train must see green signals as it proceeds and be distant enough from the preceding train to be able to stop without invading its block section. The former condition is illustrated for the orange train in Figure 39 as it is approaching a green signal since it is distant enough from the preceding train not to be influenced by its progression. This latter condition is obtained when a train has a red signal at the entrance of the block section it currently occupies, preceded by a yellow signal at a distance which is at least equal to the braking distance (this situation is shown in Figure 40 for the blue train).

Therefore, in this example, the block section must be at least as long as the braking distance of the trains (of all the trains allowed on the line). Note that trains of different kinds, brake in different ways, e.g. passenger trains as opposed to freight trains (recall the recent interest in long and heavy trains) and are scheduled at different speeds. The length of the block section should allow for all kinds of trains (also those with the longest braking distance) and in turn the maximum speed of the trains must allow them to brake before any red signal. Also, note that the length of the block sections may vary along the lines.

The minimum distance between following trains – and the time required to cover it – determine the capacity of the line. The minimum distance is sketched in Figure 41 and extends beyond the signals as it includes elements such as a sighting and reaction distance (before the signal shown as green) and a safety overlap after the signal just turned to red behind the blue train.

In summary, the capacity of a line is defined as:

$$C = \frac{T}{t_{sep}}$$

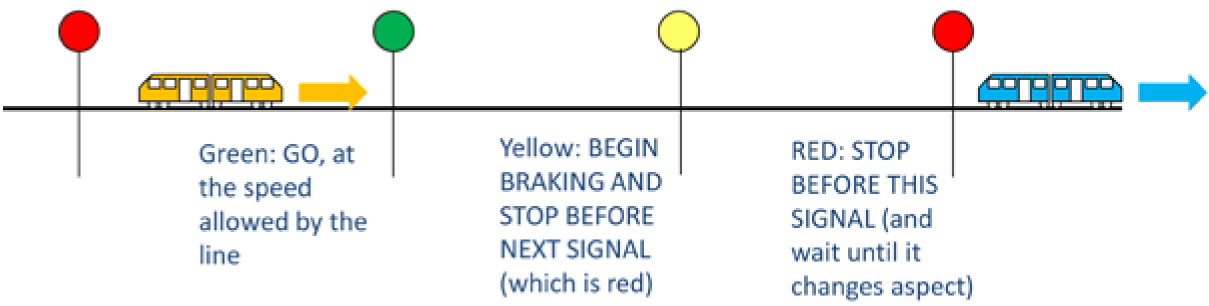


Figure 39. Simple but Realistic Example of a Train Following Another One (the Orange Train Follows the Blue One) on One of the Tracks of a Double Track Line
Source: SiTI, 2014

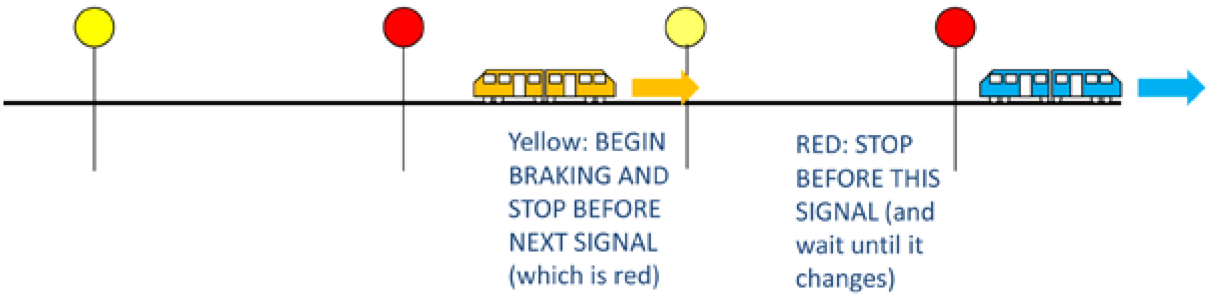


Figure 40. The Yellow Signal Informs the Orange Train and Its Driver that the Next Signal is at Red and that the Train Must Stop before It
Source: SiTI, 2014

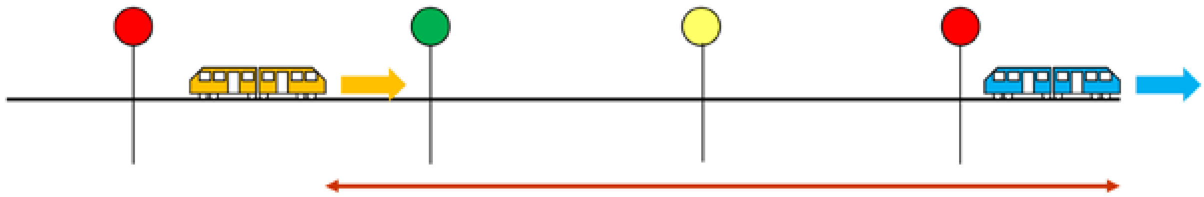


Figure 41. A Sketch of the Minimum Safe and Efficient Distance between Following Trains
Source: SiTI, 2014

where ***T*** is the time over which capacity is to be determined (e.g. the day, an hour) and tsep is the time separation between following trains.

For instance, considering a minimum separation that all trains cover in 6 minutes, a capacity of 10 trains/hour is obtained. To visualise this, without losing generality, it is possible to imagine that the first train enters the line at minutes 00 of an hour and uses the line between minutes 00-06, the seconds one uses the line between minutes 06-12 and so on, until minute 60.

The time that trains require to travel their minimum separation depends on e.g.:

- *the infrastructure* (the block sections, the signalling system, the allowed speed);
- *the trains* (scheduled speed for that rolling stock and relevant braking distance).

Figure 42 shows a slightly different example: trains on the same line considered before alternate between two different types. For any train like the ones seen before a slower train follows, and the latter covers the minimum separation distance in 9 minutes. Starting for ease of illustration again at minutes 00 of the hour, the first trains –a fast one- uses the infrastructure between minutes 00-06, then the second train uses the infrastructure between minutes 06-15, and so on, until minute 60. With such a sequence of trains, only 8 trains will now fit into one hour of line opening.

Therefore line capacity depends also on the types of trains that travel along it, on their speed, quantity, and sequencing.

In the previous examples the minimum separation between following trains were considered. However, if the aim is to ensure that possible delays do not

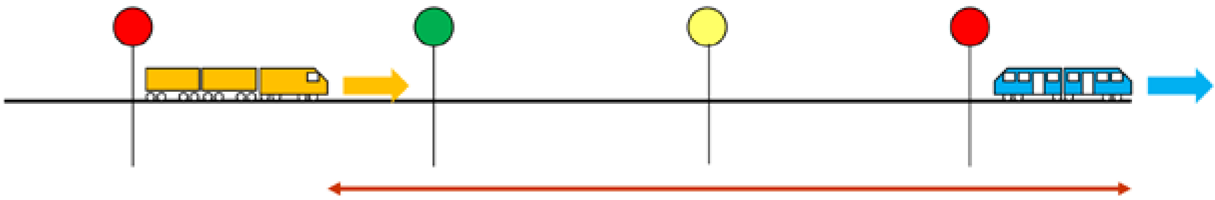


Figure 42. A Case of a Slow Train Following a Faster One
Source: SiTI, 2014

spread from one train to the following ones, it is necessary to schedule less tight a usage of the infrastructure and insert margins in between trains.

Taking the latter example with fast trains and slower trains alternating, 3 minutes of margins can be inserted between one train and the next one. Infrastructure usage will be reserved from minute 00 to minute 9 (that is for 6+3 minutes) for the first – fast train – then from minute 9 to minute 21 (that is for 9+3 trains) for the slower train and so on. This kind of operation leads to 6 trains/hours able to travel on the line only.

This brief illustration of the links between

- Line characteristics;
- Train characteristics;
- Operational procedures;

and capacity. It was intended to show how much variable the capacity of a line is and what it depends upon. Now the statement, "capacity as such does not exist. Railway infrastructure capacity depends on the way it is utilised." (Leaflet UIC 406) should be clearer. In general, and accounting also for factors that could not be illustrated by the simple example above, capacity on a line depends on:

Line characteristics, e.g.

- Alignment of tracks, sections with speed restrictions;
- Number of stations and passing loops;
- Crossings, lines diverging, lines merging;
- Signalling and safety systems and their working times;

Train characteristics, e.g.

- Homogeneity/heterogeneity of rolling stock and services;
- Sequence of trains;

Operational procedures, e.g.

- Running time supplements;
- Timetable margins.

For a reliable capacity estimation it is therefore necessary to use several of the data above. Moreover, many of the data above, even when not line or train specific, are different by location. For instance, running time supplements, added to the running time of the trains to ensure they may make up for travel disturbances and keep to the timetable, and buffer times, added in between trains and during which the infrastructure is not used: they avoid or dampen transmission of delays from one train to others (e.g., the following trains). Both added times depend on national norms and uses (and may vary by line, type of train) though there are international guidelines on running time supplements.
The overall capacity of a line is also influenced by track possession times for inspection and maintenance.

The following section reports an overview of methods for line capacity evaluation that use only a part of the information mentioned above to keep the calculations simple.

4.2.2 A Survey of Methods for the Evaluation of Railway Line Capacity

There are several methods to evaluate theoretical or practical railway line capacity. Depending on the calculation approach, they may be divided into

- Analytical methodes;
- Optimisation methodes;
- Simulation methodes;

In order of increasing

- Complexity of calculation;
- Detail of input and output data;
- Realism of the results (provided input data are realistic).

Each infrastructure manager uses one or more of the methods mentioned, depending on the application.

Optimisation and simulation work with a detailed timetable and require specific software, as well as detailed data on infrastructure and train dynamics. Analytical methods are more coarse but are more suitable within the scope of this project and we focus on those in the following.
Typically analytical methods are elaboration of the following formula (already reported above)

$$C = \frac{T}{t_{sep}} \qquad (Eq.\ 1)$$

where ***T*** is the time over which capacity is determined (e.g. the day, an hour) and t_{sep} is the time separation between following trains. The way to calculate $\boldsymbol{t_{sep}}$ is the distinguishing feature of most methods. The simplest methods uses parametric determination for $\boldsymbol{t_{sep}}$ (e.g. an average value from experience) while more elaborate methods consider explicitly the factors determining tsep and, in certain cases, add also information from practical experience.

The ensuing paragraphs review the following analytical methods:

- FS (the Italian railways, Ferrovie dello Stato);
- DB (the German railways, Deutsche Bahn);
- STRELE, Schwannhäusser (1974);
- UIC leaflet 405 R (1979);
- UIC leaflet 405-2 (1983);
- de Kort et al (2003);
- Kozan and Burdett (2005);
- Genovesi and Ronzino (2006).

Following the analytical methods, the report illustrates the current procedure suggested by the International Association of Railways (UIC):

- UIC leaflet UIC 406-1 (2004).

However, the latter method does not provide an evaluation of capacity but, rather, an evaluation of used capacity and of the possibility of adding further train paths while keeping the desired operational conditions. This comes at the cost of additional input information as explained below.

The FS Method

In the past, the Italian railways, FS, developed a method that details the basic formula (Eq. 1) by considering two types of trains (passenger and freight). It may be used for single or double track lines. The description reported here is based on Vicuna (1993) and on Ricci (2012).

The FS method calculates the time free from scheduled trains and divides it by the headway required by freight trains to obtain the number of available slots. To return the actual capacity estimate, the number of available slots is summed to the number of scheduled trains and the overall result is reduced by an empirical factor.
In more detail, the FS formula is

$$C = K\left(N + \frac{T - n_p(t_p + t_{rs}) - n_f(t_f + t_{rs})}{t_f + t_{rs}}\right)$$

where

K is an empirical factor accounting for actual operating conditions, as the safety system in place, and is typically between 0.6-0.8;
N is the number of trains currently scheduled on the line;
T is the opening time of the line, typically the day minus the time when the line is closed for scheduled maintenance;

t_p and tf are the travelling times (the headways) along the critical section (the one for which such travel times are largest), referring respectively to passenger trains and freight trains;
t_{rs} is the time to set the signalling system for the passage of each train.

As noted by Ricci (2012), it appears inconsistent that the number of currently scheduled trains is included in the reduction operated by the empirical factor K, although this may be read as an attempt to account for lost capacity.

Table 15. FS Method: Summary Information

FS method - Summary information	
Output	Theoretical capacity Practical capacity
Input information and output sensitivity	Number and type of trains currently on the line Headway time required by passenger and freight trains to travel the critical section Time required to set signals (this incorporates the safety system's characteristics)

Source: SiTI elaboration based on Vicuna, 1993 and Ricci, 2012

The DB Method

The method used by the Deutsche Bahn (DB) develops the basic formula (eq. 1) accounting for both a weighted minimum average headway between trains and a set of data on the actual or required quality of service.

This includes the maximum total delay allowed per day, the probability that trains are already delayed on entering the section of interest, and the average of such delay. The method considers two types of trains (fast and slow) and requires an input timetable or a hypothesis on the number of trains per type.

Either of those inputs allows calculating the weighted minimum average headway (as explained in more detail in the paragraph about the UIC 405 R method) and an average minimum headway related to the instances of trains of the same speed following each other. The discussion of this method reported here is based on the information by Vicuna (1993) and Ricci (2012). The formula used is:

$$C = \frac{T}{t_{fm}\,(1+q)}$$

where

C is the capacity of the stretch of railway line (trains/day);
T is the reference time (the day);
t_{fm} is the average of the minimum headway calculated over all the possible sequences of trains. Since in this method only two types of trains are considered there are four possible cases of train sequences;
q is an added time (a buffer time) representing the desired (or surveyed) quality of service.

The capacity is calculated over a reference section which is the one returning the largest value of the denominator.

The term **q** makes a difference in this formulation and links it to real operations. It is dependent on three other elements incorporating allowed and experienced (or expected) delays:

H: an element linked to the total allowed delay per day on the reference section (P_f) and to the ratio We of delayed trains over the total number of trains travelling on the reference section (which can be seen as the probability that a train entering the reference section is delayed). The formula to get H requires P_f in minutes as it includes 1440, the number of minutes in a day (the reference time period; alternatively the formula should be adapted):

$$H = \frac{P_f}{1440\left(W_e - \frac{{W_e}^2}{2}\right)}$$

- A transfer factor ü is the ratio between the average minimum headway t_{fm} and the average delay of the trains entering the section during the reference time **T**.
- A term referred to the sequences of trains of the same and different type and their minimum

headways. This, recalling that only two types of trains are considered, is:

$$W_g = \frac{t_{ff} {N_f}^2 + t_{pp} {N_p}^2}{(t_{fp} + t_{pf}) N_f N_p}$$

These three elements are then combined together using a specific chart which returns the value of q.

Table 16. DB Method: Summary Information

DB method - Summary information	
Output	Practical capacity
Input information and output sensitivity	Minimum headways between each pair of train types Number of trains by type (2 types allowed) Allowed total delay per day Probability that a train is delayed on entering the reference section Average delay of trains entering the reference section

Source: SiTI elaboration based on Vicuna, 1993 and Ricci, 2012

The STRELE / Schwannhäusser (1974) Method

Schwannhäusser (1974) devised a formula for expressing secondary (i.e. knock on) delays on a section of railway line as a function of a number of elements comprising the probability of delay at the entrance of the section and its average value, the headways between trains and the average buffer time. The formula is used to this day in the STRELE software of the University of Aachen, also employed recently for studies on line capacity with and without ETCS (VI Aachen, 2008) commissioned by the International Association of Railways (UIC).
The method used in the STRELE software and derived from the work of Schwannhäusser (1974), uses the basic formula (eq. 1) detailing it as follows:

$$C = \frac{T}{t_{fm} + t_{P,erf}}$$

where t_{fm} is the average minimum headway time obtained as seen for the UIC 405 R case (see the relevant section) and $t_{p,erf}$ is obtained by equating the delay described by the formula of Schwannhäusser (1974), which is not reported here, to the total acceptable secondary delay and solving for $t_{p,erf}$. The total acceptable secondary delay is expressed in VI Aachen (2008) as:

$$ET_{W,zul} = 0{,}257 e^{-1{,}3 p_{rz}}$$

where p_{rz} is the proportional of passenger trains on the line and the coefficients shown relate to what is deemed acceptable in German experience. VI Aachen (2008) details how the STRELE formula is adapted to account also for in-fill of signal information.

Table 17. STRELE / Schwannhäusser Method: Summary Information

STRELE / Schwannhäusser method - Summary information	
Output	Practical capacity
Input information and output sensitivity	Timetable or sequences of trains by rankings Minimum headway times between pairs of trains referred to trains of different ranking Probability that a train is delayed at the entrance of the section analysed Average value of delay at entrance Average buffer time Method to determine the total acceptable secondary delay

Source: SiTI elaboration based on VI Aachen, 2008

The UIC Leaflet 405 R Method

The UIC leaflet 405 R was the suggested standard for the determination of railway capacity until the issue of leaflet UIC 406. The latter is discussed in a following paragraph and shifted the focus from line capacity to capacity consumption.
The UIC leaflet 405 R provides an analytical formula that may be employed for both single and double track lines and was developed to provide a uniform

way to calculate railway capacity across different national networks in view of a UIC infrastructure master plan and with the intention to use it to locate bottlenecks. International use of UIC leaflet 405 R is reported, for instance, in Wahlborg (2004). The usage of UIC leaflet 405 R aimed to be:

- simple and transferable;
- able to account for actual trains circulating on the lines and their proportion;
- able to account for actual block sections and safety equipment on the lines.

In turn the method is able to estimate capacity variations resulting from changes of the latter two elements. To apply the method, the line needs to be divided in sections which, in turn, are divided in subsections. The capacity calculation is performed on the subsections. The subsection with the lowest capacity determines the capacity of the section of line.

The sections are delimited by passing or meeting stations or by junctions; train number and mix should be approximately constant along them and each section may include several subsections. The subsections are delimited by passing or meeting stations or by junctions.

The following formula is put forward UIC leaflet 405 R for the calculation of railway capacity:

$$C = \frac{T}{t_{fm} + t_r + t_{zu}}$$

where

T is the reference time for the capacity determination, the whole day or the peak hour;
t_{fm} is the average minimum headway between following trains that is the average of the time strictly necessary to separate the trains. It is obtained either from the timetable or from information on the train mix and the expected headway times (see better below);
t_r is a time margin added between successive trains to avoid knock-on delays. When considering the capacity during a whole day of operation it is assumed equal to 0.67 tfm which is consistent with an occupation of 60% of infrastructure capacity. The peak hour capacity may be determined considering lower time margins between successive trains and tr may be taken equal to 0.33 tfm which corresponds to having the infrastructure occupied for 75% of the time;
t_{zu} is a time supplement added to consider the number of subsections in which the relevant section is divided; it is given by (number of subsections) x 0.25 min.

Once the infrastructure is divided in sections and subsections (and therefore also the term tzu is determined) the key passage of the method is the calculation of the average minimum headway between following trains.

For one way operations – that is on one of the tracks of a double track line – [and without a timetable] this can be done by considering the number of train types and the time they use the subsection of the infrastructure for. The UIC leaflet suggests that the number of train types be kept less or equal to 4, best if only two train types are considered. The occupation of the infrastructure – on which the minimum headway depends – is not just the time during which the train is on a block section or subsection of line but includes all the time during which the train engages that length of line thus including the time for route formation, the time to cover the visibility distance of the first relevant signal, the time to cover the distance between the pre-signal and the signal (which is a block section in case of main-main signalling), the actual journey time over the block section, the time to clear the block section, the time for the release of the route and, in case of stops along the subsection, the time required by the train to stop, dwell, and resume the journey.

The leaflet suggests values for some of those figures when they are not known (e.g. for a standard length of the trains to calculate the time to clear the section, the timefor the formation and release of the route).
In case a graphical timetable is available, the UIC 405-R leaflet suggests the possibility of determining the minimum headway between following trains by depicting on the graphical timetable the total occupation times by each train on each section, obtaining the so called blocking time stairways. Shifting rigidly such blocking time stairways until they are adjacent to each other, the minimum

headway between following trains may be measured on the graphical timetable. This method is better explained in the section of this report about the UIC 406 method, where this procedure of "compressing" the timetable is taken further to determine total infrastructure occupation by trains.

Knowing the possible sequences of trains it is possible to fill in a table as follows

Table 18. Table of Sequences of Train Types and Numbers of Sequences

	Train type 1	Train type 2	Train type 3
Train type 1	n_{11}	n_{12}	n_{13}
Train type 2	n_{21}	n_{22}	n_{23}
Train type 3	n_{31}	n_{32}	n_{33}

Source: SiTI, elaboration on UIC, 1979

where, for instance, $\boldsymbol{n_{31}}$ is the number of cases where a train of type 3 is followed by a train of type 1. For each kind of succession there may be a different minimum time headway. Therefore a similar table of minimum time headways may be filled in

Table 19. Table of Minimum Headways by Train Type Successions

	Train type 1	Train type 2	Train type 3
Train type 1	t_{11}	t_{12}	t_{13}
Traintype 2	t_{21}	t_{22}	t_{23}
Train type 3	t_{31}	t_{32}	t33

Source: SiTI, elaboration on UIC, 1979

where, for instance, $\boldsymbol{t_{31}}$ is the minimum time interval when a train of type 3 is followed by a train of type 1. The term $\boldsymbol{t_{fm}}$ may then be obtained as the weighted average of the tij using the nij as weights:

$$t_{fm} = \frac{\sum_{ij} n_{ij}\, t_{ij}}{\sum_{ij} n_{ij}}$$

When the timetable is not known, but there is information on the minimum time intervals between types of trains and on the frequency of each type of train, the UIC405-R suggests to assume random train sequences and therefore using an average minimum time interval obtained as:

$$t_{fm} = \frac{\sum n_i n_j\, t_{ij}}{\sum n_i n_j}$$

where $\boldsymbol{n_i}$ and $\boldsymbol{n_j}$ are the numbers of trains by type. For two way operations, that is on a single track line, headways between successive trains need to be considered for each of the four possible types of successions: a) up train followed by another up train, b) up train followed by down train, c) down train followed by up train, d) down train followed by down train.

The leaflet suggests that the travel times are obtained from the timetable and that the distances on the line are obtained from the signalling diagrams. The subsection of the line which has the lowest capacity value is called the critical subsection. The capacity of a section of line is then given by the capacity of its critical subsection.

Looking at the formulae for the capacity it is possible to remark that the subsection with the lowest value of capacity is the one with the highest value of $\boldsymbol{t_{fm}+t_r+t_{zu}}$ therefore the one with the highest average total occupation time, in case of one way operations, or with the highest average value of train succession time, in case of two way operations.

Table 20. UIC Leaflet 405-1 R: Summary Information

UIC leaflet 405 R - Summary information	
Output	Practical capacity
Input information and output sensitivity	Timetable of the line or sequence of train types from the timetable or expected/actual frequency of train types Line description, including position of signals and stopping points Travel times of trains (by train type) between signals/block sections/minimum headways

Source: SiTI elaboration based on UIC, 1979

The UIC leaflet 405-2 Method

In 1983 the UIC issued a further leaflet on railway capacity, whose aim was to show the results of different possible measures to increase train capacity of trunk lines either double or single track. Measures included changes in the organisation of operations (e.g. changes to train speeds and formation of batteries), changes to safety and signalling (e.g. changes to the length of the block sections). The leaflet reports the charts obtained from a large combination of measures and train characteristics. The charts are not reported here since the elements of interest are the formulae used for capacity determination.

For single track lines this leaflet uses the same formula put forward in leaflet UIC 405-R (see the previous section).
For double track lines the formula used in UIC 405-2 is a simplification of that from UIC 405 R. In fact the formula employed is:

$$C = \frac{T}{t_{fm} + t_r}$$

where

- ***T*** is the reference time for the capacity determination, the whole day or the peak hour
- t_{fm} is the average minimum headway between following trains that is the average of the time strictly necessary to separate trains. This is determined, as seen in UIC 405 R, that knowing the minimum headways between pairs of train types and the sequence of train types
- t_r is a time margin added between successive trains to avoid knock-on delays. When considering the capacity during a day of operation it is assumed equal to 0.67 t_{fm} which is consistent with an occupation of the infrastructure of 60%. The peak hour capacity may be determined considering lower time margins between successive trains and tr may be taken equal to 0.33 t_{fm} which corresponds to having the infrastructure occupied for 75% of the time.

The difference from the UIC 405 R formula is that the present formulation considers the capacity of line sections, without getting into the detail of the subsections. Therefore it computes the capacity for stretches of line between pairs of meeting/passing stations or junctions, typically not close to each other without accounting explicitly for the critical line subsection.

Table 21. UIC Leaflet 405-2: Summary Information

UIC leaflet 405-2 - Summary information	
Output	Practical capacity
Input information and output sensitivity	Timetable of the line or sequence of train type from the timetable or expected/actual frequency of train types Line description Minimum headways of trains (by train type) between extremes of line sections

Source: SiTI elaboration, based on UIC, 1983

The de Kort et al (2003) Method

The work by de Kort et al (2003) included an application to evaluate the capacity of a section of high-speed line in relation to its physical characteristics and to its operational procedures. De Kort et al (2003) developed a formulation of the capacity of a generic building block of railway infrastructure using (max,+) algebra.

The model is flexible: it can accommodate any sort of infrastructure and block system, represented by the occupation of the section and by the rules whereby a section is available to a train, and may accommodate trains with different speeds and travel times, as well as random perturbations to traffic such as delays either at the entrance into the simulated system or generated within it.
The capacity problem is eventually reduced to an optimisation problem in conventional algebra and requires an appropriate solver (de Kort et al developed their own solver by coding a suitable algorithm).

Table 22. de Kort et al Method: Summary Information

de Kort et al method - Summary information	
Output	Theoretical capacity
Input information and output sensitivity	Mix of trains and their running characteristics Travel time by type of train Rules describing the operations (e.g. block system) Distributions of delays of entering trains Distributions of delays originating in the modelled network

Source: SiTI elaboration based on de Kort et al., 2003

The Kozan and Burdett Method

In their paper of 2005, Kozan and Burdett were concerned with the determination of an absolute capacity (which is a theoretical capacity) for line segments. Their primary concern was not the train traffic but the charging system. Kozan and Burdett (2006) further used their formulation and extended it to account for networks. The basis of the determination of the theoretical capacity value is similar to what seen above for other methods. Kozan and Burdett consider the different train types that may travel along the line, calculate the time during which each type occupies the section of interest (considering what the actual motion of the train may be, for instance whether it accelerates or decelerates) and obtain an average occupation time.

The latter is calculated by weighting the occupation times by the proportion of train types in either direction. Indeed, in Kozan and Burdett (2006) the matter of alternating direction of travel along the same track and its effect on capacity are discussed at length.
The final value of the capacity is again an elaboration of the base formula (Eq. 1) where the denominator is the average occupation time mentioned above. No account of buffer times is foreseen as the authors actually intended to obtain the theoretical value of the line capacity.

Table 23. Kozan and Burdett Method: Summary Information

Kozan and Burdett method - Summary information	
Output	Theoretical capacity
Input information and output sensitivity	Headway for each train type on the critical section Number (or frequency) of trains by type and direction

Source: SiTI elaboration based on Kozan and Burdett, 2006

The Genovesi and Ronzino Method

The paper by Genovesi and Ronzino (2006) elaborates on the minimum headway at which trains may follow each other and obtains formulae for the theoretical capacity in case of moving block and of block based on block sections, for any number of signal aspects and also considering distant-main signals. The formulation is developed for homogeneous traffic, though the authors suggest how to adapt it for mixed traffic.
With moving block, and considering that trains should be at a distance d at least equal to the sum of the braking distance (function of the deceleration ? and of a coefficient k), the length of the trains L and a safety margin sm, they obtain the capacity as:

$$C = \sqrt{\frac{\gamma}{2k(L+sm)}}$$

In case of fixed block system with n aspects with block sections of length b, they obtain the theoretical capacity as

$$C = \frac{v}{\frac{n-1}{n-2}b + L + sm}$$

The number of aspects n is at least 3, so that with 3 aspects (red, yellow, green) the result is

$$C = \frac{v}{2b + L + sm}$$

Considering virtual block sections, Genovesi and Ronzino extend their method to cases with distant-main signals. They also show that the capacity with moving block is always equal or larger than the capacity with fixed block.

Genovesi and Ronzino suggest accounting for real traffic conditions – i.e. accidental delay plus stops – by replacing in their formulation the generic maximum speed of the services with an average speed, either measured on the line of interest (in case there is enough traffic on it) or obtained from statistics about lines in similar situations and considering the reduction of average speed due to delays and stops.

They also suggest accounting for stability requirements by multiplying the theoretical capacity by a coefficient that is defined as accounting for the number of trains that may be affected by secondary delays due to a preceding train. Such coefficient is to be derived from practical experience relevant to the application of the method.

Table 24. The Genovesi and Ronzino Method: Summary Information

The Genovesi and Ronzino method - Summary information	
Output	Theoretical capacity Practical capacity
Input information and output sensitivity	Description of fixed block and signalling system, or moving blockSpeed, length of trains Coefficient to relate the maximum allowed speed to an average speed including delays and stops Coefficient to account for capacity reductions due to circulation stability needs

Source: SiTI Elaboration based on Genovesi and Ronzino, 2006

The UIC 406 Method

The latest guideline on harmonising the methods to calculate capacity issued by the UIC shifts the focus from the estimation of capacity to the calculation of the fraction of capacity used and of the residual capacity. The rationale is the acknowledgement that capacity depends on how the infrastructure is used – which is actually accounted for, to different extents, in some of the methods seen above – and the need to have similar congestion assessments across a different infrastructure manager. The latter stems from the need to clarify when when a specific part of infrastructure should officially be declared congested.

The bases of the UIC 406 (UIC, 2004) method are the idea of "compressing" the timetable, to check whether capacity used is not exceeding a suggested maximum, and a procedure to add train paths until no more may be added given the constraints on timetable stability. Note that the procedure and the methods underpinning it refer to an existing or possible timetable: the UIC 406 leaflet illustrates how to evaluate capacity usage and residual capacity on a line with reference to a timetable.

The idea of compressing the timetable has already been mentioned in the paragraph about the UIC 405-R for determining the minimum headway between train pairs. In UIC 406 such procedure is taken forward to deal with the capacity over a stretch of line. The compression method is better explained by referring to a graphical timetable extended to depict the actual occupation of each block section, which is also the ideal way to visualise the procedure.

The right side of Figure 43 shows an example of graphical timetable reporting also the occupations of the block sections for a track used in one direction only, as in the case of a double track line when one of the tracks is used in such a way. The timetable is drawn according to the central European standard, that is with distances on the horizontal axis and time on the vertical one. The figure depicts a section of line, not including stations, and the numbers on the horizontal axis marks the points where block signals are placed. It is assumed that at least three aspects signalling is in place, i.e. each block signal acts also as distant signal of the next one (this is called a main-main signal system by UIC 406). The light blue lines are the train paths and the shaded areas around them mark the time when each block section is occupied. The shaded rectangles are wide since they depict the actual occupation of the block section, which includes (UIC, 2004):

- Time for route formation (applied to cases when interlocked routes and signals need to be set, which is not the case in this example since it considers open track conditions);
- Time for visual distance (that is the time during which a train travels the distance between when the driver is able to see the signal and when the train reaches the signal);
- Time for the approach section (in case of a main-main signal system this is the time for the train to travel at scheduled speed along the preceding block section);
- Journey time over the block section;
- Time for clearing the block section (since the depiction of the train path refers to the head of the train, the time for clearing a block section accounts for the whole length of the train to leave the route – and covers the possible safety distance beyond the signal marking the end of the section. As such it depends also on length and speed of the trains);
- Time for the route to be released (this is the time required by the safety and signalling system to release the block section for the next train)

Table 25. Guidelines for Maximum Infrastructure Occupation Given by UIC 406

Type of line	Peak hour	Day
Dedicated suburban passenger lines	85 %	70 %
Dedicated high-speed lines	75 %	60 %
Mixed traffic lines	75 %	60 %

Source: UIC, 2004

The compression procedure consists of rigidly shifting the blocking time "stairways" until they are adjacent to each other, as shown on the left side of Figure 43. The total time covered by the compressed stairways is called 'infrastructure occupation' and measures the capacity consumed by the timetable. The rigid shifting implies that no changes may be made, for instance, to the sequence of trains or to

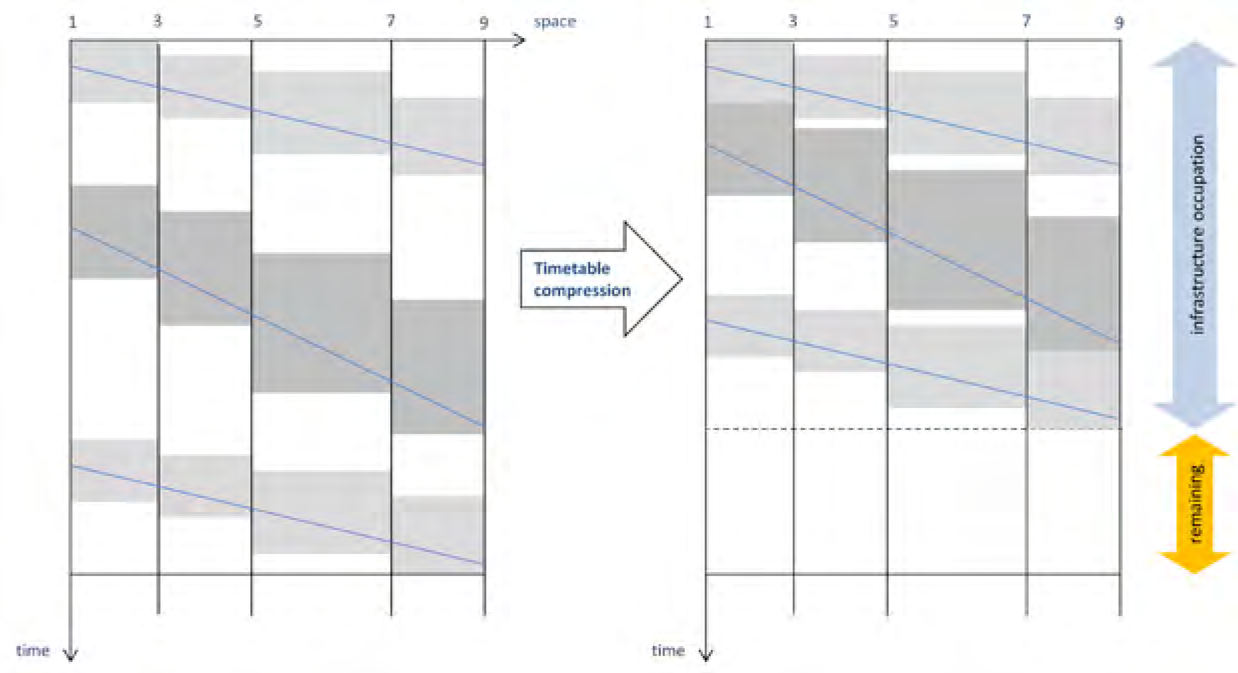


Figure 43. Graphical Timetable (on the Right) and Its Compression (on the Left) with the Characterisation of Infrastructure Occupation and Remaining (Unused) Capacity
Source: SiTI, 2014

train crossings. The point of the procedure is to push the paths as close as made possible by technical constraints and irrespective of the operators' needs (i.e. market needs) to check whether the consumed capacity is under a suggested threshold which goes towards ensuring stability of the timetable.

To carry out this check, the infrastructure occupation is expressed as a percentage of the total time window it refers to (e.g. peak hour or whole day). Table 25 reports the limits that UIC 406 suggests should not be exceeded for timetable stability. Total capacity consumption should also include buffer times inserted to avoid or dampen knock on delays. Remaining capacity resulting after a timetable compression may be used to add train paths or it may be impossible to add further train paths (even after some commercially acceptable shifting of existing train paths). In the latter case the infrastructure is congested. When the remaining capacity allows for additional train paths, the UIC 406 leaflet suggests to check for additional available capacity by an iterative procedure that consists of adding new paths (similar to the ones already timetabled), compress the timetable and check the percentage of infrastructure occupation and so on, until the relevant maximum infrastructure occupation value is reached.

It is interesting to note that some leftover capacity which may not be put to any use may remain even when no more train paths can be added. This is recognised by the leaflet which calls such leftover capacity "lost capacity".

Table 26. UIC 406 Method: Summary Information

UIC 406 method - Summary information	
Output	Infrastructure occupation by train paths and number of train paths that may still be added
Input information and output sensitivity	Detailed line description (including block sections and their details, and information to obtain block section occupation times Actual or proposed timetable Length of trains Detailed description of the progression of the trains along the line

Source: SiTI elaboration based on UIC, 2004

4.2.3 Summary of Features and Inputs of the Methods Surveyed

To summarise the description of the methods surveyed above, Table 27 reports whether each method is able to estimate the practical capacity or only the theoretical capacity, and whether traffic composed by different types of trains may be accounted for. Table 28 recaps the input requirements for the same methods. The UIC 406 method is not reported in the table since it is based on a different working principle.

Table 27. Key Output and Feature of the Analytical Capacity Estimation Methods Surveyed

Methods / Features	FS	DB	Schwann-haüßer	UIC 405-R	UIC 405-2	de Kort et al	Kozan - Burdett	Genovesi - Ronzino
Returns practical capacity	≈	✓	✓	✓	✓	x	x	≈
Returns theoretical capacity only	✓	x	x	x	x	✓	✓	✓
Handles heterogeneous traffic	✓	✓	✓	✓	✓	✓	≈	≈

Legend: ✓feature present x feature not present ≈feature obtained in a case by case empirical way

Source: SiTI, 2014

For the purpose of this work the methods returning the theoretical capacity only or mainly – marked in light orange in Table 27 – are excluded, as well as those unable to account directly for heterogeneous traffic – marked in light yellow on the bottom line of Table 27. Looking at the input requirements, in Table 28, the UIC 405 methods, either accounting or not for subsections of lines seems the most readily useable.

4.2.4 Calculation of the Capacity on the Pavia-Milano Rogoredo Railway Line

Following the review reported above and acknowledging that railway line capacity estimation provides only a part of the picture, as there are other railway elements interacting, an estimation of the capacity was performed by developing a spreadsheet substantially implementing the UIC 405-2 method which is the simplest method available for inputting data and returning practical capacity.

The estimate was performed on the Pavia-Milano Rogoredo section of the line linking Genova and Milano as it is expected to be particularly challenging in terms of adding a train: traffic is already very dense and there exist several trains working on a clock-face timetable which may act as further constraints when trying to add an additional train that does not fit into that framework.

To consider the succession of trains, which is the first key input to the procedure, only the public passenger timetable was available together with the number of freight trains by three time bands of the day. Considering the minimum schedule time required to insert a train path in between others,

Table 28. Main Input Required to Use the Analytical Capacity Estimation Methods Surveyed (Methods with Name in Italics Return the Theoretical Capacity Only)

Methods / Inputs	FS	DB	Schwann-haüßer	UIC 405-R	UIC 405-2	de Kort et al	Kozan - Burdett	Genovesi - Ronzino
Time headways between trains of different type	✓	✓	✓	✓	✓	✓	✓	✓
Sequence of trains of different kind/speed	x	✓	✓	✓	✓	x	x	x
Present/hypothesised number of trains by type	✓	✓	✓	✓	✓	✓	✓	✓
Number of block sections	x	x	x	✓	x	x	x	x
Total allowed delay/day	x	✓	✓	x	x	x	x	x
Present/hypothesised probability that a train is delayed on entering the section	x	✓	✓	x	x	✓	x	x
Average delay of trains entering the section	x	✓	✓	x	x	✓	x	x
Average buffer time	x	x	✓	x	x	x	x	x
Additional time margin	x	x	x	✓	x	x	x	✓
Case by case empirical coefficient to obtain practical capacity	✓	x	x	x	x	x	x	✓

Legend: ✓required x not required

Source: SiTI, 2014

assumptions on the timetabling of the freight trains led to an estimated timetable consistent will all data available. Altogether 4 categories of trains were identified: fast long distance passenger trains, fast regional passenger trains, slower regional passenger trains (belonging to the suburban services of Milano) and freight trains. The three categories of passenger trains are characterised by different average speeds (considering intermediate stops, when present).
To fit the freight trains, these were assumed as travelling at an average speed equal to that of the slower passenger trains, which work on the densest clock-face timetable.
The other key input to the procedure is the minimum headway between trains. Lacking detailed timetable data, this piece of information was obtained from first principles, considering example rolling stock, their average and maximum speed and braking behaviour (for an example, though using different braking formulae, see e.g. Landex et al, 2006) and an average length of the block sections.

Finally, theoretical train headways were expanded to limit infrastructure usage to 60% of its theoretical capacity, and were weighted by train sequences as prescribed by the UIC 405 formulation. The results for the Pavia-Milano Rogoredo line section are shown in Table 29.

Table 29. Actual Traffic and Estimated Capacity between Milano Rogoredo and Pavia. The Estimate of Capacity over 22 Hours is a Conventional Value that Accounts for Line Possessions for Maintenance

	Traffic during a working day [trains]	Practical capacity 22h [trains]
North bound	108	126
South bound	108	128
Total	216	254

Source: SiTI elaboration, with "traffic during a working day" from Trenitalia timetable 15/12/2013-14/06/2014"

As mentioned in the introduction the value of the capacity is a reference value – not an exact one – and should be taken with caution. The fact that the capacity values obtained are above the real number of trains does not necessarily mean that there are train paths available at useable times. There may be available slots at night, for instance. Moreover, experience leads to expect value of practical capacity for a line like the one analysed in the range of 220-240 trains/day, which suggests that the capacity values obtained are plausible. However, it should be recalled that several input data were obtained from (reasonable) assumptions so actual capacity may be slightly different from that estimated here.

In summary, the capacity value is rather close to the actual usage of the line, whose timetable – from inspection – appears very dense. This suggests that to check whether a new service may be added between Pavia and Milano it is necessary to look in detail at the traffic pattern as it is done in the following section.

4.3 Method and Application to Investigate the Feasibility of a Dedicated Railway Service between Genova and the EXPO Centre

The present section investigates the feasibility of adding a special railway service between Genova and Rho-Fiera for the EXPO2015 event. Rho-Fiera is the railway station that directly serves the EXPO2015 venue.

As discussed above, there is no direct link between Genova and Rho-Fiera and the analyses reported in the previous chapter on the time to the EXPO venue showed that travelling by train from Genova to EXPO takes more than 90 minutes.

With the current rail services, the visitors wishing to travel from Genova to Milano by train would travel to a station in Milano where they may connect to a suburban or regional service taking them to Rho-Fiera. With the work discussed in the present section the intention is to assess whether a direct service could provide a better travel option both by avoiding the need to transfer and by offering a shorter journey time.

The investigation was carried out considering as possible travellers:

- visitors from Genova and Liguria, and from the Alessandria province;
- holidaymakers on cruises who wish to go for a day trip to EXPO 2015;

following the demand outlook reported below. It was noted that direct train services would be particularly appropriate to cater for the letter segment of travellers. Both cases considered travellers on a day trip to EXPO.

The EXPO2015 event will last from 1 May to 30 October 2015 and the venue will be open:

- Monday – Tuesday: 9:00 – 21:00;
- Wednesday – Sunday and holidays: 9:00 – 23:30.

The working group considered appropriate to investigate the feasibility of a train leaving Genova between 7:00 and 9:00 so as to reach EXPO early enough in the morning for visitors to take part in events. The return trip would leave Rho-Fiera between 17:00 and 19:00.

4.3.1 Method

The study has been conducted by considering:

- an estimate of the potential demand for travelling to the EXPO from Genova and surroundings, and from the area around Voghera;
- whether a new service fits into the existing railway traffic pattern at times useful to reach the event, which results also in the departure and arrival times of the service as well as the total travel time;
- a comparison among the time taken using the special EXPO train and existing services departing at about the same time, so as to have an idea of the convenience of the added service;
- which local trains may connect and feed the special EXPO service in Genova and Voghera (an intermediate stop, which has been added as explained below).

A check for connections was carried out rather than using them as starting points to add a service. This work sequence is due to the very dense rail traffic pattern around Milano which strongly limits the freedom of deciding the departure time of an additional service.The work to check whether a new service fits into the existing railway traffic pattern was carried out using a graphic timetable of the railway links involved and looking for the possibility of placing a train path within a time corridor of at least 10 minutes, that is a train path following the preceding train path by at least five minutes and preceding the next path by at least five minutes. Such value is deemed appropriate as minimum time interval given the block equipment on the lines.

Since an actual graphic timetable was not available, one was reconstructed from the public timetable therefore the present work considers scheduled passenger trains only (obtained from the timetablevalid during 15/12/2013 – 14/06/2014). As a result this work could not check whether the possible added service conflicts with freight trains and transfer trains. However, it was possible to consider scheduled track possessions for maintenance as those are in the public domain.

It should also be acknowledged that services that travel across one of the most complex and densely used city networks in Italy are examined and so it is possible to miss some restrictions to circulation, especially in stations. Moreover, at this stage the costs of the services borne by the railway undertaking are not considered. In the same vein there is no account of possible issues with revenue abstraction from other train services. All of this is acknowledged noting that this is a pre-feasibility study.

4.3.2 Transport Demand Outlook

An outlook of the possible transport demand has been obtained from the visit forecasts published by EXPO2015. A study issued in 2013 on EXPO and its visitors (GfK, Eurisko, 2013) forecast about 8 million visits from Northern Italy. The same study estimated the visits per day during the peak period of the event, which is expected in June 2015. Since no further detail was available and a more detailed distribution of visitors' origins was required, the forecast of visits from different provinces (NUTS 3 zones for Italy) was calculated by dividing the 8 million visits mentioned above in proportion to the population and in inverse proportion to the distance of the capital of the province from the EXPO venue. The outlook of visits per day thus obtained is reported in Table 30, which lists the total estimated visits from each of a number of Italian provinces as well as the daily visits during June 2015.

Table 30. Total estimated visits to EXPO2015 detailed by NUTS 3 relevant for the added direct train service

NUTS_id	NUTS_label	Total estimated visits	Total estimated visits during the June peak	Total estimated daily visits during the June peak
ITC18	Alessandria	77.953	28.063	935
ITC31	Imperia	15.247	5.489	183
ITC32	Savona	27.563	9.923	331
ITC33	Genova	97.280	35.021	1.167
ITC34	La Spezia	18.483	6.654	222

Source: SiTI elaboration, based on GfK, Eurisko, 2013 and ISTAT, 2013

4.3.3 Transport Capacity

In order to obtain an examplary estimate of the transport capacity that a train pair between Genova and Rho-Fiera may offer daily, the number of seats offered on the long distance train services commercialised by Trenitalia[14] as Frecciabianca, is taken as reference. Those services are operated with block trains comprising 2 first class coaches and 7 second class coaches (half of one of those is dedicated to bar and refreshments) for a total of 604 seats. When this study was discussed at the expert workshop held in Frankfurt on 12 June 2014, it was noted that for services similar to the one discussed, first class coaches only were available. In that case coaches providing 54 to 64 first class seats can be considered. Therefore a consist made up by 8-9 coaches, would provide 432-486 to 512-576 seats.

Accordingly, for reference it can be considered that a train pair between Genova and Rho-Fiera provides a transport capacity in the range of 432-604 seats.

4.3.4 Route

Travelling between Genova and Rho-Fiera is possible both via Novara (avoiding to travel through the railway node of Milano) or via Pavia and Milano. The two routes have the Apennine crossings in common and differ north of the Apennine crossings, which means North of Arquata Scrivia.

The key disadvantage of a route via Novara is that trains need to change direction of travel in Novara and this, even with current block trains, requires a dwell time of some 15 minutes at least, during which the travellers would have to wait on the train stopped at the station. Travelling via Milano there is no need to reverse the direction of the train, although the path for a new service is highly likely to conflict with the existing dense traffic of that railway node.

As the service to be checked for feasibility is to be more attractive in terms of travel time than existing ones –which are going via Milano- and since the train standing idle in a station for some 15 minutes to change direction does not seem to go in that direction, the feasibility of a path via Milano was investigated.

The additional train would travel along the route Genova-Voghera-Milano Rogoredo-Milano Certosa-Rho-Fiera shown in Figure 44 whereas Figure 45 depicts the possible path across the railway node of Milano. The added rail service on its way to the EXPO would travel –without stopping- via Milano Rogoredo, Milano Porta Garibaldi and Milano Certosa using the conventional lines illustrated in Figure 45 and thus avoiding to enter Milano Centrale, which is a terminus station.

The lines travelled are listed with their network statement code and their block system in Table 31.

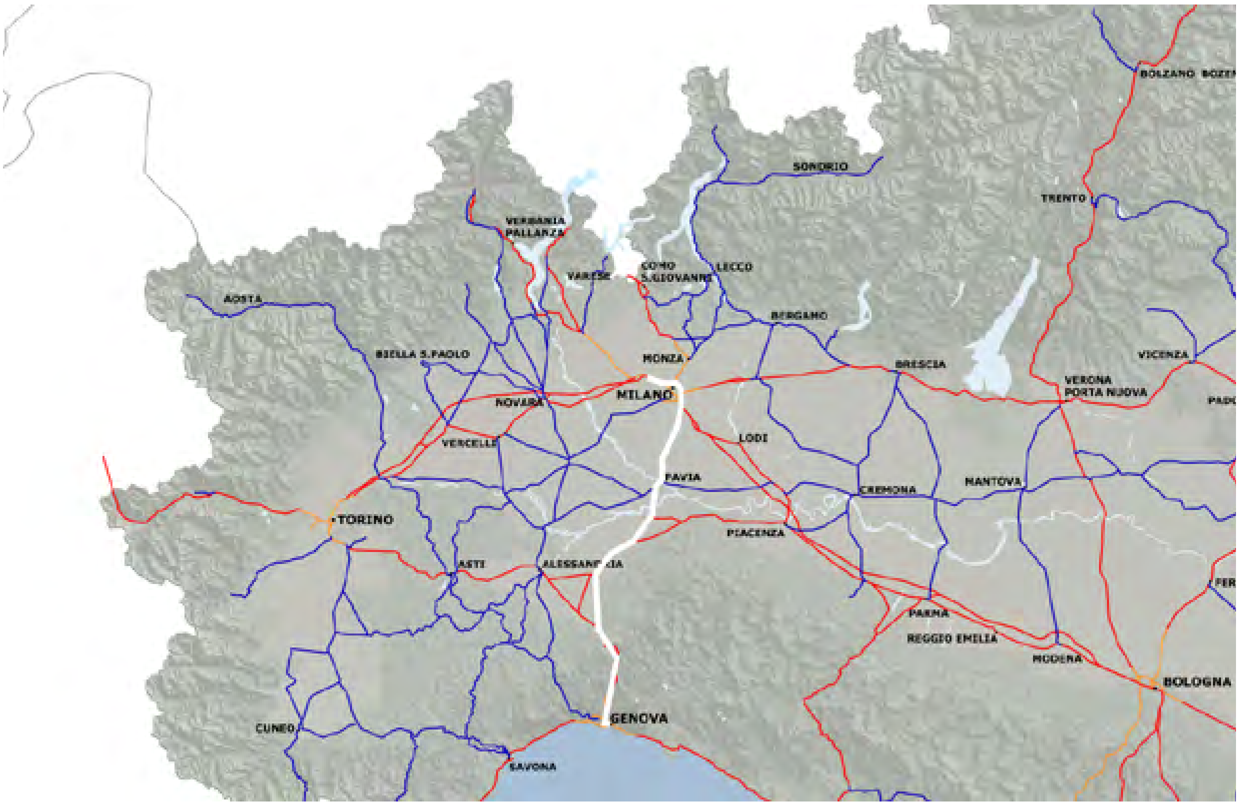


Figure 44. The Possible Route from Genova to Rho-Fiera

Source: SiTI elaboration based on map from www.rfi.it, accessed June 2014

Table 31. Name and Coding of the Lines Used by the Added Rail Service with Indication of the Block System in Operation

Line	code	block system
Milano Rogoredo-Arquata	J05/J06	Automated (4 codes)
Genova Mignanego/ Genova Rivarolo/Genova Campasso-Arquata	J19/J20	Automated (4 codes)
Nodo di Milano	R02	Automated (4 codes)
Nodo di Genova	R04	Automated (4 codes)

Source: RFI, Network Statement, 2014

For ease of illustration and for the purpose of depicting the graphic timetables, the route of the additional train may be divided in three sections

- Genova Piazza Principe to Milano Rogoredo;
- Milano Rogoredo to Milano Certosa (the section of route through the node of Milano);
- Milano Certosa to Rho-Fiera.

Since, as mentioned above, a single service may offer up to some 600 seats (per direction), depending on the composition of the train, to expand the catchment area and ensure an adequate load factor, this study considers also that the train may stop in Voghera, located some 65 km south

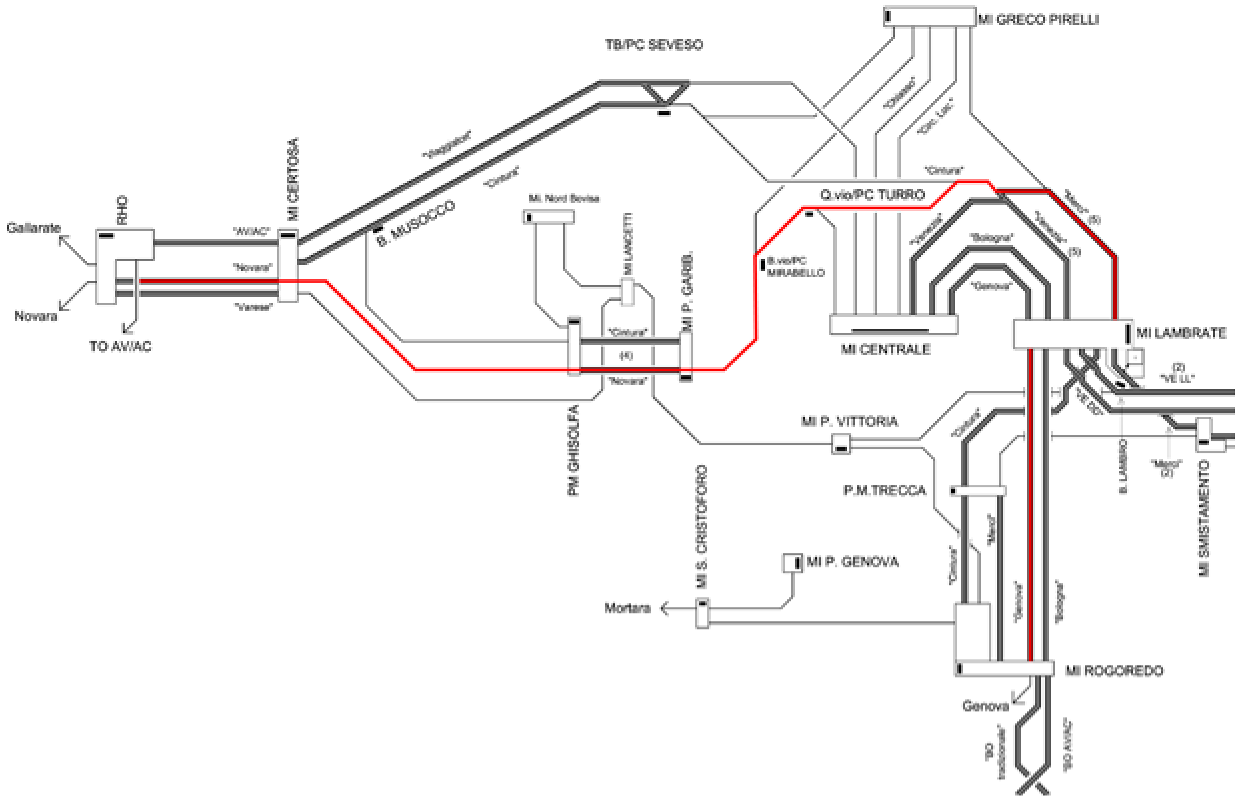


Figure 45. The Possible Path across the Node of Milano
Source: SiTI elaboration based on map from RFI, FCL21, updated to C.T.23/2013

of Milano along the Genova-Milano railway line (see Figure 46). Voghera is a useful stop to serve the southern part of the province of Pavia and to connect with local trains serving the province of Alessandria. In fact, Voghera is the connecting stop at which also intercity trains call.

4.3.5 The Feasibility of an Added Rail Path between Genova and Rho-Fiera and Back

The feasibility of adding train paths has been checked as indicated in the method section above. The base travelling times for the new service have been extracted from those of fast long distance trains on the same connections. However, in some cases they had to be slightly lengthened to fit the new path into the existing pattern. This was required especially due to the intense traffic in and around the node of Milano.

Existing paths are particularly dense between Pavia and Milano Rogoredo, which is the most constraining section of the route for this study. To illustrate it, Figure 47 shows, for instance, the pattern of regional and long distance trains on the double track line between Genova and Milano Rogoredo during the morning, while Figure 48 shows a detail of the services between Pavia and Milano during the same time period. The half-hourly pattern of S (suburban) services -depicted in green in the picture- stands out.
The final leg of the route, between Milano Certosa and Rho-Fiera has an apparently very

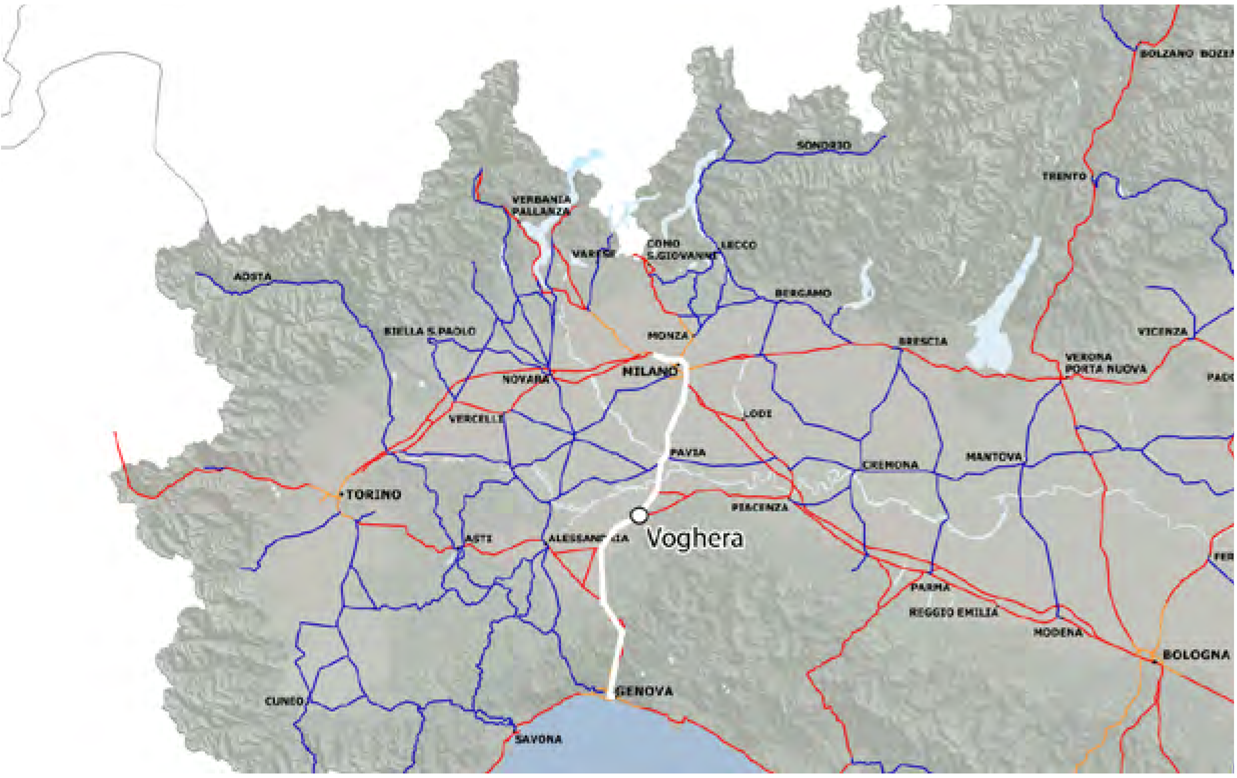


Figure 46. The Location of Voghera, Proposed Intermediate Stop for the Genova-EXPO Shuttle Train
Source: SiTI elaboration based on map from www.rfi.it, accessed June 2014

complex traffic pattern. Figure 49 illustrates traffic between those two locations which, however, is actually travelling on three parallel double track lines. In fact that section includes

- The double track of the conventional line to Torino;
- The double track of the line to Varese;
- The double track for the high-speed line to Torino.

Track possessions are organised so that two out of three lines are always available and traffic may be rerouted on open lines. It was assumed that the additional service would be routed on the conventional Milano-Torino line. Notice that Rho-Fiera is a stop and cannot accommodate stabled trains: a Genova-Rho-Fiera train would have to travel further than Rho-Fiera to be stabled before being re-used

Table 32. Timetable of the Possible Added Train Services Genova Piazza Principe – Rho-Fiera and back

Station	time	time
Genova Piazza Principe	7:45 (d)	22:22 (a)
Voghera	8:35 (a)	21:22 (d)
	8:37 (d)	21:20 (a)
Rho-Fiera	9:45 (a)	20:15 (d)

Source: SiTI, 2014

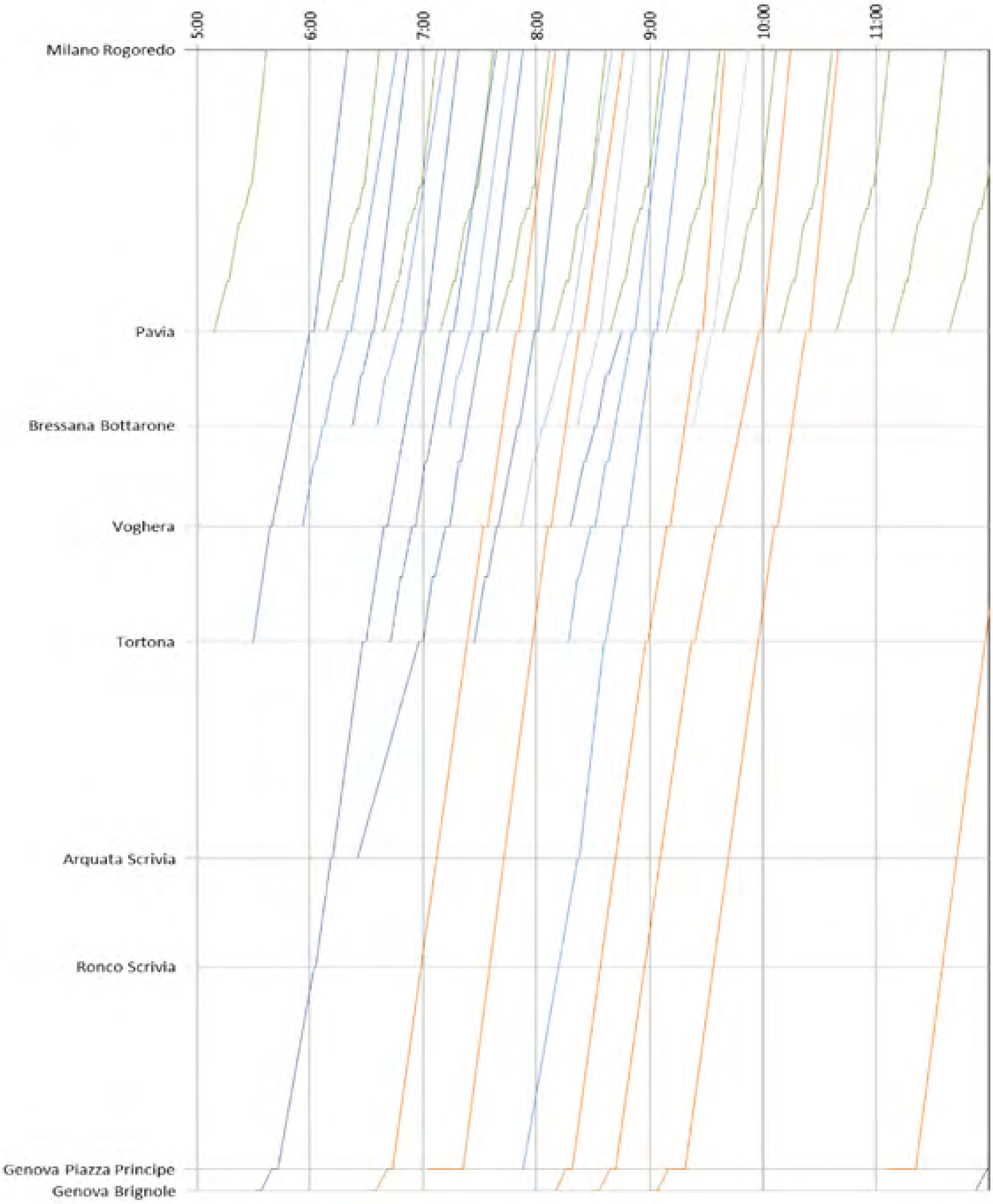


Figure 47. The Pattern of Long Distance and Regional Services between 5:00 and 12:00 on the Genova Brignole-Milano Rogoredo Section of the Route between Genova and Rho-Fiera. Long Distance Trains are Depicted in Orange and Regional Services are Shown in Dark Blue (Distance Axes not to Scale)
Source: SiTI elaboration based on Trenitalia timetable 15/12/2013-14/06/2014

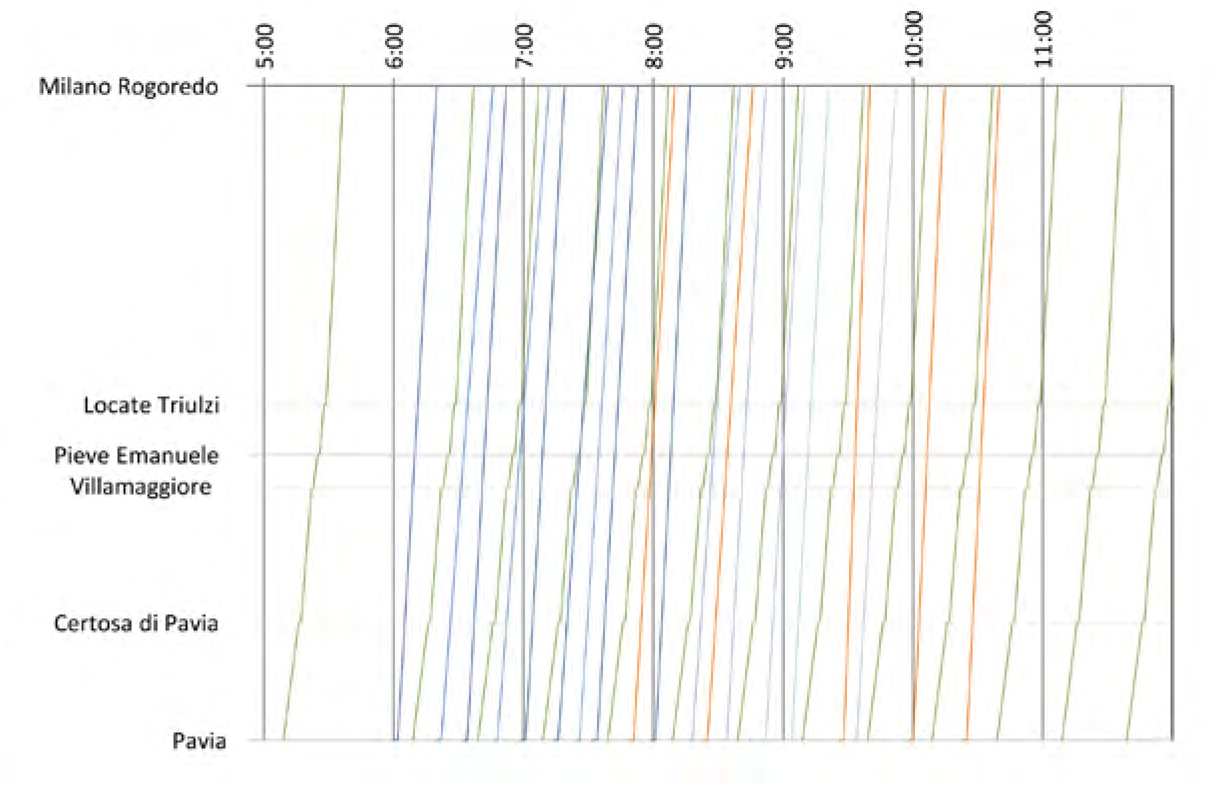


Figure 48. The Pattern of Services along the Pavia and Milano Rogoredo Section of the Route between Genova and Rho-Fiera with the Half-Hourly Suburban Services in Green. The Picture Reports the Graphic Timetable between 5:00 and 12:00.
Source: SiTI elaboration, based on Trenitalia timetable 15/12/2013-14/06/2014

Following the investigation on the existing train paths it was possible to fit the trains shown on Table 32. The total travel time from Genova is 2 hours on the way to Rho-Fiera and 2 hours and 7 minutes on the way back. From Voghera the added service would take travellers to Rho-Fiera in 1 hour and 8 minutes and back in 1 hour and 7 minutes. It was not possible to fit an earlier return path and, as noted below, this has consequences on the connections that may be made. However it was noted that a train leaving Rho-Fiera at 17:10 and arriving in Genova at 19:14 could have been considered, had it not been for the fact that it interfered with an existing train in the node of Milano. The latter seemed a one-off train traversing the node of Milano along the same route of the added special service. However, that train was rerouted changing its departure station on the timetable valid for the summer of 2014.

It is believed that this is a point worth noting since, in case of actual deployment of a special service, discussions with the infrastructure manager and the railway undertaking involved may solve this kind of issues and allow more flexibility than initially apparent from reading the timetable.

There do not seem to be interferences with scheduled track possessions reported on the IM documentation checked, except between Milano,

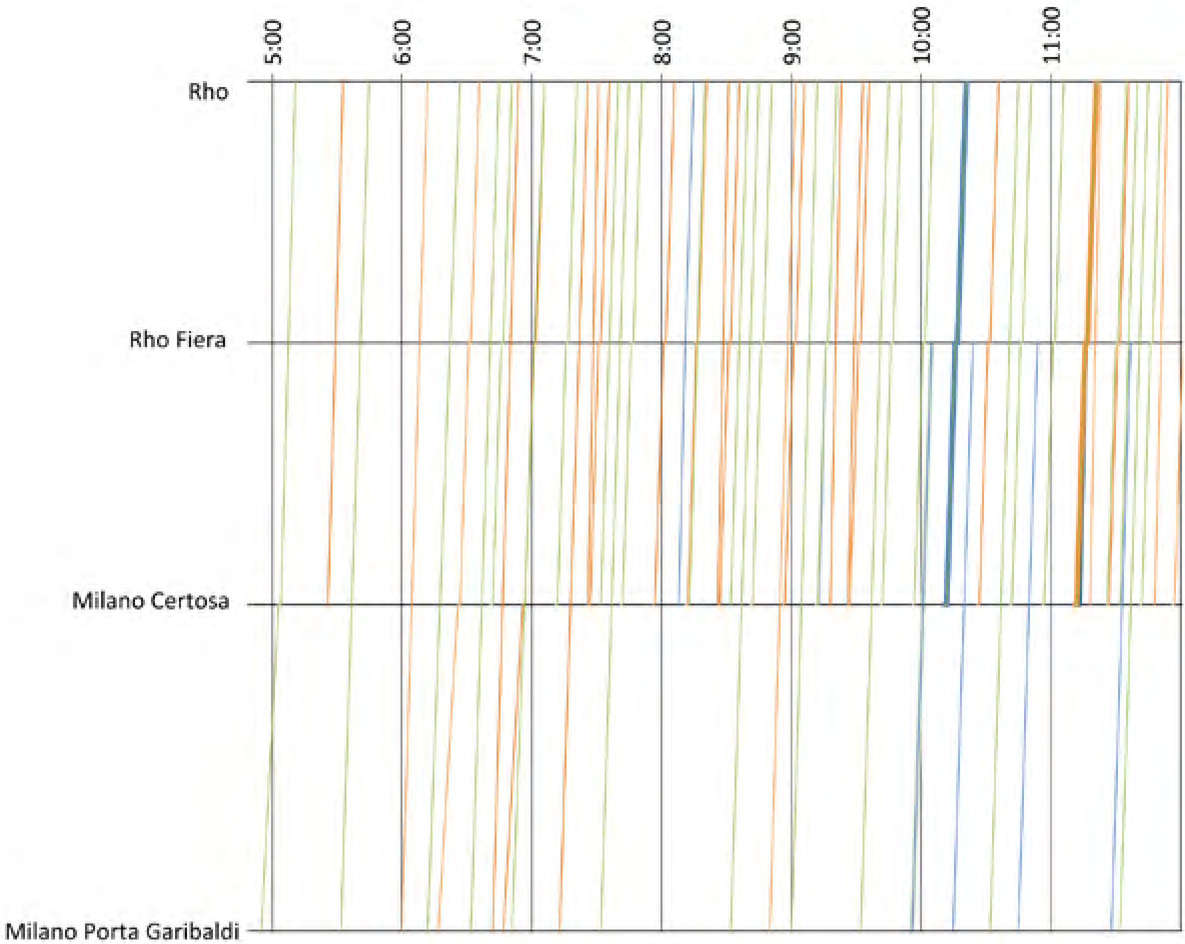


Figure 49. Pattern of Rail Services between Milano Certosa and Rho-Fiera. The Services Shown Are Actually Travelling on Three Parallel Double Track Lines. Source: SiTI elaboration, based on Trenitalia and NTV timetables for 15/12/2013-14/06/2014

Certosa, and Rho, for the train to Rho in the morning. However, as mentioned, this section of line is composed by three parallel double tracks lines and track possessions are organised so that two out of three lines are always open and trains may be re-routed. At the time when it was estimated that the shuttle may travel along this stretch of multiple lines only one of the other two was occupied, so it was assumed that the train may be rerouted on the line that is still available.

To exemplify the work carried out, the proposed train path departing 20:15 from Rho-Fiera is shown in Figure 50, Figure 51, and Figure 52 respectively for the Rho-Fiera Milano – Milano Certosa section, the Milano Certosa – Milano Rogoredo section, the Milano Rogoredo – Genova Piazza Principe section. In all pictures the proposed new path is depicted as a continuous red line. while the minimum “canal” required to fit the new path is enclosed by dashed red lines.

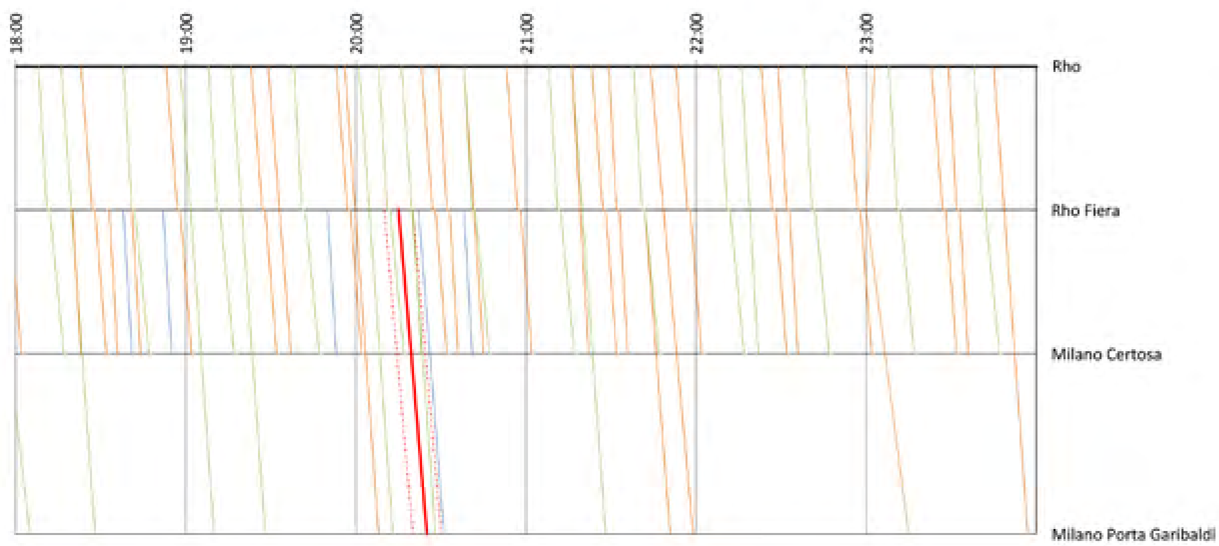


Figure 50. The Added Path on the Rho-Fiera - Milano Porta Garibaldi Section of the Route. The Added Path is Depicted as a Continuous Red Line while the Dashed Red Lines before and after It Show the "Canal" Taken as Minimum Requirement to Insert a New Path. Train Paths on the Same Line Are Depicted in Orange. Other Colours Denote Paths on Parallel Lines.
Source: SiTI, elaboration, based on Trenitalia and NTV timetables for 15/12/2013-14/06/2014

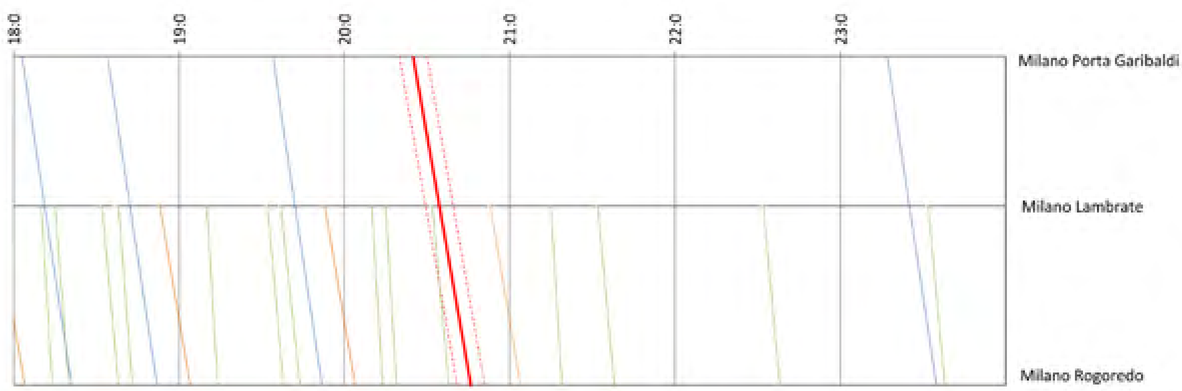


Figure 51. The Added Path on the Milano Porta Garibaldi – Milano Rogoredo Section of the Route. The Added Path is Depicted as a Continuous Red Line while the Dashed Red Lines before and after It Show the "Canal" Taken as Minimum Requirement to Insert a New Path. Train Paths on the Same Line are Depicted in Blue. Other Colours Denote Paths on Parallel Lines.
Source: SiTI elaboration based on Trenitalia and NTV timetables 15/12/2013-14/06/2014

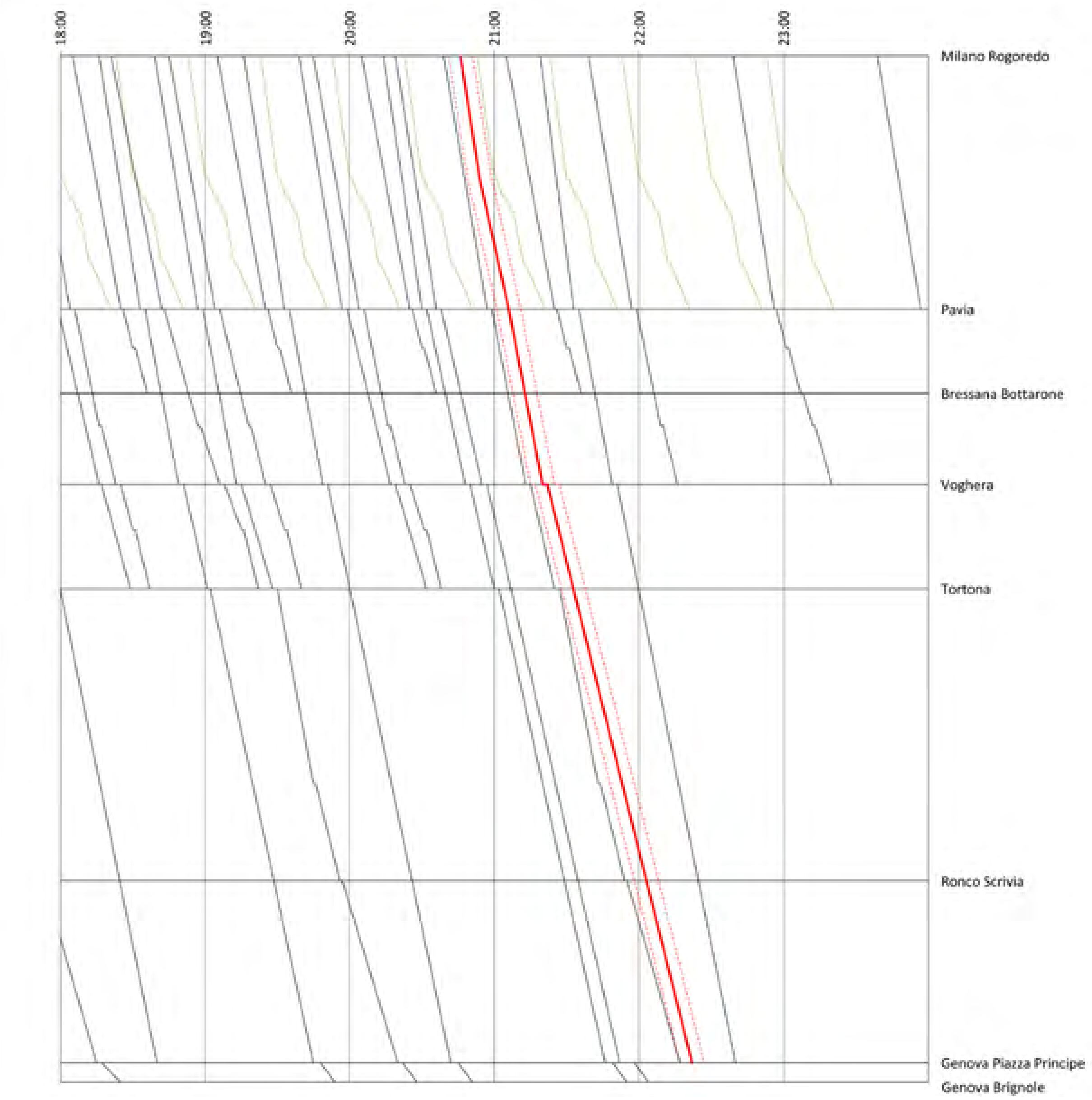


Figure 52. The Added Path on the Milano Rogoredo-Genova Piazza Principe Section of the Route. The Added path is Depicted as a Continuous Red Line while the Dashed Red Lines before and after It Show the "Canal" Taken as Minimum Requirement to Insert a New Path. All Train Paths Depicted Are on the Same Line.

Source: SiTI elaboration based on Trenitalia timetable 15/12/2013-14/06/2014

4.3.6 Connections

Since the new service should be useful for visitors travelling from the Liguria region (not just Genova) and the area around Voghera, the work included checking for useful connections in Genova Piazza Principe and Voghera both on the way to Rho-Fiera and back. Starting from the publicly available timetable valid 15/12/2013 – 14/06/2014, services were considered usefully integrated with the new service if the transfer time between their arrival and the departure of the proposed new service is between 5-15 minutes.

Figure 53 shows the departure of the proposed shuttle service from Genova Piazza Principe at 7:45 as a red arrow, and in the vein of the station clocks used in preceding chapters, shows existing departing and arriving services between 7:00 and 8:00. Figure 54 illustrates the services arriving and departing from Voghera between 8:00 and 9:00 and, again, the proposed shuttle departure time as a red arrow.

The analyses with the station clocks as those portrayed in Figure 53 and Figure 54 were also carried out for the return journey. The results indicate that:

Departing from Genova Piazza Principe, the proposed shuttle may be usefully boarded by passengers arriving on services from:

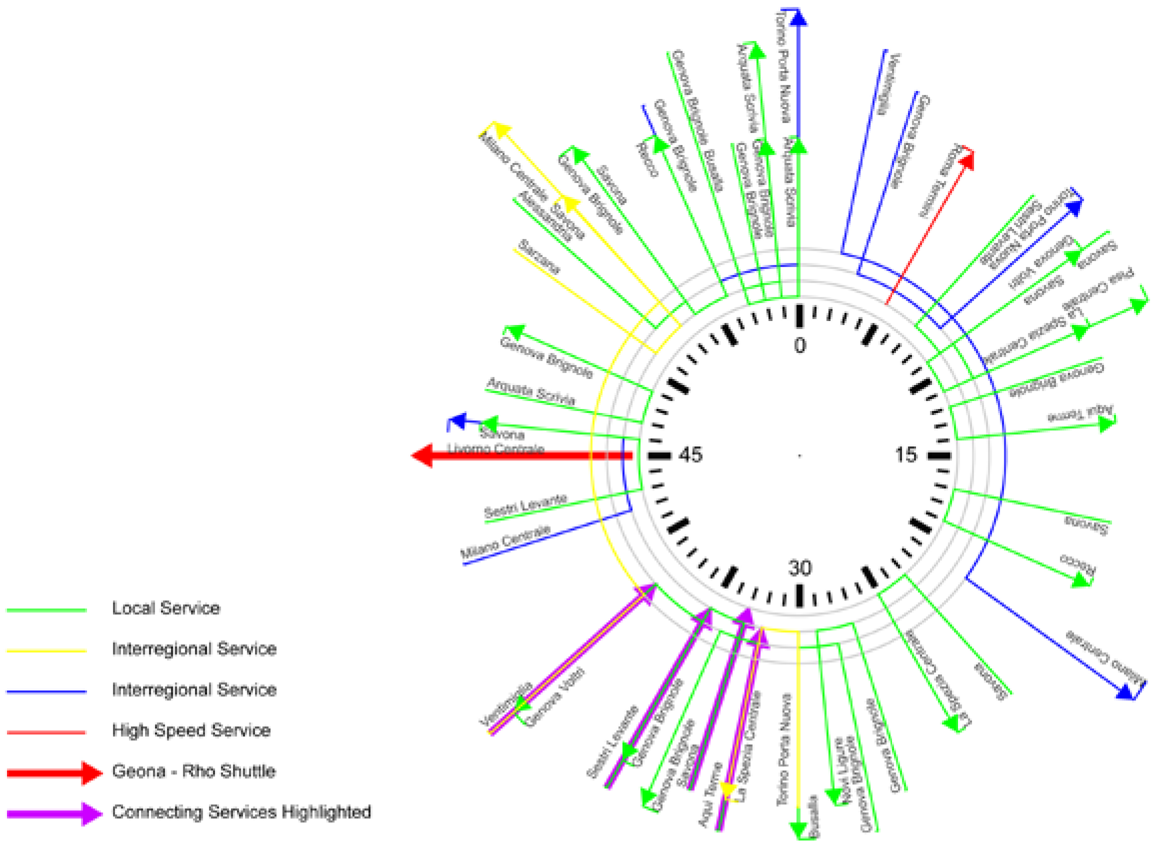


Figure 53. Services Arriving and Departing from Genova Piazza Principe at the Departure Time of the Shuttle Services Investigated
Source: SiTI elaboration based on Trenitalia timetable 15/12/2013-14/06/2014

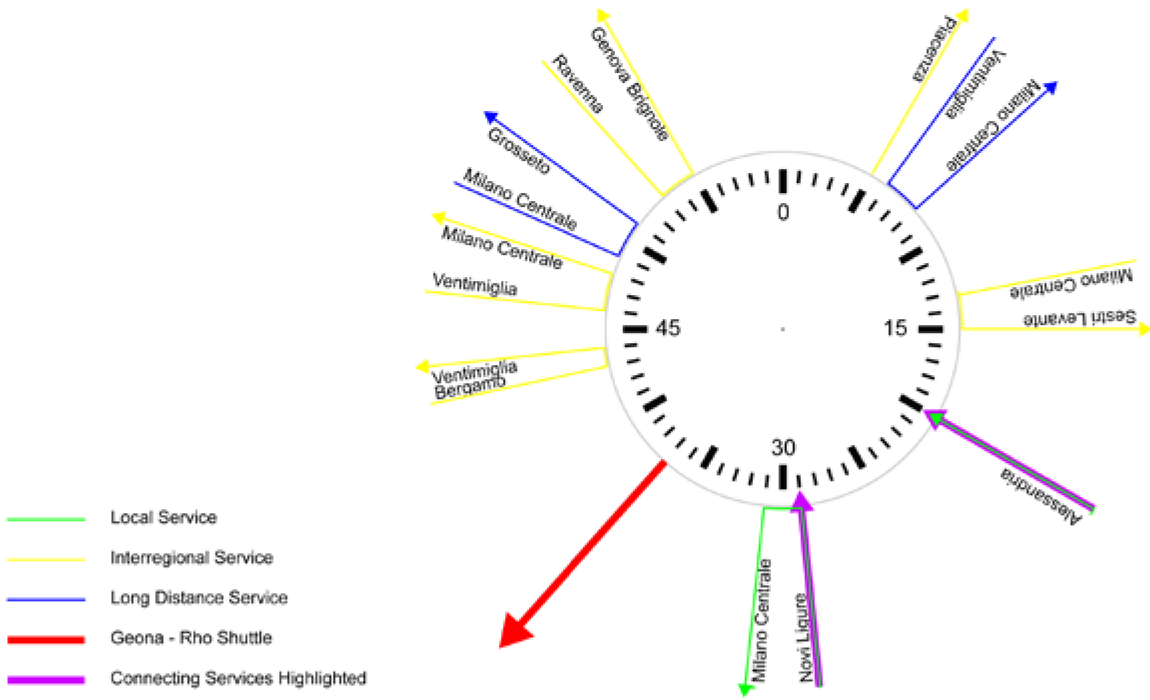


Figure 54. Services Arriving and Departing from Voghera at the Departure Time of the Shuttle Services Investigated
Source: SiTI elaboration based on Trenitalia timetable 15/12/2013-14/06/2014

- Ventimiglia;
- Sestri Levante (GE);
- Savona;
- Acqui Terme (AL).

On their way back travellers find connecting trains within the same 5-15 minutes time band only if they continue towards:

- Ventimiglia;
- Sestri Levante (GE);
- Savona;

while it is no longer possible to connect with services to Acqui Terme since they cease earlier than the arrival of the shuttle.
In Voghera travellers from Novi Ligure may transfer onto the proposed shuttle within 5-15 minutes of their arrival whereas, considering 17 minutes as an acceptable transfer time, the new shuttle may be used also by travellers on the inbound train from Alessandria.

However, travelling back from Rho-Fiera passengers cannot proceed to Novi Ligure nor to Alessandria as the last trains of the day to those destinations depart earlier than the shuttle arrival.
Summarising, the new shuttle could be useful both for rail travellers arriving and returning to

- Ventimiglia via Genova Piazza Principe;
- Sestri Levante (GE) via Genova Piazza Principe;
- Savona via Genova Piazza Principe;

and to passengers travelling to and from Voghera, but not for travellers needing a transfer connections in Voghera for their return trip.

An earlier train, notably the one mentioned in the previous paragraph, would have allowed more connections. In particular all return connections would have been possible with an arrival in Genova PP at 19:14 and considering an arrival at 18:21 in Voghera return trips both to Alessandria and Novi Ligure would have been possible, although with connecting times well exceeding 15 minutes.

4.3.7 Competing Alternatives

To be competitive the proposed shuttle service should offer shorter travel times than competing services, considering also connection times. The following Table 33 contrasts the times required to reach Rho-Fiera from Genova Piazza Principe using existing services and using the possible new shuttle, as well as the times required to travel from Savona or Ventimiglia to Rho-Fiera by connecting in Genova Piazza Principe with the proposed shuttle. Table 34 refers to the return journeys.

Table 33. Competing Travelling Times by Train for the Onward Journey. Travel via Genova Piazza Principe.

Route	times	changes	services
Genova PP - Mi Rogoredo - MI Porta Vittoria – Rho Fiera	7:53 – 10:01 (128 minutes)	2	RV+S+S
Genova PP – Mi Centrale – Rho Fiera	9:19 – 11:30 (131 minutes)	1	IC+RV
Genova PP – Rho Fiera (proposed service)	*7:45 – 9:45 (120 minutes)*	-	*[IC]*
Savona - Mi Rogoredo - MI Porta Vittoria –- Rho Fiera	6:50 – 10:01 (191 minutes)	2	RV + S +S
Savona – Genova PP – Rho Fiera (proposed serivice)	*6:34 – 9:45 (191 minutes)*	*1*	*R + [IC]*
Ventimiglia – MI Centrale - Rho Fiera	6:33 – 11:30 (297 minutes)	1	IC+RV
Ventimiglia – Genova PP – Rho Fiera (proposed service)	*5:02 – 9:45 (283 minutes)*	*1*	*R + [IC]*

Source: SiTI elaboration based on Trenitalia timetable 15/12/2013-14/06/2014

It may be noted that there is little or no time difference in travelling with the shuttle as competing trains offer similar travel times, except in the case of Ventimiglia with a return trip much longer than the onward one. There is, however, the advantage of the direct service which avoids at least one connection. Similarly, Table 35 compares the time to Rho-Fiera from Voghera and from Alessandria, and Table 36 reports the travelling information for the return journeys, limited to travelling to Voghera since, as seen in the previous section, no onward connections are available at the time when the proposed shuttle gets into Voghera. Direct travel from Voghera with the proposed shuttle in this case results in the avoidance of connections and in a shorter travel time.

It seems therefore that the advantages of travelling with the new shuttle train may be enjoyed only by those passengers travelling from the cities where the train stops. Times with the proposed shuttle are very similar, and not always shorter, when at least one connection is required. In this sense the shuttle would introduce a useful alternative for passengers from Genova and Voghera and an added option for other travellers, although only for some of the other origins.
It is worthwhile to note that were the earlier train mentioned in Section 4.3.5 (arriving in Genova

at 19:14) actually possible, there would be time advantages –if only limited- in returning to Genova or Savona with the shuttle, compared to the trains scheduled for the winter 2013 timetable, while the return trip to Ventimiglia would be longer with the shuttle. Concerning travels via Voghera, again there would be limited advantages with travelling with the shuttle from Rho-Fiera to Voghera or continuing to Alessandria.

4.3.8 Conclusions

In the search for feasible new train paths from Genova Piazza Principe to Rho-Fiera and back this piece of work opted for a route via Milano with a stop in Voghera. The investigation was based on publicly available data and returns a possible timetable reported in Table 32, also summarised in the following:

- From Genova to Rho-Fiera;
  - departure from Genova at 7:45;
  - departure from Voghera at 8:37;
  - arrival at Rho-Fiera at 9:45;
- for a total journey time of 2 hours.
- From Rho-Fiera to Genova;
  - departure from Rho-Fiera at 20:15;
  - departure from Voghera at 21:22;
  - arrival at Rho-Fiera at 22:22;
- for a total journey time of 2 hours and 7 minutes.

Table 34. Competing Travelling Times by Train for the Return Journey. Travel via Genova Piazza Principe.

Route	times	changes	services
Rho Fiera – Mi Centrale - Genova PP	20:33 – 22:40 (127 minutes)	1	RV+I
Rho Fiera – Genova PP (proposed service)	*20:15 – 22:22 (127 minutes)*	-	*[IC]*
Rho Fiera – Mi Centrale - Genova PP - Savona	20:33 – 23:26 (173 minutes)	2	RV + IC +IC
Rho Fiera – Genoa PP – Savona (proposed service)	*20:15 – 23:21 (186 minutes)*	*1*	*[IC] + RV*
Rho Fiera – Mi Centrale - Genova PP - Ventimiglia	20:33 – 01:05 (272 minutes)	2	RV + IC +IC
Rho Fiera – Genova PP – Ventimiglia (proposed service)	*20:15 – 01:20 (305 minutes)*	*1*	*[IC] + RV*

Source: SiTI elaboration based on Trenitalia timetable 15/12/2013-14/06/2014

Table 35. Competing Travelling Times by Train for the Onward Journey. Travel via Voghera.

Route	times	changes	services
Voghera – Rogoredo – Porta Vittoria - Rho Fiera	8:08 – 9:31 (83 minutes)	2	IC+S+S
Voghera – Mi Certosa – Rho Fiera	7:52 – 9:16 (84 minutes)	1	R + S
Voghera – Rho Fiera (proposed service)	*8:37 – 9:45 (68 minutes)*	-	*[IC]*
Alessandria – Mortara – Novara – Rho Fiera	7:35 – 9:32 (117 minutes)	2	R + R+ RV
Alessandria – Voghera – Rho Fiera (proposed service)	*7:44 – 9:45 (121 minutes)*	*1*	*R + [IC]*

Source: SiTI elaboration based on Trenitalia timetable 15/12/2013-14/06/2014

Table 36. Competing Travelling Times by Train for the Return Journey. Travel to Voghera.

Route	times	changes	services
Rho Fiera - Porta Vittoria – Rogoredo - Voghera	20:12 – 22:16 (124 minutes)	2	S+S+R
Rho Fiera – Mi Centrale - Voghera	20:33 – 21:49 (76 minutes)	1	R + IC
Rho Fiera - Voghera (proposed service)	*20:15 – 21:20 (65 minutes)*	-	*[IC]*

Source: SiTI elaboration based on Trenitalia timetable 15/12/2013-14/06/2014

Travel times are not the minimum possible as in certain cases it was necessary to slow down the train path in order to fit it into the very dense existing traffic. Indeed the exercise resulted very difficult due to the high number of already existing trains, especially around Milano, which barely leave any room for additional circulations. The shuttle trains suggested fit the requirements only partially, since the return trip is later than desired, again due to the difficulty of fitting new paths into the existing pattern. Whilst attempting to fit an earlier train, it was noted that an appealing return path was made impossible by a conflict with an existing path that, however, was moved to a different line on the following timetable. Were that path already feasible at the time of this exercise it would have been possible to put forward a return train departing at 17:10 from Rho-Fiera, calling at Voghera at 18:21 and, finally, reaching Genova at 19:14. This would have been much better in terms of connections as summarised below.

It is worthwhile to note that this observation is a reminder that a timetable might be more flexible than it initially shows, once discussions with the infrastructure manager, the train operators and the authorities purchasing the services

Two Trenitalia HS trains „Freccia Rossa“ in Milano Centrale.

are started. In this case the change mentioned above occurred in the following timetable period which could have possibly been anticipated allowing an earlier return train to Genova.

Checking the timetable for connections within 5-15 minutes it was shown that the shuttle may be boarded by passenger changing trains in Genova and arriving on trains from Ventimiglia, Sestri Levante (GE), Savona. Other connections, and especially connections at the intermediate stop in Voghera are not feasible due to the time at which the return train gets there: later than the last departure of the day.

The key advantage of travelling with the shuttle seems to be able to avoid the need to change trains in Milano, since checking again the existing timetables for competing trains revealed that travelling times are often similar. Shorter times for the shuttle were not possible due to the need to comply with the constraints imposed by existing traffic. Travellers from Voghera may enjoy travel time savings too, compared to travelling with scheduled trains at about the same time.

In closing, given the number of trains circulating on the lines, and the difficulty of inserting one more, it would be interesting to consider the shuttle train discussed here as an addition to the existing offer of services rather than as special train used by travellers both ways of their return trip. Travellers would then have more options to organise their journeys and would be able to use the shuttle either both ways or just on way, travelling with other services the other way.

The Swiss Pendolino ETR 610 in Milano Centrale.

5 Expert Workshop

5.1 Workshop Outline

The workshop aimed to explore the future possibilities of increasing network accessibility of HS rail along the trans-European railway axis Rotterdam-Genova. This also provided a useful opportunity to test methodologies and preliminary results with experts in the fields of HS rail development, transport and spatial planning as well as railway management. In total eight experts from five countries attended the workshop and they are key academic figures in HS rail development and train operators. The experts had been given an extensive introduction to the workshop beforehand by an introduction paper (CODE24 Action 17 team, 2014).

The workshop started by a brief introduction by the host Regionalverband FrankfurtRheinMain followed by a presentation of the work and results achieved at that time in the three activities:

- Assessment of HS rail Integration within Corridor 24 Railway Services (Chapter 3);
- EXPO 2015 Case Study: Genova and Rho-Fiera Connection (Chapter 4);
- Proposal for a Systematic Timetable (Chapter 6).

Following the presentation of each activity, the issues related to the preliminary findings were discussed with the invited experts in two discussion sessions: session 1 and session 2. A preliminary conclusion, which summed up outcomes of the workshop, was presented at the end of the workshop day.

5.2 Workshop Outcome

Based on the issues raised in the introduction paper (CODE24 Action 17 team, 2014) and during the workshop, the following topics have been summarised as key results of the workshop.

5.2.1 Transfer Time

Current European standards require at least 15 minutes to provide an efficient transfer between HS/LD services and from HS/LD services to local services. This takes into account the HS station size (usually large stations, sometimes with dedicated HS tracks not always near tracks used by local services) and the average get on/get off time (people travelling on HS trains usually have luggage).

A suitable transfer time, from the users' point of view, also depends on total travel time and on trip purpose. For example, leisure travellers, who are less time sensitive than business travellers, may consider a longer waiting time at a (transfer) station not as a loss but as an opportunity to rest and to secure the whole trip chain.

Service robustness, in terms of service frequency (within capacity restrictions due to traffic in nodes) and reliability, is even more important than saving transfer time in order to realize an efficient integration. More frequent train services increase the possible transfer choices. Reliability is very important and entails reducing the risk of delays. In this respect it is noteworthy that track managers' targets to consider "trains on time (punctuality)" are different for HS and local services in Italy and Switzerland:

- RFI considers 'trains on time' if their delay is less than 15 min for HS/LD services and less than 5 min for IR/L trains;
- NTV tries to keep the maximum delay within 5 min for HS;
- SBB has increased scheduled train travel time to reduce the risk of delays. However, as the train headway will be every 15 minutes on some trunk lines, there will be no necessary transfer coordination as a higher service frequency will generally reduce the risk of delays.

5.2.2 Integration

In addition to service reliability and frequency, another important factor to be considered is the integration of fares, especially along a corridor where different operators are offering services:

- The ticketing system needs to be regulated so that it is possible to transfer on the next HS train in case of delayed arrival in transfer nodes.
- Integration of fares should be extended also to interregional and local services: all the participants agree on the importance of connecting HS trains with local services (not only trains but also urban public transport) to widen the HS rail catchment area, even

if a mixed use of tracks may be needed and which could result in difficulties. NTV is trying to increase integration with other services, for instance, the tickets to stations in the region of Campania include 1 hour of regional public transport use. On the other hand, RFI notes that in Italy integration between HS and local trains are often not taken into account, even in terms of scheduling.

Achieving an efficient integration also depends on the - not always easy - cooperation among:

- Different institutional levels: transnational, national and regional authorities are involved;
- Different operators that are competing against one another.

A clear regulation (e.g. who is regulating fares and operations? who is responsible for delays?) is needed to coordinate cooperation among both the public authorities and the operators. Talking about operators' competition a question arises: is the free market orientation an opportunity to increase integration (helping to increase the number of services while decreasing prices) or a bottleneck (i.e. lack of transparency, lack of information)?

5.2.3 HS Service Models

Different HS service models have been developed in different countries on the basis of their geography:

- In Japan and France, for instance, big important cities are very distant from one another so stations served by HS services are up to 500 km apart;
- In Germany and Italy, on the other hand, important cities are closer and HS relations are shorter than French/Japanese ones: HS services connect stations that are up to 200 km apart.

Two different visions on how to operate HS trains emerged: in Italy HS services use only dedicated tracks while in Germany HS is a "product" characterized by high quality and high level of service, although trains also run on conventional tracks shared with other train types. This mixed use of rail lines is more difficult to manage because it needs to take into account different speeds and also freight trains, which run especially at night.

The Italian model (with HS services linking cities relatively near to one another) has generated a big amount of induced demand since its introduction: on the basis of a survey it has been estimated that from 2009 to 2013 there has been an increase in HS train passengers of 81 % (from 17 to 30.8 million of passengers), 42 % of them diverted from other modes, 18 % diverted from other train services while 40 % were new customers (Cascetta and Coppola, 2015). The last figure was even higher when considering "short distance" services (relations of 100/150 km) thanks to the change of passengers' habits induced by the new HS service (for instance a marked increase in daily commuting between city pairs).

Another important reason for induced demand on Italian HS services is represented by low prices. In fact, prices decreased with the introduction of competition in the market (the same phenomenon observed when low cost flights were introduced).

A multi-scale approach is suggested: HS rail passenger flows are relevant for various lengths along the Corridor. For example, some people need to travel Stuttgart-Frankfurt, others Utrecht-Basel or Köln-Zürich. Of course almost nobody would travel from Rotterdam to Genova by HS rail. To achieve successful integration along all possibly relevant sections of the Corridor, it is necessary to also consider it as a whole. A very efficient and effective model along the Corridor could be a mix of the two different services:

- Trains with stops close to each other, calling at medium-sized cities to serve commuters at certain times of the day;
- Trains with less stops and longer distances between the main stations during the other time slots.

Two workshop participants recalled that the Corridor also needs to serve spontaneous travellers and their needs. This means flexible use of trains without being bound to long-time booked trips with fixed schedule and seat reservation which are often the case for the air sector. In addition they claimed high service quality on board such as comfortable seats for long-distance travel.

The question that is then raised: Which factors warrant a new stop on HS services?

It came up that identifying standard factors influencing the choice of a new HS stop is very difficult, because that is not only based on a technical but also a political decision.

Anyway, some of the factors should be considered:

- The regional structure and the location of the station: for instance, a station located "out of town" is less accessible but reduces losses of time due to crossing large railway nodes. That is the case of many HS stations in France, and of Reggio Emilia in Italy which is 4 km away from the city centre but performs very well with a very high demand.
- Integrations already existing in nodes: for instance SBB normally does not add new stops (with the risk of bigger delays) if an important connection is provided at the end station.
- Possible connections with airports and air services.

5.2.4 HS/LD Service Models

HS and LD service models are different in different countries (e.g. in Germany and Switzerland both services have similar functions, in Italy HS are replacing LD services) depending both on operators' choices and on the regional structure of the countries.

LD services in Italy are not competitive with HS trains due to their longer travel time; for this reason operators started reorganizing such trains, cutting some of them off or shortening their path in order to set up a system of feeder services to connect HS rail to cities not served directly. The number of IR trains (subsidised by regions) was expected to increase so as to provide connections between HS trains and stations no more linked with LD services, but this reorganization encountered the difficulty of coordination between the regions involved in the new service management and regulation.
However, reorganisation of LD and IR services is feasible only if HS services have high frequencies.

The idea of re-introducing night LD trains along the Corridor (e.g. Amsterdam-Zürich) with modern comforts and high quality standards was proposed.

5.2.5 Competition HS Rail/Air

Some of the main factors affecting competition between rail and air are:

- Travel time: a study of the European Commission (Steer Davies Gleave, 2006) proves that if the travel time difference between air and plane is around 2-3 hours the train market share is bigger than 50%. A recent survey on the entire HS network in Italy (Cascetta and Coppola, 2014) shows that trip frequency elasticity increases if door-to-door travel time difference is less than 2 hours (i.e. the shorter the distance the greater the increase in demand volumes) due to agglomeration effects.
- Service frequency: the higher the number of services, the higher the probability of choosing that service instead of a less frequent one.
- Connections to the city centres: usually train stops are more accessible than airports since they are located in city centres.
- Comfort and quality of the services: it is very important to improve the travel experience for passengers.

Considering the air transport figures presented in the workshop, some participants argued that there is still a potential to gain air travellers on some routes, e.g. Milano-Brussels, Roma-Milano or Zürich-Frankfurt. However, there are relevant air connections such as Roma-Milano, Milano-Brussels that still have substantial demand. This in line with the existing literature where it was found that air still increases though there is competing high-speed rail (Dobruszkes, 2011).

5.2.6 Cross-Border Trains

RFI and SBB have been asked to introduce a new service between Ticino and Lombardia. However, even though many people commute everyday between the two regions, almost all of them live in the proximities of the border so there is no need of introducing a LD service from Milano to Zürich stopping in Lugano, but rather a regional service is needed. They plan to provide a local hourly service.

Important factors to be considered when introducing new cross-border services are interoperability, integration (e.g. ticket integration:

some trains require reservation and there is no possibility to use the same ticket for another train) and regulation. Moreover different trip purposes need to be considered in order to capture all possible customers.

The idea of a web platform which is useful to organize trips came up: such a tool should include all information and knowledge about available services (e.g. costs, timetables, stops) as well as the possibility of comparing them to choose the most convenient one (need for transparency in the competition between railway operators). When dealing with such a tool, the problem of how all countries and all operators can cooperate and share information needs to be faced.

5.2.7 EXPO 2015

SBB has an agreement with Trenitalia to add new direct services to the EXPO site: nowadays there are still available seats on existing trains linking Switzerland to Milano, but they think the seats will not be enough during the EXPO period. If the capacity of the trains will not be sufficient, there will be a significant decrease of the level of service perceived by existing users who could stop travelling by train as a result. Moreover, if all the available seats will be occupied by EXPO visitors there will not be enough room for other visitors just wanting to visit the city of Milano. So the operators decided to offer new services to avoid losing already existing and potential clients. Integration (in terms of services, tickets, regulation, and information) is a basic factor to be considered when introducing new services. In Italy some years ago a special train linking Milano to the mountains was introduced: tickets were sold with ski-passes at special prices but they were valid only on one specific outbound service and on one particular return service. Other generally available hourly services could not be used. Such a special offer appears to be negative because integration and flexibility were completely missing.

It was reported that, since the opening times of the EXPO do not coincide with peak hours, Trenitalia thinks that there are enough seats on trains already running to the EXPO sites. This, together with the possibility of failure and unsustainability of such service after EXPO 2015, is one of the reasons why experts think there is no need for a new customised rail shuttle service Genova-Milano during the event.

Participaints of the CODE24 workshop on high speed-rail.

6 International Integrated Timed Transfer

According to the outcome of previous chapters, travel savings can be better and more easily realised on the Rhine-Alpine Corridor through shorter transfer time than by building new or improving existing lines. This is due to the fact that the main velocity in most of the tracks is already relatively high. The Integration of fares, regulations and rules and the collaboration of operators are important to achieve a more costumer friendly service. Essentially there are two HS service models for the Corridor to choose from. A French/Japanese model that proposes high velocity services between far away cities and an Italian/German model that is characterised by fast connections also between medium sized cities. For the densely populated Rhine-Alpine Corridor a multi scale approach can be considered, as doing one thing (integrated service between medium sized nodes) without leaving another (proposing fast connections between main nodes).

Discussion for the integration of services has to meet further main requirements. There is a real necessity for further investment in the rail infrastructure to improve rail passenger service. Proposals for these investments are defined in the CODE24 common strategy. The further development of the lines has to be realised based on the following priorities: Inner development of railway lines, intended as improvements of signal headway, elimination of very low velocity sections and intersections. New line sections are to be built only where necessary.

Another strong impediment for the costumer friendly concept of the Corridor are the missing integration of national tickets, at least ticketing and reservation system, missing compatibility of regulations, and missing integration with local traffic.

6.1 CODE24 Methodology

A proposal of an IITT model for the Rhine-Alpine Corridor has to start with the settlement structure of the Corridor and to define a desirable spatial structure based on a categorisation of the nodes. This categorisation has to be sustained by the spatial strategic vision, defined in the CODE24 corridor strategy (CODE24, 2014). These nodes are fixed for being served at minutes 00 and minute 30. For more frequent train services than every 30 minutes the integration is not further needed. The CODE24 partnership in establishing a common strategy has defined a clear settlement structure that is not limited to a few metropolitan areas, but includes also smaller and middle-sized cities. This settlement structure is meant to underlie a long distance rail offer, which meets the reality of a sequence of historically differentiated and economically important cities without dominating capitals. Public transport in these cities is further characterised by S-Bahn systems, which should be connected with fast and frequent service to create a flexible transport chain.

Most of these cities are not only connected along the Corridor, but, through other corridors, tied to other important cities. This opens up the possibility to combine these different corridors in their nodes by slim connections (i.e. short transfer times) and thus establishing a European network of cities out of independent lines. Thus, a system of ITT, modelled based on Swiss timetable concept, that offers connections on the hour or the half-hour arranges, would guarantee not only slim connections in both directions, but also a simply memorable timetable for trains in all directions in every city. An ideal proposal would combine the model with stops in the major metropolitan areas, with the multi stop model (German model).

To achieve best effects with transfer times in nodes and between the different transport services for a proposal of an IITT, the following criteria must best be fulfilled:

- The transport system should offer and create as many as connections as possible, to improve benefits for large areas in the metropolitan regions;
- To facilitate access to the service and reduce waiting times, an easily memorable timetable should be provided. Trains should therefore depart always on the same minute every two hours;
- As a result of the settlement structure and the proposed spatial model in the common strategy, station headway linking relevant nodes should be placed at a relatively short distance (50-100 km).

Such a concept guarantees the best network effects considering both the access to the hinterland and

the links with other long distance nodes.
An IITT transport system of this configuration allows an easy use for different kinds of customers. It is convenient not only for business travellers in the big urban and economic centres of the metropolitan areas, but also for different kinds of other users in intermediate and medium sized cities. It would further improve the probable modal shift from the car and a possible modal shift also from air for some long distances (> 200 km). It may result in a shift away from conventional rail services, which is not desired. A compensation of eventual passenger losses on conventional services may be replaced by a major demand on feeder lines on intermediate distances. However, it is an open question whether these national services will be replaced by IR/L services which thus needed to be subsidised by the local or regional transport authorities.

6.2 Different Scenarios of Rail Service Offer

Today's situation along the Corridor is characterised as follows and can be viewed in Figure 55. By 2014, there is no international train linking more than two of the countries with exception of only one ICE service connecting Amsterdam with Basel SBB and calling - amongst other - at the relevant rail nodes such as Utrecht, Duisburg, Köln, Frankfurt, Mannheim and Karlsruhe. This train is embedded in the German long distance systematic timetable and thus allowing good transfers with other long-distance services and mainly with the regional services.

There is an hourly backbone between Germany-Switzerland with direct or integrated transfer services all along the Rhine axis between Duisburg and Lugano respectively Brig. In Switzerland, there is mainly a 30 minutes headway. On the German side, there are several additional services along the Rhine axis but lacking constant intervals every 30 minutes. Between Basel and Milano there are four direct services requiring about 4 hours travel and some transfer connections of about 4 ½ hours travel time. Though there are lacks during the day at this border crossing, at least every two hours there is an hourly transfer connection link via Lugano with partly regional trains. From Zürich to Milano there are currently six direct services with a travel time of 3:40 hours[15]. As Zürich is well connected with the German long distance system, a seamless travel chain is guaranteed but with travel time losses.
The travel chain between Germany and Northern Italy could be better if the timetables services via Basel SBB would fit better. Generally, the trains to Italy leave at another time slot than those arriving from Germany, which require up to 45 minutes waiting time in Basel SBB. On the German and Dutch border, the main line from Duisburg to Amsterdam has no regular time schedule though there are five ICE-services as mentioned in Chapter 2. From Köln Hbf (Hauptbahnhof) there are regional services to other Dutch locations, from Düsseldorf Hbf there is only a regional hourly service to the Dutch border city Venlo with an integrated transfer to the Dutch network. An interesting offer is the IC-Bus offered by Deutsche Bahn four times a day and linking Düsseldorf with the Dutch city Eindhoven from where frequent connections allow a seamless travel chain to Rotterdam and many other Dutch cities.

Along the Rhine-Alpine axis, there are relevant integrated transfer nodes enabling connections with cities on other corridors and axes which can be described as follows:

- Utrecht <----> Rotterdam, Amsterdam
- Cologne <----> Brussel/Bruxelles, Dortmund, Hamburg, Hannover
- Frankfurt Airport/Frankfurt Hbf <----> Mainz, Dresden, Hannover, Berlin
- Mannheim <----> München, Stuttgart, Paris, Berlin, Hannover
- Karlsruhe <----> Paris, Lyon, Stuttgart, Strasbourg
- Basel SBB <----> Paris, Lyon, Switzerland
- Brig <----> Genève, Switzerland
- Zürich <----> Stuttgart, Switzerland
- Milano <----> Genova, Torino, Bologna, Roma .

The analysis shows that there are some barriers to overcome:

- Gaps between Germany and the Netherlands;
- Gaps between Italy and Switzerland;
- Travel time losses at nodes such as Basel SBB or Köln Hbf.

In the following, two different scenarios of rail service offer will be presented in order to reduce the aforementioned problems. First an International Integrated Timed Transfer (IITT) concept will take up

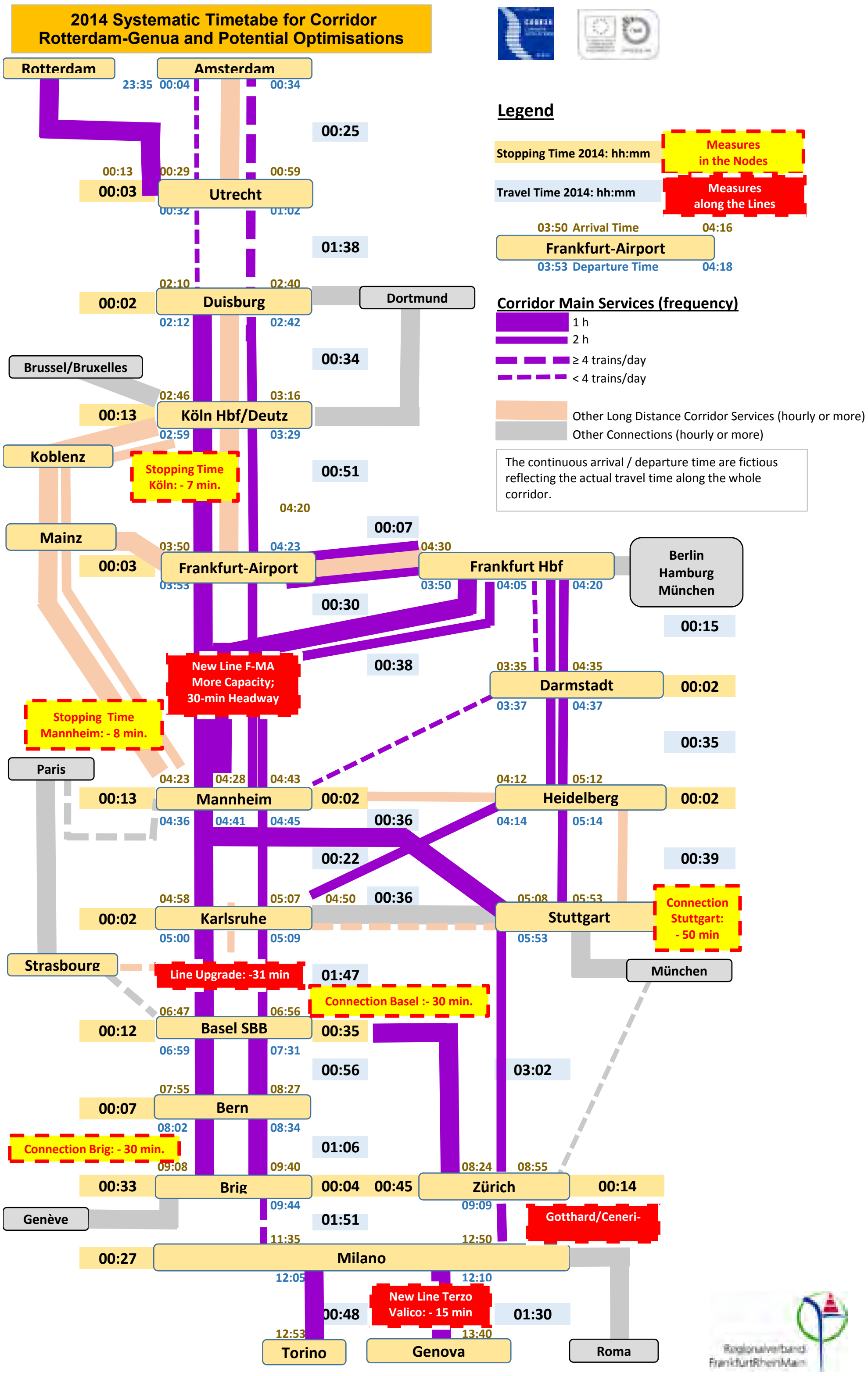


Figure 55. Today's Schematic Timetable Along Corridor Rotterdam-Genova

Source: Regionalverband FrankfurtRheinMain for CODE24, 2014 the infrastructure developments by the year 2020 and propose some additional elements in order to achieve regular hourly services along the Corridor which may be justified by relevant amounts of demand. The basic idea of an IITT is outlined before and can be deepened by reading Maxwell (1999), Clever (1997) and Speck (1996). A second scenario refers to so called "trains on-top[16]" idea, exploring possible travel time savings due to an increase in travel speed, fewer stops and less transfers and thus fewer waiting time.

6.2.1 Integrated International Timed Transfer Concept 2020

In order to get a common service concept, the following developments and infrastructure investments along the Corridor, including measures in the nodes, are assumed as they contribute to the fulfilment of an IITT (Table 37 and Table 38). Figure 57 visualises the schematised timetable based on the scenario S-Bahn of the CODE24-common strategy (Figure 56).

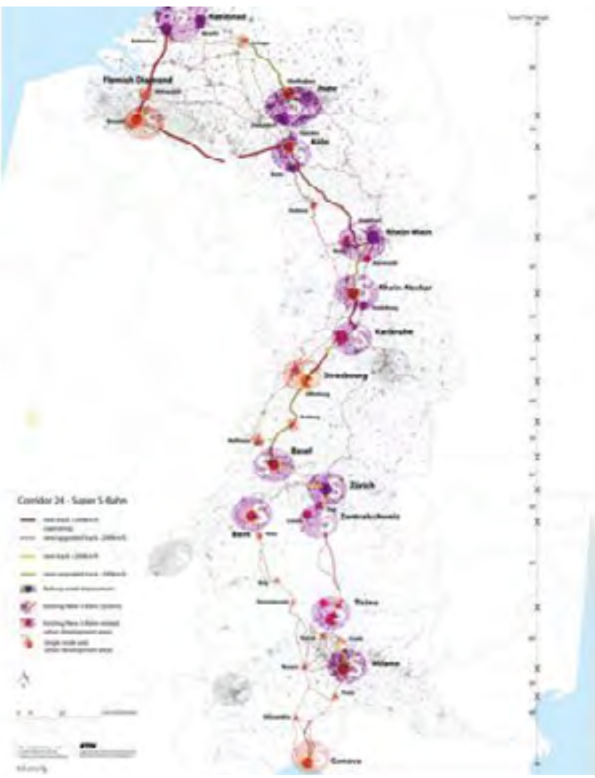


Figure 56. CODE24 Common Strategy Visualised Scenario Euro S-Bahn: Main Nodes for the IITT

Source: ETH Zürich for CODE24, September 2013

Table 37. New or Upgraded Lines Along Corridor and Travel Time Effects

Section and Infrastructure Measure	Travel Time Effects	
	Before (hh:min)	After (hh:min)
Utrecht-Duisburg: Third track	01:38	01:30
Duisburg-Köln: New regional line with demixing of traffic	00:34	00:30
Frankfurt-Mannheim: New line	00:37	00:30
Karlsruhe-Basel: Upgrade four tracks	01:47	01:17
Stuttgart-Zürich: Use of Pendolino technique	03:02	02:47
Zürich-Lugano: Gotthard and Ceneri Tunnel	03:40 (04:03)	02:58
Lugano-Milano: Upgrades and new line Chiasso - Monza	1:07 (1:00 till 2013)	0:50
Milano: Genova: Terzo Valico	01:30	00:58

Source: Authors' elaboration based on own assumptions requirements, expert workshop June 2014, Transpadana, Gruppo Clas (2014) and http://www.karlsruhe-basel.de/ (accessed 23 January 2015).

Table 38. Node Improving Measures and Travel Time Effects

Node and Measure	Travel Time Effects	
	Before (hh:min)	After (hh:min)
Köln-Hbf/Deutz: Improvement of Deutz as a node	00:13	00:07
Mannheim Hbf: Efficient track use	00:13	00:08
Basel SBB: Improvement of Swiss-/German integration	00:47	00:17
Basel SBB: "Herzstück" allows to avoid stop in Basel SBB)	00:15/00:30	00:00
Stuttgart Hbf: Other time slot for interchange trains from/to Heidelberg and Frankfurt	00:53	00:23
Brig: Other time slot for trains from/to Italy (related to Basel SBB)	00:33	00:03
Node of Milano Centrale/ Porta Garibaldi	00:15	00:00

Source: Authors' elaboration based on own assumptions/requirements.[17]

These measures need to be accompanied by a better timetable and service organisation and integration in order to make full benefit from the implementation of an IITT. The first aspect is the creation of a memorable and regular timetable. This means that at each station trains leave at the same minute each hour/every half hour as an example. For example, by 2014, trains from Frankfurt to Basel leave at minute 50 every hour and minute 05 every hour respectively two hours. Another criterion needs to be met: train departure times or headways should have the same intervals throughout the day. In the case of Frankfurt-Basel this means changing intervals from minutes 05/50 at the hour to, as example, 20/50 at the hour. Figure 57 shows such a systematic IITT based on the assumptions for the year 2020.

The discussion during the expert workshop in June 2014 revealed the necessity of better integration. Integration is concerned with reliability of services and important factors such as timetables, ticketing systems and user information should be taken into account. Contexts and service models of HS rail operation are different among the five corridor countries and thus they require some adaptation.

One aspect is how to benefit from rail competition that may lead to ensuring more services with lower prices. In order to make full benefits from competing operators and their services, they need to be integrated into the IITT concept that, in case of delay, allows transfer without additional costs. The latter is still missing on the Italian market, where NTV and Trenitalia compete, and on the Brussel/ Bruxelles – Köln connection where Thalys and ICE-trains create almost a one hour headway during the day.

The integration of timetables and chains needs to be improved: While creating a seamless mobility chain, operators may depend on other operators (e.g. Trenitalia, regional services, NTV, Thalys) to offer a full network availability which ensures good onwards and feeder train services. On the other hand, there is still the problem of getting access to the network for third parties and thus institutional barriers if network and national incumbent train operations are mainly under the same holding as it is the cases of Germany and Italy. There is the question of institutional barriers and integration in terms of rail operation, ticketing system, long-distance versus regional passenger services and supply of different

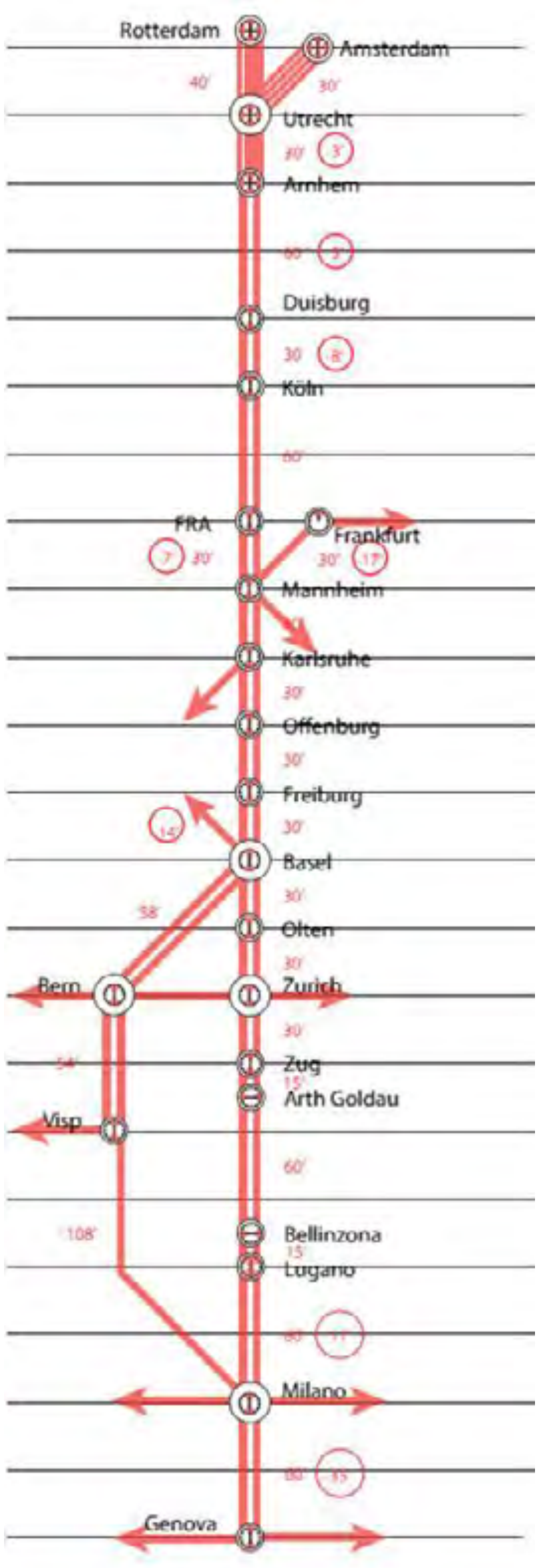


Figure 57. Schematic Corridor24 IITT-Scenario for 2020
Source: ETH Zürich, 2014

train services. EU regulation on better integration (e.g. fare, service and operational factors) may help to overcome these issues and a regulating authority should monitor and intervene accordingly. For the monitoring there is a need of setting up criteria which will be measured through indicators.

6.2.2 Rhine-Alpine Express

The introduction of a "train on-top" has to deal not so much with the existing problem, but to find an answer to the question which spatial configuration of the Rhine-Alpine Corridor is desired. An "all in one system" that satisfies every traveller's purpose does not exist. The aim is to develop a passenger rail scheme and a strategy which does not only follow possible proposals based on today's restrictions, but also to take into account future desirable links.

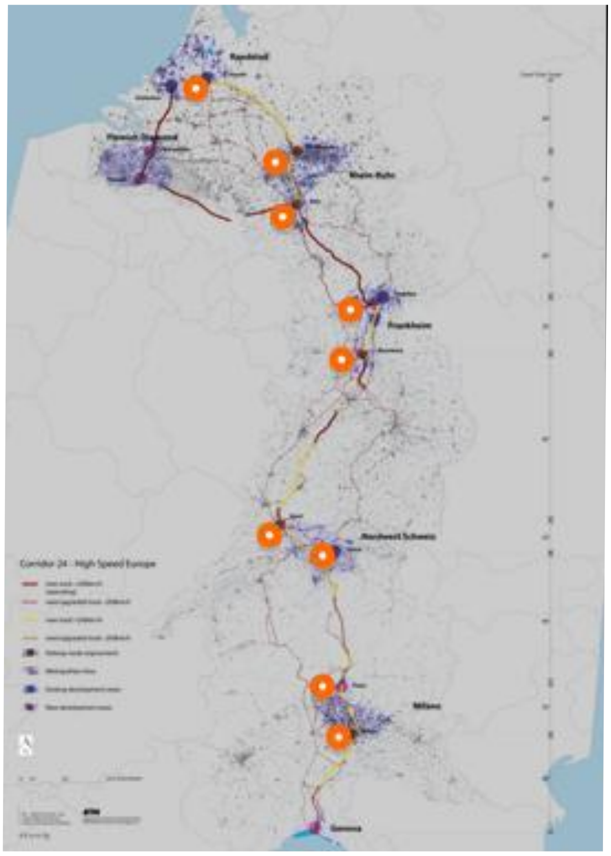


Figure 58. CODE 24 Common Strategy Visualised Scenario Centralline: Stops for "trains on top"
Source: ETH Zürich for CODE 24, September 2013

The proposal of the Rhine-Alpine Express as "train on-top" in addition to the IITT is based on the assumption that more customers will be foreseen due to travel time savings and fewer stops. Table 39 visualises figures of air travellers on selected OD pairs along the Corridor for the year 2012. An express service may lead to a shift in number of passengers towards rail though this must be carefully assessed as outlined in Chapter 3.

Table 39. Annual Passenger Data for Corridor Relevant Air Connections

OD Pair	Annual Passengers 2012	Distance (km)
Milano-Brussel/Bruxelles	458,503	664
Milano-Frankfurt	689,387	557
Milano-Zürich	259,414	228
Zürich-Frankfurt	607,192	334
Milano-Amsterdam	887,267	840
Amsterdam-Frankfurt	703,778	346
Paris-Frankfurt	1,108,738	512
Milano-Düsseldorf	277,754	691
Zürich-Düsseldorf	699,845	463
Milano-Roma	1,980,187	519
Frankfurt-Torino	189,286	561

Source : ENAC Air Transport Data, distances according to http://www.worldatlas.com/travelaids/flight_distance.htm (accessed 9 April 2014)

As the train offer is increasing on the Corridor – in many parts of the Corridor the train headway is already every 15 to 30 minutes – there is the possibility to have a segmentation in train supply for different types of demand.

Guidelines for the integration of an "on-top train" in the IITT, has to start from the node categories, which are based on regional and the corridor-wide spatial strategies, shown in Figure 59. These nodes are fixed for being served at minute 00 and minute 30. For more frequent train services than every 30 minutes the integration is not further needed.

Based on the spatial structure of the Corridor, the following stops are proposed as main nodes, where transfer between main train categories should always be possible on an hourly basis (Table 40). These nodes guarantee a convenient access to regional trains for costumers from the entire metropolitan region. These central stations serve as access points to the metropolitan regions, considering not just "point to point relations" in high-speed links, but also offering faster links between all stops of the respective metropolitan areas.

Table 40. Proposed Main Nodes

Metropolitan area	Proposed nodes (2030)[18]	Transfer time
Randstad	Amsterdam, Utrecht	30/00
		30/00
Rhein-Ruhr	Oberhausen, Köln	00
		00
Rhein-Main-Neckar	Frankfurt Airport/ Frankfurt Hbf-Mannheim	00
		00
North West-Switzerland	Basel, Zürich	30/00
		30/00
Milano	Lugano, Milano	00
		00

Source. Authors' elaboration based on own assumptions/requirements

As a basic IITT requirement the Rhine-Alpine Express has to meet with transfer times in the nodes mentioned before. For the rest, service providers are free to decide where to stop and what travel time to propose. The travel times showed in Table 41 indicate the potential travel time savings for the specific sections on Corridor 24. A further development of the lines has to meet two basic priorities proposed by the common strategy (CODE24 Consortium, 2014). As for the first step of the IITT, first and second priority measures proposed in the common strategy are sufficient to improve the timetable. These measures are essentially dealing with the "inner development" along the existing tracks, as organizational and technical measures as well as regulations or elimination of intersections in the nodes. For the second step with the introduction of a Rhine-Alpine-Express as a fast through train, the construction of new dedicated line sections are needed, defined as a further priority in the common strategy (CODE24 Consortium, 2014). These measures are namely the fast connections Oberhausen - Köln and Basel-Zürich, the completion of the access routes to the Gotthard base tunnel, North and South of the Alps and the new line from Lugano to Chiasso. Since these measures require further time, and are in line with the work commissioned by the new core corridor coordinators, the year 2030 should be targeted (N. U., 2014).

These improvements to the infrastructure – planned in the long-run – allow additional trains to run. These offers bring still relatively small improvements in terms of travel time, due to frequent stops and a still fragmented HS infrastructure on the Corridor. But they allow direct connections to be offered between the metropolitan regions using suitable time-paths with slim connections to other train categories in order to complete the transport chain.

In particular 15 minutes can be saved between Milano and Zürich which would allow previous connections to be reached at minutes 15/45 in the node of Zürich. With an additional travel time saving of 15 minutes between Zürich and Basel, direct connections to Germany, still fitting the IITT-System, become possible. Also the travel time gains between Mannheim and Basel, offered by the third and fourth track in the upper Rhine, can be summed up to 90 minutes according to the Rhine-Alpine Express proposal. Thus, a travel time of two hours and 40 minutes between Zürich and Frankfurt with an additional saving of 15 minutes is potentially possible, showing a huge potential in the substitution of air travel.

After the introduction of such a Rhine-Alpine Express there would still remain the following challenges: the limited accessibility of rail offered, lacking integration of a ticketing system (train categories, reservation, three or more tickets necessary for one trip, lack of integration in selling, no admittance of some tickets in train categories), limits integration with regional transport supply.

6.3 Towards an Optimal Timetable Concept

The timetable exercise showed that improvements can be made without creating too much infrastructure and that some upgrades and measures in the nodes are sufficient to increase the whole door-to-door travel chain. It is important to stress that the density of the Corridor, the polycentric character of the regions and the

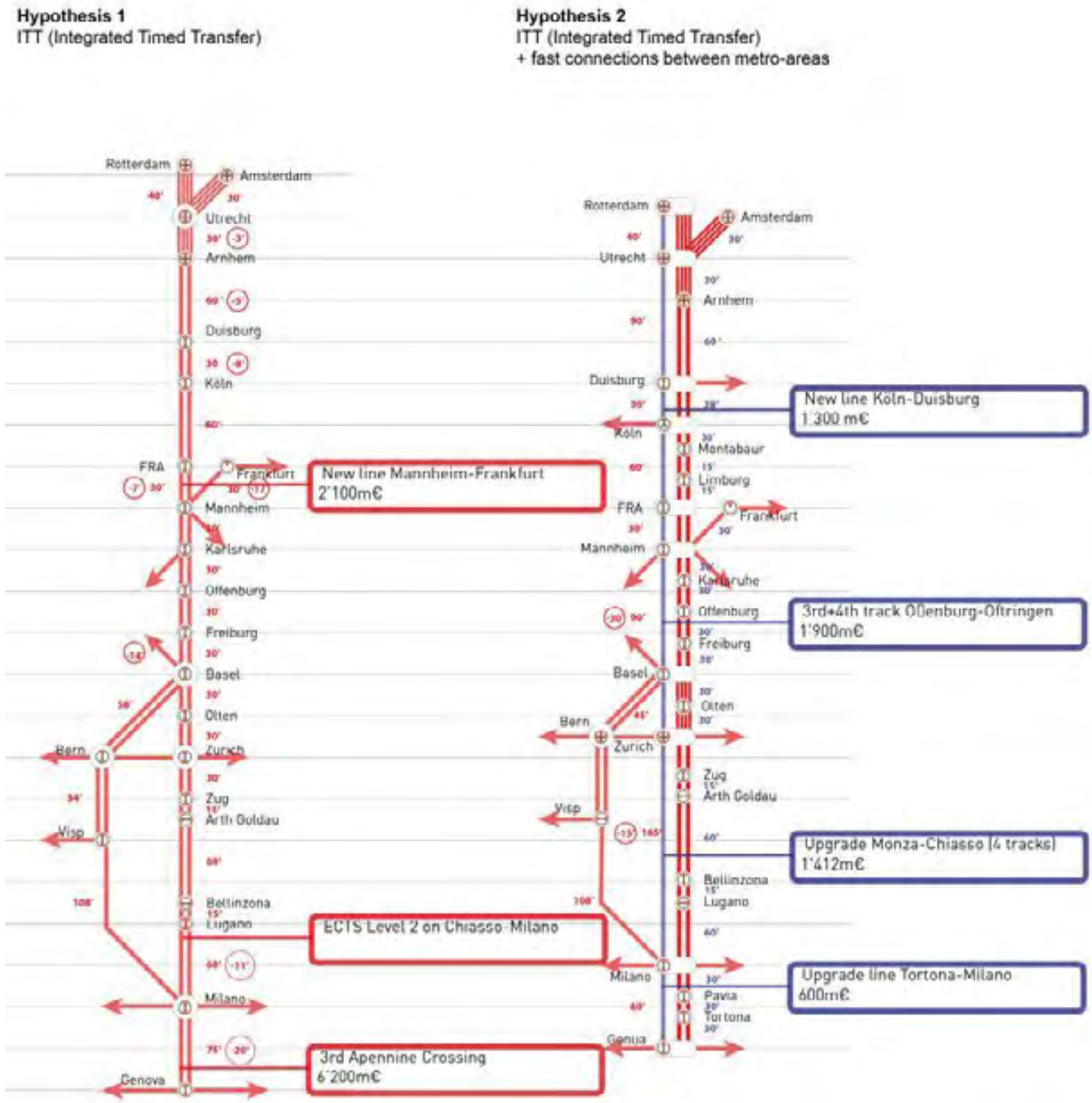


Figure 59. Schematic Corridor 24 IITT-Scenarios 2020 and with "train on-top" for 2030
Source: ETH Zürich for CODE 24, 2014

interregional relations along the Corridor again suggest a multi-scale strategy. This means that both international demand and domestic travel need can be satisfied. Backbone is an hourly long distance train service which serves the most relevant nodes along the Corridor regardless of the domestic or international catchment and where transfer from/ to regional services and with other long distance services towards other corridors is guaranteed. Additional sped up train services calling at fewer stations may be an on-top option to cope with considerable air demand levels as can be found between Frankfurt and Zürich or Amsterdam, Zürich and Milano or Köln and Zürich. To be competitive with air, the train needs a travel time of less than four hours (Table 39).

These services should be carefully designed in order to avoid demand shift from the hourly backbone services which in turn may be under threat. Caution is also necessary since there may be more air passengers if their HS rail accessibility to airport rail stations may increase. This issue arose in the expert's discussion which included a meeting of Action 17 members with a rail consultant.[19] Table 41 summarises the different scenarios and attainable travel time effects.

Table 41. Summary of Travel Time Effects on Selected Connections

Relation (all times in h:min)	Situation 2014	IITT Concept 2020	„Train on-top"
Rotterdam-Köln	3:09	2:56	2:40
Frankfurt-Zürich	3:55	3:22	2:45
Frankfurt-Milano	7:30	6:30	5:30
Zürich-Milano	3:41 (4:03)	2:58	2:45
Zürich-Köln	5:05	4:50	3:45

Source. Authors' elaboration based on own assumptions/requirements

Air demand between larger cities - like Düsseldorf - could be targeted with additional speeded up services so-called trains on-top.

7 Conclusions and Guidelines for the Development of an Integrated Railway Network

This chapter concludes by presenting the corridor concept for integrating HS rail to Corridor 24, and reflecting methodologies developed for carrying out three activities which are identified at the beginning of this report (Section 1.1). The Action 17 team has identified a number of remaining issues and future research areas. At the end of the report follow-up activities are summarised in two ways: within the framework of Corridor 24 and beyond the CODE24 project.

7.1 Corridor Concept

The Corridor concept to achieve more integrated railway network should be concerned with the following four key aspects:

1. Integration of LD and regional transport;
2. Customer needs;
3. Multi-scale access;
4. Corridor vision.

7.1.1 Integration Regarding Accessibility, Transfer Times and IITT

Integration of railway network is important – also from the viewpoint of the land use and transport interaction – to avoid loss of level of service for locations not served by HS services and to ensure that the whole corridor may benefit from HS links thanks to feeder services. Two aspects of integration were explored: integration of services along the Corridor (to provide corridor accessibility) and integration of long-distance and HS services with regional ones (to provide regional accessibility).
In terms of corridor accessibility, a comparison between demand and supply of HS and LD services between the most significant OD pairs revealed that the number of direct services is not necessarily similar across OD with similar potential demand, and that dissimilarities in supply reduce when IR/L services are also considered. Different service models for HS and LD connections were observed: in Germany and Switzerland HS and LD trains provide a similar service and are used to connect similar OD pairs with a different quality and level of service (different number of stops, speeds, etc.) while in Italy HS services are increasingly replacing LD services. Connecting services have an important role in ensuring a high level of supply between the main OD pairs: in particular transnational ODs have scarce direct services but in some cases (e.g. Germany and Switzerland) they are served by very good indirect connections with similar total travel times. This indicates that even indirect connections can ensure a high standard of service as long as transfers at cross-border stations are well coordinated. In other cases lack of interoperability may also hamper a better (direct) cross-border connection.

Concerning regional accessibility, the analysis of the integration between HS/LD and IR/L services pointed out the good integration especially at German and Swiss main stations. In Italy transfer times are usually longer than in the 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 which is evident in the case of Milano. In contrast, in other countries both IR and L services are usually available at the central station.

Good connections between HS and regional/local trains in the main HS stations along the Corridor are also a key element to provide railway services that are competitive with the air mode and have the potential target air travellers. If railway services are frequent and with reasonable short transfer times in the main HS nodes, the total travel time from an origin to a destination by train can be reduced significantly and become shorter than the total travel time needed to connect the same OD pair by plane. This is often due to the longer distances needed on average to reach airports and to the lower frequency of air services compared to its rail counterparts.

However, it is important to underline that other factors could be even more important than just saving transfer time in order to realise an efficient integration. The following factors should be also improved:

- Service frequency that increases the number of possible transfer choices;
- Service reliability that reduces the risk of missing the connection in case of delays;
- Integration of fares (especially when different operators offer services on the same route: the ticketing system needs to be regulated

and extended also to interregional and local services so that it is possible to transfer on the next available train in case of delayed arrival in transfer nodes regardless of the operators);
- Information allowing users to share knowledge about available services (e.g. costs, timetables, stops) and to compare them in order to choose the most convenient operator;
- Regulation to coordinate cooperation among both the public authorities and the operators.

7.1.2 Customer Needs

Travel time savings for long-distance services along the Corridor have been a major concern for the Action 17 activities. However, they should not be seen as a dominating criterion when assessing HS rail suitability and effectiveness for the Corridor. The importance of rail nodes in providing good connections from/to hinterland has been emphasised and the emergence of new dedicated HS lines and corresponding "out-of-town" stations has been often criticised. However, during the expert workshop new HS stations created on greenfield sites have been perceived differently. For example, in France "out-of-town" stations are justified with achieving higher speeds and bypassing the central urban areas so that operational time saving can be assured. Though Italy has less "out-of-town" stations, some regard them as well performing. On the other hand, in general, remote location has been viewed negatively concerning transfer to other LD/HS-trains and to the regional network. Since more efforts have to be made in terms of getting to/from the "out-of-town" stations, they appear to be not very sustainable. This question is also linked to the integration with spatial and land-use planning (strategy/concept/scheme) and the location of HS stations therefore have a great influence on the quality of life of customers. In essence, "out-of-town" stations need to be carefully considered and should be applied only for exceptional cases. Most importantly stations in the greenfield should not be created, unless a very good connection with conventional LD or regional trains is secured.

In addition, the improvement of facilities in HS rail stations should be taken into account. It is important to consider how HS users spend their waiting time at HS stations in case they miss connections between HS and IR/L or have a longer transfer time.

Finally, better connection of HS with other transport modes - not only with air, but also with car - has a lot of potential to demonstrate attractiveness of using HS to customers. Design of HS lines needs to be responsive to other transport modes.

7.1.3 Multi-Scale Accessibility

To achieve successful integration along all possibly relevant sections of the Corridor, it is necessary to create the HS corridor network as a whole, even though it is unlikely that people would travel by train on the entire route between Rotterdam and Genova. Although demand levels along Corridor 24 are lower across the border than within several domestic relations, there is sufficient potential for increasing cross-border connections which feed domestic services accordingly. Furthermore, (potential) demand is generated by several medium-sized stations and their hinterland along the Corridor, and not predominantly by few metropolises. The national networks mostly offer hourly long-distance services partially by HS trains, partially by LD trains. This ensures a very good cross-border service level on the Swiss-German frontier, but lacks service frequency across the other borders. Though there are only few direct cross-border trains, service continuity is guaranteed by train-to-train transfers at relevant transfer-nodes as discussed above, which thus ensure accessibility of the respective hinterland.

In this context multi-scale accessibility should be considered with reference to an OD-matrix to appraise the network function of LD/HS rail services and the integration with regional and local train services. A multi-scale accessibility takes into consideration the numerous nodes along the Corridor (cf. Frankhauser et al., 2008). This multi-scale accessibility bears hence another advantage: integration of regional feeder services in relevant regional and national transfer nodes ensures better accessibility than a focus on HS services with fewer stops. The latter may risk in losing customers along the lines, notably when the accessibility of stations not served by HSR is undermined as a result of creating parallel HSR lines.

Moreover, there is a possibility to shift the demand from car to rail if the multi-scale strategy is applied. The multi-scale strategy can be also justified by other reasons such as the density of the Corridor, the polycentric character of the regions and the interregional relations along the Corridor. In essence, a multi-scale approach fits perfectly to the initial idea of developing an international integrated-timed transfer (IITT) which links the existing regional and national networks with the whole corridor network and thus fills the remaining timetable and access gaps along the Corridor and across the frontiers. Frequent and integrated services contribute to keep transfer times low. Experts at the workshop have suggested that 15 minutes was considered as a good standard for transfer times. Stations offering only few connections per day need longer transfer times than those providing frequent connections within an IITT which makes it possible to allow for shorter transfer times.

7.1.4 Corridor Vision

For the Corridor strategy it is very important for CODE24 initiative to develop a vision for a long-term outlook and to fulfil a pioneer function for future ideas on this TEN-T Corridor. Though the analysis reveals larger demand levels on domestic relations, a certain supply standard overcoming deficits on border crossings is required for building a future vision of train services along the Corridor in order to foster the Corridor's coherence. The following two points have been identified as examples of important factors which should be considered in drawing up the Corridor vision. Firstly, events such as the EXPO2015 with additional services would function as a catalyst to induce new rail demand in the long-term beyond the period of event. One key to success is the effective integration of event-related services into the existing network and all other service aspects should be enhanced. Secondly, there is the lack of information for gathering demand data from train users. Thus, data needs to be available from operators, notably network operators. Since access to relevant data is not always guaranteed, a neutral entity, e.g. regulating authorities like the German Federal Railways Agency or Network regulation Agency, is necessary to take an action in order to ensure the data availability.

7.2 Methodology

New methodologies have been developed to carry out the three activities for the Action 17. This section highlights successful aspects of these methodologies, some difficulties in developing the methodologies and future improvement areas.

First of all, the analysis of train timetables of selected stations has been supported by innovative visualisation tools which are used for presenting the results of the clock study and the demand analysis (Chapter 3) as well as IITT (Chapter 6). These techniques have appeared to be effective in communicating a vast amount of data, not only within the Action 17 team during project meetings, but also with the professionals during the expert workshop (Chapter 5). There is a room for further improvement of these visualisation tools, which can be, for example, integrated with the Corridor Info System (CIS) of CODE24.

The Study area for the timetable analysis has covered the entire Corridor (IITT) and regional and local catchment areas of 27 selected rail stations along the Corridor (clock study and demand analysis). However, data availability for the 27 stations was limited. Although timetables for passenger trains in each station are publically accessible and most of the analysis relied on these data, timetables for freight trains were not able to be obtained from relevant operators. Thus it was not possible to carry out a full range of the line capacity analysis for both passenger and freight trains in mixed-use tracks. Missing data is also concerned with the actual number of passenger train users and estimated potential users for certain routes which has become an obstacle to the accessibility study for EXPO Milano 2015 (Chapter 4). More involvement of train operators and timetabling experts (e.g. DB Fernverkehr, SBB, Trenitalia) is necessary for this kind of studies in the future.

The expert workshop was well prepared and used effectively to discuss preliminary findings of the three activities. Experts were selected from five European countries, ranging from academics, rail related practitioners from the operational side and transport and spatial planning consultants. The only drawback was the absence of timetabling experts and national incumbent train operators apart from SBB. The workshop day went very well and it was successful in terms of expanding knowledge of the Action 17 team and clarifying focal points for remaining work. The Action 17 team members have perceived that a one-day workshop is not enough to exchange all the information with the experts, but the workshop should have been repeated. For example, another workshop could have been planned earlier once the methodologies for data collection and analysis, and visualisation tools were decided so that it was possible to include experts' input in refining the methodologies before the data collection.

It should be noted that demand data were not available directly from train operators. Thus it still remains unclear how good the OD pairs derived from official data per NUTS-zone reflect the actual use in trains and along respective routes.

Finally, it should be noted that the project duration was limited to only one year and a half since the Action 17 started in April 2013 as an extension activity of CODE24. Time restriction has been the main reason why the study had to focus on timetable of selected key stations with a limited analysis of OD and line capacity. Some results of the expert workshop suggest a more holistic approach towards the integration of HS rail to the Corridor. Other aspects such as customer's needs, multi-scale access and corridor visions should be carefully considered in future studies.

7.3 Follow-up Activities within the Corridor: CODE24plus

This section describes four follow-up activities which have derived from a number of discussions held by the Action 17 team. These activities should be pursued within the framework of Corridor 24.

7.3.1 Rhine-Alpine Express

As a follow-up activity within the Corridor it is envisaged to create the so-called Rhine-Alpine Express. In the work of Action 17, it was found that a lot of trains along the Corridor lose considerable time in the nodes. For example, in the node of Basel the ICE coming from Germany loses on the way to Zürich up to 40 minutes for waiting in the Basel SBB station. In addition, there is a big potential of gaining customers for rail from the airplane and the car especially for relevant connections between the big cities. The idea is to design "a train on-top" which runs in addition to the hourly backbone service already connecting these big cities. Such a connection could be realised between Frankfurt, Mannheim and Zürich or Amsterdam, Zürich and Milano or Köln and Zürich. To be competitive with the airplane, the train needs a travel time of less than four hours. The advantage of trains is that they normally travel direct in the centre of the cities, while the airports are arriving mostly outside the cities which means an extra time for travelling to the centre. With the introduction of "Rhine-Alpine Express" it is possible to increase the attractiveness of the Corridor and to strengthen the big nodes. Furthermore, it can help to avoid air pollution und to reduce the noise problems at the airports (Responsible person: Thomas Satzinger, VRRN).

7.3.2 Accessibility of the Key Nodes along the Corridor

This project idea aims to improve the regional and local accessibility to key railway nodes along the Corridor 24 which are facing an increasing demand of coordinating different modes of train services (HS, regional and local trains and freight). Transport sector is one of the major polluters in GHG emissions, and railway is recognised as a much cleaner transport mode than road or air transport. Hence railway's contribution to reducing GHG is crucial and modal shift from other transport modes to rail should be further promoted in both passenger and freight services. For passenger rail service, major obstacles to the modal shift are related to the reliability and frequency of different types of train services as well as the competition from low-cost airline, which have been clarified through the Action 17 activities.

In order to overcome these problems, the regional and local accessibility to key railway nodes would play important roles in providing a direct link to TEN-T networks, particularly in transfer stations serving more than one Core Network Corridors such as Milano, Basel, Mannheim, Frankfurt am Main, Köln and Rotterdam. The regional and local accessibility to such major stations is an influencing factor for people to choose between trains and other transport modes concerning their LD journey. In order to make more people to opt for LD train services, it is crucial to ensure them to reach their closest node stations within a short time and enjoy benefits from TEN-T networks. The accessibility improvement has a close link with the capacity of railway station in terms of not only the coordination of different train services with a limited number of platforms and rail tracks, but also the better passenger flow and pedestrian access to/within stations. The project will examine the regional and local accessibility to key rail nodes from the perspectives of train users including all the public transport (e.g. bus, metro) and non-motorised modes (pedestrians and cyclist). As it has been pointed out through the Action 17, customer's needs should be more taken into account for the future railway corridor development.

The ultimate aim of the project is to increase people's willingness to take a LD rail journey and their awareness of contributing to reducing GHG emission through selecting railway journey as part of taking social responsibility for mitigating effects from climate change (Responsible person: Noriko Otsuka, ILS).

7.3.3 Coordination of Regional Transport and Sustainability

Regional and interregional public transport services (both trains and buses) are crucial for guaranteeing the connection among cities of the same region, different regions and even different countries. They also have the important role of connecting peripheral regions to the TEN-T core network. Achieving a sustainable regional and interregional public transport will allow a harmonious social and economic development of the entire Rhine-Alpine Corridor, preserving accessibility, environmental sustainability and liveability (i.e. reducing GHG emissions due to the modal diversion from car to public transport) and vitality of rural communities and tackling the problem of rural depopulation.

Unfortunately, in the last years, partly due to the current economic downturn, public funds for regional public transport services have been mainly dedicated to urban services (where there is more mobility demand), overlooking interurban services. The lack of funds combined with the lack of standards in public transport service planning and monitoring have resulted in calling the necessity for a wide set of policies and actions throughout Europe. Usually less profitable services are cut causing, in some cases, considerable social problems related to lack of regional and interregional connections between cities and the decreasing accessibility of rural areas.

Taking into account those facts, this follow-up project idea aims at developing and implementing a common European framework for regional and interregional public transport that increases economic, social and environmental sustainability of public transport services while maintaining or even increasing the level of service provided. Based on the results of CODE24 and the sharing of international best practices regarding public transport, the project will define a common framework for sustainable regional and interregional public transport and identify innovative and effective solutions, in line with the framework, to be implemented by the Public Administrations involved in the project regarding, for example: planning (i.e. in order to achieve better spatial and temporal accessibility, efficiency and effectiveness of the services), integration regarding services, ticketing and information (i.e. between trains and buses, among different public transport lines and companies, regions and countries, interurban and urban services), monitoring (i.e. standards regarding indicators, data collection systems, business intelligence tools), business models (i.e. foster cooperation between the public and private sector in order to explore innovative financing mechanisms; ensure a balance among costs, funding and ticket revenues that guarantees equity and inclusion of lower income users while being economically sustainable for PAs), governance models, and accessibility for the elderly and people with reduced mobility (Responsible person: Maurizio Arnone, SiTI).

7.3.4 Working programme for the newly founded European Grouping for Territorial Cooperation (EGTC)

As part of the CODE24 strategy a follow-up organisation should continue to jointly tackling future challenges and developing the Corridor beyond the project's lifetime, a follow-up organisation is necessary. Such a European Grouping for Territorial Cooperation (EGTC) entitled "Interregional Alliance for the Rhine-Alpine Corridor EGTC" has been meanwhile founded. For the Action 17 team, the EGTC can be a catalyst to achieve the goals set by the group actions identified in this paper. There are three ambits of action: legal framework, infrastructural investments and organisational aspects.

In the ambit of legislation EGTC should raise awareness towards harmonisation of international with national framework which is needed as liberalisation shows further effect in some member countries such as Italy, Great Britain, Spain and Germany. As an example, international through-trains passenger and adjacent operator's strategy may follow different rules than the nationally oriented ITT (Integrated Timed Transfer) with more fixed departure times. Another challenge is to improve the reliability of HS/LD trains by reducing international standards for maximum delays to 15 minutes to meet requirements of local trains.

The exercise of the "trains on-top" shows that investments in new tracks, set as one priority in the CODE24 common strategy, are essentially important for improvements in the passenger LD offer (CODE24 Consortium, 2014). In a long-term perspective and in order to envisage a further option of shifting demand from air to rail, EGTC should explore the feasibility of such an "train on-top"-concept, labelled also as Rhine-Alpine Express for an enduring and competitive Rhine-Alpine Corridor.

One main problem would remain even after the introduction of the Rhine-Alpine Express: the limited accessibility to rail offer due to lacking integration of ticketing system, in terms of train categories, reservation, three or more tickets necessary for one trip, lack of integration in selling and no admittance of some tickets in train categories. These issues are further limiting integration with local and regional rail transport offer.

Therefore, EGTC should advocate for the introduction of a so-called Rhine-Alpine Corridor Transport Association, applied to the whole Corridor and based on the idea of the German, Austrian or Swiss public transport organising "Verkehrsverbund", well-known for a well-functioning local/regional public transport system with integrated timetabling, ticketing and marketing for many regions in these countries. Such well-performing transport associations or authorities exist also in other Corridor countries and beyond but may have different competences even beyond the public transport matter.[20] Therefore, the authors used the German term which fits best to the idea suggested for the Rhine-Alpine Corridor (Responsible persons: Thomas Satzinger, VRRN and Peter Endemann, Regionalverband)

7.4 Further Research Areas beyond CODE24

The final section of the report concludes by suggesting future research areas beyond the CODE24 framework. Four research ideas have emerged as a result of Action 17 activities.

7.4.1 Losing Customers or Winning Customers: What is the most Appropriate Operational Concept?

As stated before, the action 17 group proposes a rather conservative approach in terms of HS trains development by postulating their integration within an international integrated long distance transfer timetable and to a lesser extent the development of a pure HS rail network. This is thus the dilemma HS rail planning and policy practice face nowadays: "To increase the overall benefits of the HST [HS train] (and decrease its negative effects), it should serve many cities and include many stops, but more stations on an HST [HS train] line lead to a lower average speed and thus to lower capacity on the route and a longer travel time, reducing the benefits of the HST [HS train] (Givoni, 2006: 609)". Given the different trades-off to be made between speed and targeted customers, high accessibility and disintegration, winning and losing position of municipalities and regions, the design of HS rail and general major rail infrastructure needs a "multi-modal and multi-national approach (Vickerman, 1997: 35)" including careful evaluation of interactions with the existing network, level of HS service and the spatial patterns within a region respectively along a corridor. Air traveller figures from Table 39 presented in the previous Chapter 6 suggest some potential customers from the air market hence suitable for train services in addition to the IITT-concept, previously introduced as Rhine-Alpine Express. Further research may however assess how the benefits of HS rail development are demonstrated and how its benefits can be multiplied in order to gain more customers from the air market segment without losing its capacity to target road users as a relevant user group. This holds true for the integrated capacity of long-distance rail which needs its integration with the connected regional network and its important rail feeder function. (Responsible person: Peter Endemann, Regionalverband).

7.4.2 HS Competition while Losing Integration?

Besides the Italian HS network and the Thalys/TGV competition between Paris and Bruxelles/Brussel as well as the ICE/Thalys competition further on to Köln, there are few experiences with effects of LD *competition along the Corridor. More recently, the British National Express obtained a license to run HS* trains in Spain which hence may deliver new insights in a near future[21] though the Spanish Government has postponed the full liberalisation for another year.[22] In Italy, Cascetta's and Coppola's (2014) observation suggest a reduction in average price of a HS rail ticket after the introduction of incumbent Trenitalia's competitor NTV and an increasing train ridership with gains in the market share if comparing it with competing modes such as airplane and car. Research work could target the long term effect of HS competition on ridership and assess the success' or failure`s contribution of aspects such as travel times, train frequency and fares if controlled for other factors of influence, notably the problem of missing fare and partly timetable integration (Responsible person: Peter Endemann, Regionalverband).

7.4.3 Improving the Internal Accessibility of Rail Nodes

Previous studies on improving the accessibility of passenger rail nodes to European Core-Network Corridors have carried out analyses in terms of different aspects such as train timetable, origin-destination study, rail line capacity for new services, integrated ticketing and infrastructure investment (e.g. Action 17 of CODE24, other INTERREG funded projects such as RAILHUC[23] and RAIL4SEE[24]). These criteria have been predominately decided by transport professionals based on technical and quantitative data and rail accessibility seems to be narrowly defined by technical criteria such as train timetable and line capacity. There is a need for examining the accessibility from the users' point of view which is concerned with good access information system, the usability of facilities (e.g. ticket office, waiting area, toilets, left language, shops, restaurants) and the quality time spent by users while waiting at stations. Five out of nine Core Network Corridors are connected with the Rhine-Alpine Corridor, and the increasing volume of passenger train flow will therefore impose challenges for rail node stations to coordinate HS, LD, regional and local trains. In addition, providing high-standard service to a growing number of station users is a critical issue to be tackled. Some of the rail stations will reach or have already reached their capacity limit. They hence urgently require redevelopment strategies to maintain the current level of service. Given limited resource available for rebuilding new stations, a strategic thinking for modernising and upgrading old stations is of paramount importance. This project idea has two objectives:

- To improve the accessibility of different user groups to/within rail stations as an interchange for different transport modes (e.g. public transport, car share, non-motorised transport modes such as pedestrians and cyclists) in order to optimise the regional and local connection to European Core Network Corridors;
- To enhance the public space of rail stations by addressing different users' needs (e.g. vulnerable populations such as elderly and disabled) and to increase the integration and the legibility of rail stations (i.e. how to find right places without getting lost) using methodologies of urban and spatial design (Responsible person: Noriko Otsuka, ILS).

7.4.4 New Collaborative Visualisation Tools

In Action 17, a GIS-based tool was built for internal use to visualize the correlations between the collected data (demand data between the main nodes, timetables, integrated services, etc.). This first version provided positive feedbacks, showing its effectiveness in data mining processes and analysis of big sets of data. The tool is now facing a new implementation concerning the graphic interface, the back-end interface and its user-friendliness, which should improve specific elements for enhancing the involvement of different actors in the decision processes and increasing its usability also by non-expert users. The tool will offer a simple interface to visualise GIS data on the basis of users' requests, providing a support for planners and decision-makers to explore data and detect issues of inefficiency, ineffectiveness or critical areas which need further reasoning on their planning or design. In addition, it will be possible to use it in collaborative and participatory session so to improve the information sharing among participants. Further developments will allow the tool to perform a multi-criteria analysis on selected and filtered data. Finally, the new tool will include the integration with the Corridor Info System (CIS), in order to provide the possibilities for exploring and querying the data concerning the project on the Corridor 24 (Responsible person: Stefano Pensa, SiTI).

Stations like Basel SBB fulfil integration at different levels.

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9 List of Abbreviations

AV	Alta Velocità (Italian HS)
AVE	Alta Velocidad Española (Spanish HS)
CODE24	Corridor Development 24 Rotterdam – Genoa
Country Codes	Used in some graphics and for statistical units: Belgium (BE), Germany (DE), ES (Spain), FR (France), IT (Italy), NL (the Netherlands), SE (Sweden).
EC	Eurocity train; European conventional long distance interurban train
EGTC	European Grouping for Territorial Cooperation
EU	European Union
GHG	Green House Gas
GIS	Geographical Information Systems
Hbf/HB	Hauptbahnhof (Central station of the respective city)
HS	High-Speed
IC	Intercity train; national conventional long-distance interurban train
ICE	Intercity Express (German HS train)
IITT	International Integrated Timed Transfer
IR	Interregional
KPH	Kilometres per hour
L	Local
LD	Long distance
NTV	Nuovo Trasporto Viaggiatori (Italian HS train operator)
NUTS	Nomenclature of Territorial Units for Statistic
OD	Origin – Destination
RFI	Rete Ferroviaria Italiana (Italian network operator)
SBB	Schweizerische Bundesbahn (Swiss federal railway company)
TGV	Train à Grande Vitesse (French HS train)
TEN-T	Trans-European Transport Network
UIC	Union Internationale des Chemins de Fer (International Railway Union)

10 Action 17 Members and their Responsibility

Surname	Name	Organisation	Responsibility
Africani	Alessandro	Uniontrasporti	Activity 3: EXPO case study
Arnone	Maurizio	SiTI	Activity 1: HS/LD integration
Delmastro	Tiziana	SiTI	Activity 1: HS/LD integration
Delpiano	Roberta	Uniontrasporti	Activity 3: EXPO case study
Endemann	Peter	Regionalverband FrankfurtRheinMain	Action leader Activity 2: IITT & review
Fontanilli	Antonello	Uniontrasporti	Activity 3: EXPO case study
Ghio	Laura	Autorità Portuale di Genova	Expert workshop Knowledge and data transfer
Günther	Felix	ETH Zürich	WP1 leader Activity 2: IITT
Otsuka	Noriko	ILS	Expert workshop leader Moderator
Pensa	Stefano	SiTI	Activity 1: HS/LD integration
Profice	Emanuele	Autorità Portuale di Genova	Knowledge and data transfer
Rosa	Andrea	SiTI	Activity 1: HS/LD integration Activity 3: EXPO case study
Satzinger	Thomas	Verband Region Rhein-Neckar	Action leader, Activity 2: IITT

Endnotes

1 With this kind of timetable the service pattern repeats itself throughout the day so that services from an origin to a destination are always departing or arriving at the same minute past the hour (e.g. 8:05, 9:05, 10:05 and so on), the half hour etc. Train services call together at key stations and depart after a time sufficient for travellers to transfer to a different train service. That results in memorable timetables and high connectivity among locations.

2 Length of lines or of sections of lines on which trains can run at 250 kph or more at some point during the journey (EU, 2014: 78).

3 With this kind of timetable the service pattern repeats itself throughout the day so that services from an origin to a destination are always departing or arriving at the same minute past the hour (e.g. 8:05, 9:05, 10:05 and so on), or the half hour etc. Train services call together at key stations and depart after a time sufficient for travellers to transfer to a different train service. That result in memorable timetables and high connectivity among locations obtained with connections.

4 People going by plane to an airport to catch another plane and go to a different destination.

5 ETIS+ was a project funded by the EC through the 7th FP for research with the aim of building a European database on the flow of goods and people.

6 A study of the European Commission (Steer Davies Gleave, 2006) proves that if the travel time difference between air and plane is around 2-3 hours the train market share is bigger than 50%. Another study (Cascetta et al., 2001) states that travel time elasticity decreases if travel time is less than 1 hour or more than 3.5 hours.

7 The number of bed places in a tourist accommodation establishment is determined by the number of persons who can stay overnight in the beds set up in the establishment, ignoring any extra beds that may be set up upon customer request. Source: http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Bed_places (accessed 20 February 2015).

8 As mentioned before, EXPO event will impact particularly on tourism market.

9 The computation of connections is based on data retrievable on rail operators' websites in Lombardy (Trenitalia – www.trenitalia.com and Trenord – www.trenord.it), during a standard working day in mid-week in April 2014, and does not consider all the stops between an origin and a destination, but only the final destination.

10 It is worth pointing out that in this analysis were not be taken into account the travel costs and the altimetrical features of the routes.

11 Lacking Eurostat data, with reference to some rural districts in Germany and all Swiss cantons, have been filled through other specific sources of reference (Federal Statistical Office for Germany and the Swiss Statistics Portal).

12 The basin integrations take into account the 3 High-Speed stations in Milano as possible nodes of exchange and the minimum travel time, but do not consider all the other stations that are in Milano city (such as Porta Genova, Lambrate, etc.).

13 The road network, having a more capillary distribution throughout the territory compared to the rail network, and without particular restrictions on use, allows a greater accessibility, also to the most remote areas, and seamless travel. As a consequence, to be able to compare the two scenarios of accessibility, by rail and by road mode, some parameters of reference were defined in order to somehow equalize the two layouts and then compare them with. First of all, the choice of aggregating the rail accessibility of the four stations of Milano (as referring to one point of access so as done for road mode) and then the election of a limit of 1 hour and 30 minutes as border line of car travel time.

14 ChronoMap is a fully plug&play MapInfo Professional add-on for creating, analysing and combining proximity maps (isochrones, catchment areas, sectors, etc.).

15 Trenitalia is the incumbent rail undertaking in Italy. Provision of rail services on long distances is on a commercial basis but the only new entrant active at the time of writing is NTV which operates mostly on high-speed lines and, anyway, on lines different from those linking Genoa and Milan.

16 From June 2014 till June 2015 the travel time is 4:03 hours due to operational constraints.

17 A "train on-top" means extra trains in addition to the ordinary services of the ITT-scheme and trains that do not stop so often and mainly serve bigger metropolises. The idea behind is to save travel time and thus makes the train more competitive with the airplane.

18 Travel time effects for the node of Milano are a rough estimation of time saved for not entering Milano Centrale Station. Detailed savings depend also on the respective origin/destination of trains going through the node of Milano. On the route to Torino Italian operators use already the HS line whereas TGV trains from/to France still need to use the conventional rail line due to missing security equipment for the HS line and thus travel a longer time.

19 This year 2030 used as target for several forecasts and is justified that additional measures are expected to be realised by then.

20 Meeting with SMA rail consultants in Zürich in May 2014.

21 The idea of a "Verkehrsverbund" corresponds to "Agenzia per la Mobilità Metropolitana" for Italy, "Syndicat des Transports" for France and "Stadsregio" for the Netherlands.

22 National Express targets Spanish high-speed rail, Global Rail News, 22 April 2014, http://www.globalrailnews.com/blog/2014/04/22/national-express-targets-spanish-high-speed-rail/?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A%20Railco%20%28rail.co%29 (accessed 16 December 2014).

23 Otro año sin competencia en la alta velocidad española, El Mundo 24 November 2014, http://www.elmundo.es/ecnoia/2014/11/24/5472187122601d29698b457a.html (accessed 23 January 2015).

24 Railway Hub Cities and TEN-T network (http://www.railhuc.eu/ accessed 29 January 2015)

25 Rail Hub Cities for South-East Europe (http://rail4see.eu/, accessed 29 January 2015)

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