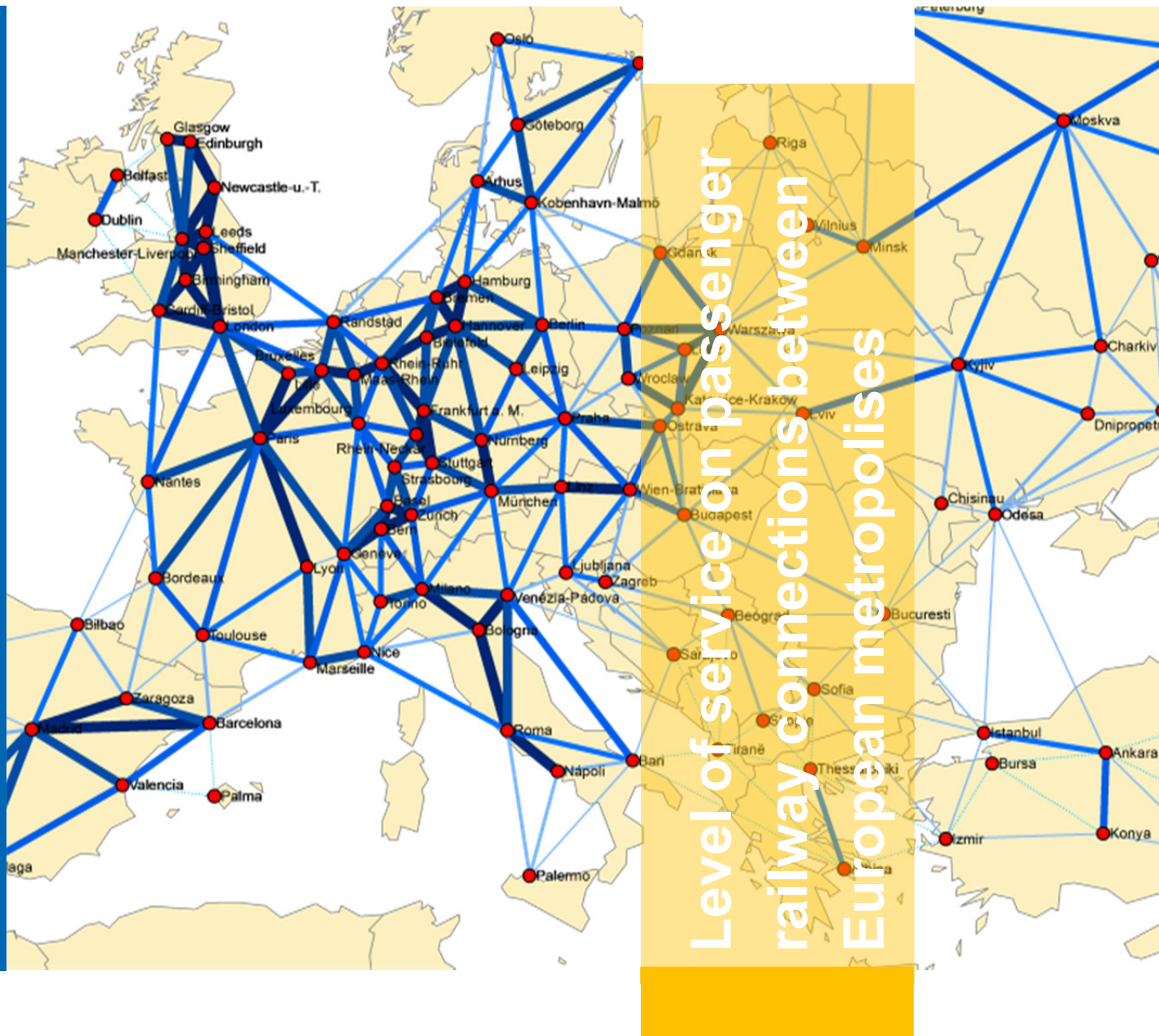


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Level of service on passenger railway connections between European metropolises

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LIST OF ABBREVIATIONS

BBSR	<i>Bundesinstitut für Bau-, Stadt- und Raumforschung</i> (German: Federal Institute for Research on Building, Urban Affairs and Spatial Development)
ESPON	European Spatial Planning Observation Network
FGSV	<i>Forschungsgesellschaft für Straßen- und Verkehrswesen</i> (German: Research Association for Roads and Traffic)
HSR	High Speed Railway
LUZ	Larger Urban Zones
Maas-Rhine	Metropolis consisting of Aachen, Liège and Maastricht (ALMA)
Randstad	Metropolis consisting of Amsterdam, Rotterdam and The Hague
Rhine-Neckar	Metropolis consisting of Mannheim, Ludwigshafen and Heidelberg
Rhine-Ruhr	Metropolis consisting of Cologne, Düsseldorf, Dortmund, etc.
RIN	<i>Richtlinien Integrierter Netzgestaltung</i> (German: Guidelines for the Development of Integrated Networks)
TEN-T	Trans-European Transport Network
UK	United Kingdom

ABSTRACT

In Europe the quality of railway lines varies strongly, as there are regions with very high levels of services between metropolises, and others with very few and slow connections. This study illustrates a comprehensive analysis of the railway connections between the main urban centres in whole Europe. The main factors in assessing the level of service of passenger railway connections are speed, frequency and the lack of need to change trains. In a first step the most important European metropolises based on population and metropolitan functions are selected for the study. On the basis of these nodes in a second step the most relevant connecting lines between neighbouring metropolises are identified. In a third step these connections are analysed with regard to frequency based on the number of trains per day, whereas the beeline speed along these lines is assessed on maximum and average speed including calculations for transfers.

The analysis of the level of services resulted in 6 quality categories and showed that the highest quality of passenger railway connection can be found in Switzerland and in some parts of Germany and the UK. Further very high levels of service are present in Austria, Italy, Belgium, France and Spain. The connections in Switzerland and the UK are served very frequently but with not that high average speed. The Spanish and French metropolises are connected very fast but not that frequently. Italy has both fast and frequent lines, whereas Germany has a great variety of types of connections. In general the international lines crossing boundaries have significantly worse levels of service, only Paris, Brussels and Strasbourg are linked to neighbouring countries in a high quality. Mountains and break of gauge play the key role in limiting levels of service of international railway connections. The Baltic States stand out with very low levels of services although having favourable topographic conditions.

1 INTRODUCTION

In many parts of the world passenger rail transport has an increasing role in long and mid distance transport. Especially in connecting large metropolises many new high speed railway (HSR) lines had been constructed in the last decades. In Europe the quality of railway lines varies strongly, as there are regions with very high levels of services between metropolises, and others with very few and slow connections. In various countries high speed lines are under construction. In some countries new private companies started to offer new train offers, like on the Italian and Austrian main lines and between Cologne and Hamburg, raising the level of service. This paper presents a comprehensive European-wide assessment of the level of service of passenger railway between metropolises. Recently two papers on the impact of high speed rail on cities and metropolises and its network were published, showing an influence of railway connections on the European urban hierarchy (Mazzeo, 2012; Garmendia et al., 2012). Most high quality railway services are located within national countries and as Ureña (2012) stated: “HSR has not yet had a major role in international inter-metropolitan passenger transport. The current usage of international HSR is not satisfactory”. Apart from the exemplary connections between London, Paris, Brussels and Amsterdam, there are several other potential international interurban lines in Europe like Madrid – Lisbon, Lyon – Milan, Berlin – Warsaw, Berlin – Copenhagen and Munich – Vienna (Ureña, 2012).

2 METHODOLOGICAL APPROACH

This paper aims to present a comprehensive analysis of the railway connections between the main urban centres in whole Europe. The main factors in assessing the level of service of passenger railway connections are speed, frequency and the number of transfers. The methodology strongly focuses on a network approach of linking neighbouring European metropolises and not on a corridor approach still eminent in the TEN-T (Trans-European Transport Network) core network concept (European Commission, 2012, 2011).

On a European scale there is no such analysis of the level of service, i.e. the supply side, of the passenger railway connections, but various studies on general accessibility (e.g. ESPON, 2010; European Commission, 2010). Regarding railway accessibility in Europe there are a lot of papers, which deal with this in a way of considering population or economic catchment areas at the scale of the whole continent (e.g. ESPON, 2006, Gutiérrez et al., 1996; Bruinsma and Rietveld, 1998). Here instead, we deal with the accessibility between neighbouring metropolises in the sense of quality of service, thus speed and frequency. In the mid-90s two rudimentary and basic studies about the level of service and the quality of rail networks were published (Milan, 1996, 1997). They analysed the average train speed and schedule delays on rail connections between main cities in Central and Eastern Europe and defined three levels of service quality. Both studies just focus on speed and not on frequencies, are geographically limited and only compare networks rather than explicit connections between pairs of urban centres.

Our methodology is based partially on the German “Guidelines for the development of integrated networks (*RIN*)” which are used to compare levels of service between cities and towns in public and individual transport. The levels of service in these guidelines are very detailed and based on beeline speed, local entry times, directness factors, numbers of transfers, frequency and reliability (Friedrich, 2006; FGSV, 2008). Starting from Germany the RIN were also used for assessing the quality of services to adjacent metropolis in neighbouring countries (Spangenberg and Pütz, 2002; Bäuerle et al., 2007). Another systematic study delivered a comparison of the connection quality of German largest cities (Voskamp, 2002), which is also based on beeline speed and train frequencies. Recently a study on the evaluation of regional accessibility in long-distance rail passenger service was published (Bunge, 2011, 2012), which tries to give a comprehensive analysis but has some methodological weaknesses, as it does not consider the beeline distance in the speed calculations, but the track distance. For the passengers it does not matter whether the speed is increased by higher track speeds or by less curves due to rebuilding of tracks. Furthermore the speed analysis of named study includes a comparison with car transport speed, which is also questionable as for an analysis of railway quality not only car transport is essential, but also air transport, as described widely (e.g. Dobruszkes, 2011). Furthermore, an analysis of regional connectivity between various regions should rather compare intramodally and not intermodally. Buthe et al. (2012) analysed the connection quality within the TEN-T core network, assessing both car and rail transport, but regarding rail just focused on the fastest connection between metropolises. This means, the more important average travel time of all daily connections was not considered and even more critical when analysing the level of services, the frequency i.e. the number of train per day was not included.

Thus, our paper tries to give a clear, comparable and transferable methodology in assessing the level of service between European metropolises as a way of analysing the quality of a network.

3 SELECTION OF METROPOLISES

The first step in assessing the quality of a network consists in the selection of the area which is relevant for this study. As we did not want to limit our analysis to the EU, we took a broader view and included all countries entirely and partly lying in Europe, thus including whole Turkey, southern Caucasus (Armenia, Azerbaijan and Georgia) and the European part of Russia. These countries are part of European political organisations as the Council of Europe, whereas the Asian part of Russia was left aside in order to limit the geographical area.

The second step leads to the selection of the nodes, i.e. the selection of the metropolises. As each of the countries of Europe has an own concept of classification of important cities with different naming like agglomeration, conurbation, metropolitan area or metropolis, we took as a starting point the Eurostat concept of *Larger Urban Zones* (European Commission, 2007). This concept of the European Commission's Urban Audit of 2004 and 2007 is an effort to harmonize definitions of urbanisation in the EU and most other European countries. Though not perfect, this is the only pan-European methodology to define and limit urban areas. For our purpose we started with the mere look on the number of inhabitants in these Larger Urban Zones (LUZ). As the LUZs were not applied in Russia, Ukraine, Belarus, Georgia, Armenia and Azerbaijan, for these countries we took the average of the population figures in the agglomerations based on the main relevant city statistics of world-gazetteer.com, citypopulation.de and en.wikipedia.org. Firstly, we selected all LUZs with a population of more than 1 million inhabitants.

In order to base the selection process not only on the number of inhabitants, we also included cities with a population of less than 1 million but with strong metropolitan functions and thus important for a territorial structure of transport networks. The following considerations are leading to a list of 116 entities, which we call metropolises, and are shown in Figure 1.



Fig. 1: The 116 European metropolises

In 2011 the German Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) published a study on *Metropolitan areas in Europe*, where metropolitan functions were defined and measured on the base of politics, economy, science, transport, and culture (BBSR, 2011). This evaluation ranges from 0 to 100 for London with the highest index of metropolitan function in Europe. Having this in mind, we added LUZs with a population between 500,000 and 1 million, if they have a strong metropolitan function with an index larger than 7.5, adding LUZs like Strasbourg, Edinburgh, Basel and Bologna. Furthermore all LUZs with a strong political metropolitan function (political index > 2.5) were included leading to the addition of spatially important LUZs like Vilnius, Bilbao, Tirana, and Geneva. Lastly, in order to avoid territorial gaps and ensure a cohesive territorial structure, we also picked out LUZs with a medium metropolitan function (index > 2.5) but a distance of more than 150 km to the nearest already selected LUZ, thus including LUZs like Bordeaux, Leipzig and Palermo. If two or more LUZs are forming a single metropolitan area within the BBSR methodology, these are combined, like it is the case with Manchester and Liverpool, forming Manchester-Liverpool or also Rhine-Ruhr, Randstad (Amsterdam-Rotterdam-The Hague), Katowice-Krakow, etc.

4 SELECTION OF ACCESS POINTS: METHODOLOGICAL APPROACH

The next selection process included the decision of choosing the access points in each metropolis. We selected all central long distance railway stations of a metropolis as access points and for each railway connection we selected the most convenient access point for each relation. To illustrate this, for the connection Paris – Bordeaux we selected Paris Montparnasse and for Paris – Luxembourg the station Paris Est as access point. Same applies for other monocentric metropolises with multiple long distance railway stations as Madrid, London or Budapest. In case of a polycentric metropolitan structure, we included also the long distance railway stations of those cities with a population higher than 50% of the primate city's population, both within its administrative borders. This means, e.g. for the metropolis Manchester-Liverpool, we not only selected Manchester's (458,000 inhab. in administrative border) long distance railway stations, but also those of Liverpool (435,000 inhab. = 95% of Manchester), but not those of Warrington with only 43% of Manchester's population. Same applies for polycentric metropolises as Rhine-Ruhr, Randstad, Copenhagen-Malmö, Rhine-Neckar, Bristol-Cardiff, Venice-Padua and Maas-Rhine. Due to territorial and political functions in two cases this 50%-rule was not followed strictly, which are Krakow-Katowice and the binational metropolis of Vienna-Bratislava, where Katowice and Bratislava were included although having less than half of its primate cities population.

5 SELECTION OF CONNECTION LINES

In order to systematically create a grid of connections between these access point on a next-neighbouring basis, the mathematical method called triangulation was selected and performed with the Geographic Information System. The triangulation links the given access points in a manner that leads to a grid of triangles formed by the connections, with no crossings of lines and, most importantly, that the variance of the area of the triangles is minimal. This means, the triangulation tries to construct triangles with as similar size of areas as possible. This methodology of triangulation also implies that important connections between non-neighbouring metropolises like Paris – Randstad and Zurich – Frankfurt are not included directly, as this study focuses on the connection quality between next-neighbouring metropolises, which is most important in order to create a continuous railway network instead of long corridors. The resulting net is shown in Fig. 2.

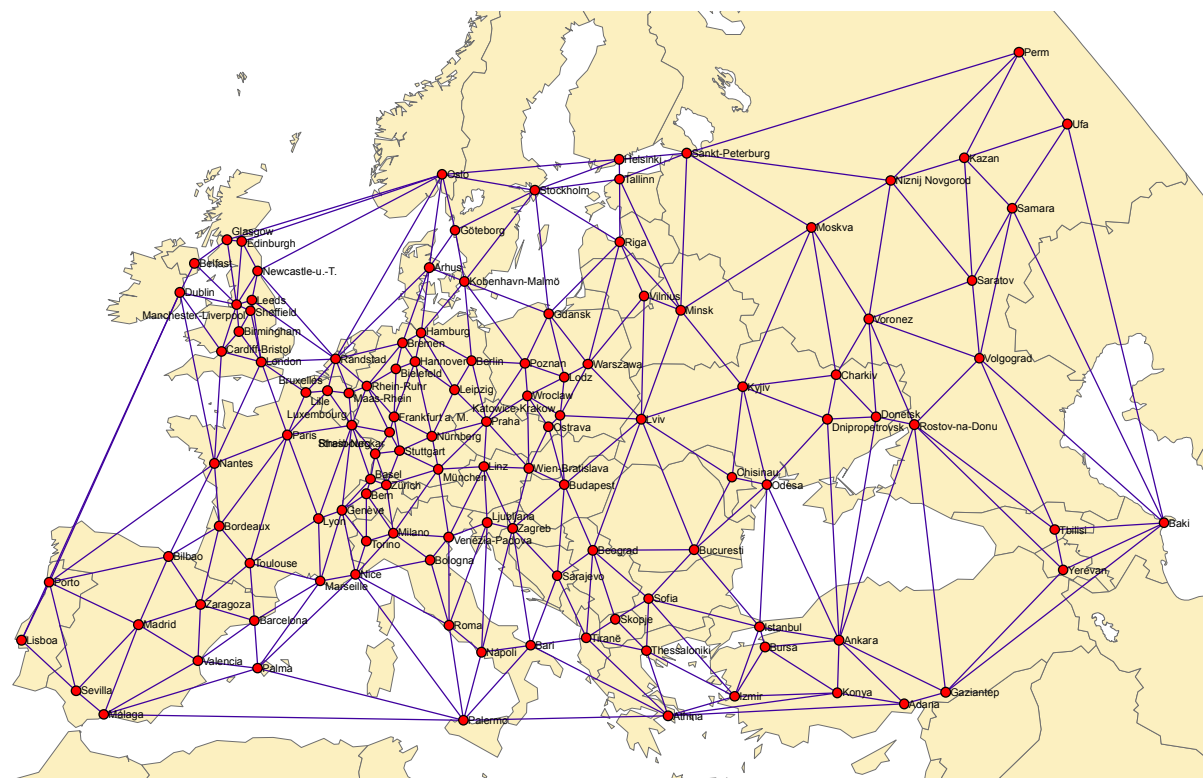


Fig. 2: The network based on triangulation

As the triangulation also created connection lines at the edges of the study area, some very long lines as Málaga – Palermo, Palermo – Athens, Stockholm – Helsinki or Edinburgh – Oslo, were deleted for practical reasons. Most of these connections could be done by train but travel journeys are not really realistic as they imply huge detour factors. In some cases the mathematical triangulation produced connection lines between cities which were obviously less important than the potential crossing line. For example the triangulation produced the link Porto-Seville instead of Madrid-Lisbon, where obviously the latter is more important. We defined a relation as more important if a capital city is included in the connection and changed this in those cases when the new connection was nearly equidistant as the original one. The average length of the 306 connections between the metropolises is 321 km, ranging from 47 km (Leeds – Sheffield) to 1493 km (St. Petersburg – Perm). The resulting modified network is shown in Fig. 3.



Fig. 3: The 306 connections after network modifications

The only transport mode we have selected are the regular scheduled passenger railway lines including real passenger railroad ferries, where railways are transhipped. These are Puttgarden-Rødby (Germany-Denmark), Sassnitz-Trelleborg (Germany-Sweden), Messina-Villa San Giovanni (Italy) and Tatvan-Van on Lake Van (Turkey).

However, some European metropolises are not connected to the European railway network by regular trains:

- Ireland and Mallorca are the only islands with metropolises which are not connected to the rest of Europe by railways or railroad ferries.
- The Albanian passenger railway network hosts the metropolis of Tirana but has only freight railway connections to Montenegro and thus is not linked by passenger rails to other metropolises.
- On 11th of February 2011 the Greek government has cut off all international passenger lines, leading to the situation that Athens and Thessaloniki are no longer connected by rail to the rest of Europe.
- Although having a good urban rail network, Bursa in north-western Turkey with almost 2 million inhabitants is the only European metropolis which is not connected to the long distance railway network. Constructions for a high-speed line between Bursa and the Ankara-Istanbul line have started in 2012 and are planned to be completed in 2015, expanding the rapidly growing Turkish high-speed network.
- Due to long-term engineering works west of Gaziantep in south-eastern Turkey this metropolis is temporarily not connected to the other Turkish metropolises.

Since 1993 the Armenian-Turkish cross-border railway line is out of use due to political reasons, leading to a missing link between Turkey and the southern Caucasus. However a new line between Kars in north-eastern Turkey and Akhalkalaki in southern Georgia is under construction and is planned to be opened in late 2014.

6 NUMBER OF TRAINS / FREQUENCY

The first criterion for the assessment of the quality and level of service between metropolises is the number of trains per day, i.e. the frequency. For the data collection we selected Tuesday, the 20th of March 2012, in a 24h time frame from 3 a.m. to 3 a.m. of the next day. As timetable sources we used mainly the www.bahn.de homepage of the Deutsche Bahn (German Rail). As not all connections are included on www.bahn.de, we used www.ose.gr for Greece, www.railway.ge for southern Caucasus and seat61.com for some connections in the Baltics and Turkey.

Within this 24h time period we chose every possible railway connection on one direction between the two metropolises, be it high-speed, standard or local train, which is not overtaken by a connection with a later starting time. We just selected one direction, although having in mind that not every connection is paired. In some minor cases more train connections do exist from A to B, than from B to A - same applies for travel time and speed. The possible links also include connections with change of train en route. Connections with a long night-time waiting time at a transfer station of more than 30% of the total journey time were excluded, in case these are not the only connection, i.e. there exist normal evening and morning connections. This is often the case when from A you can take the last local train to a station en route and wait there overnight for the first local train to get to B. We did not consider the number of seats in the trains for the assessment, because we took a look from the traveller's perspective, for whom the number of trains per day is more important than the number of seats. Figure 4 shows the number of trains between the European metropolises. The darker and thicker the lines are, the more trains per day do exist. Figure 4a shows an enlargement of Central Europe.

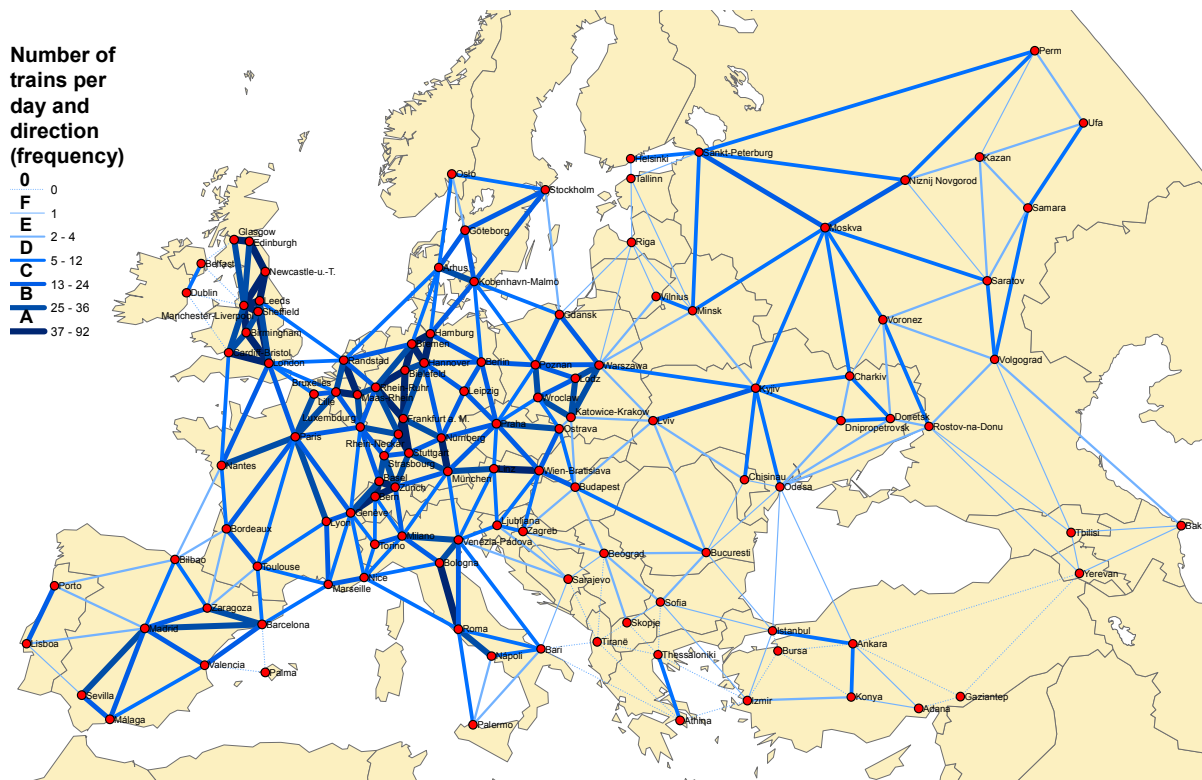


Fig. 4: Number of trains on Tuesday, 20th of March 2012, from 3 a.m. to 3 a.m. next day

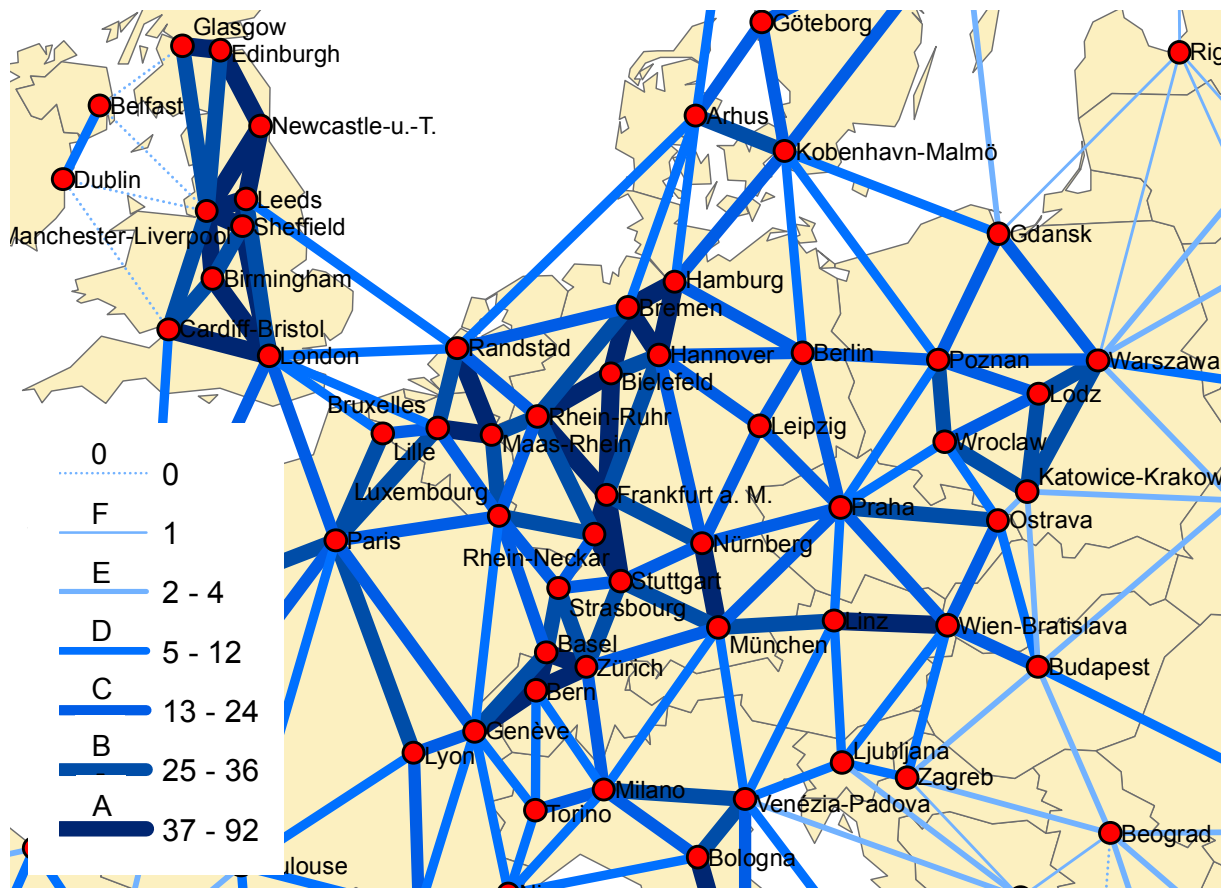


Fig. 4a: Number of trains on Tuesday, 20th of March 2012, from 3 a.m. to 3 a.m. next day
(Central Europe)

We classified the number of trains per day into categories of A to F. Each category has a similar number of entries. A stands for 37-92 trains per day and F for 1 train per day. Assuming equal distribution of trains around 24 hours, category A represents at least one connection every 40 minute. In case of no train connection the connection is dashed and named with 0. The connections with the most number of trains between metropolises are shown in Table 1.

Table 1: Connections with the highest frequencies

Connection	Trains per day	Category	Connection	Trains per day	Category
Basel – Zürich	92	A	Linz – Vienna-Bratislava	60	A
Rhine-Neckar – Frankfurt	79	A	London – Birmingham	56	A
Bern – Zürich	74	A	Sheffield – London	53	A
Basel – Bern	72	A	Rhine-Ruhr – Bielefeld	52	A
Edinburgh – Glasgow	66	A	Manchester-Liverpool – Birmingham	52	A
Manchester-Liverpool – Leeds	63	A	Bern – Geneva	51	A

First you can see that all the top connections regarding frequency are national connections within one country. An impressive number of 92 trains per day connect Basel and Zürich. The Swiss triangle of Basel-Zürich-Bern as well as the connections from Rhine-Neckar (Mannheim-Ludwigshafen) to Frankfurt in Germany and from Edinburgh to Glasgow in Scotland are served by most trains per day. While those connections are more a sort of short distance connections, the highest number of trains per day on longer, i.e. bee-line distance of over 150 km, sections are found between Linz and Vienna-Bratislava, London and Birmingham, as well as between London and Sheffield with 53 to 60 trains per day. The named Austrian main section is additionally served by a new private company next to the state railways since November 2011, explaining this high frequency.

Looking on the map, the highest frequencies can be found in Switzerland, the UK, western Germany and parts of Benelux, Austria and Italy. A large number of trains also connect Paris and Madrid to its neighbouring metropolises, as well as the metropolises in Central Poland, the Czech Republic and Italy north of Naples. Category C (13-24 trains/day) can be found in Russia and Ukraine as well as in the not mentioned regions of Central Europe apart from the Alps. In general the natural borders like the Alps and the Pyreneans and the artificial rail borders caused by the break of gauge can be observed well as they result in fewer numbers of trains.

Areas with very few trains per day include the Baltics with extremely bad rail links, the connections between Spain and Portugal, parts of the Balkans, southern Caucasus and parts of Turkey and Russia.

Looking just on international connection the top links are those in Table 2.

Table 2: International connections with the highest frequencies

International connection	Trains per day	Category	International connection	Trains per day	Category
Luxembourg – Maas-Rhine	32	B	Luxembourg – Rhine-Neckar	24	C
Basel – Strasbourg	31	B	Strasbourg – Zürich	24	C
Brussels – Paris	28	B	Rhine-Ruhr – Randstad	22	C
Munich – Linz	27	B	Bremen – Randstad	21	C
Stuttgart – Zürich	27	B	Brussels – Luxembourg	21	C
Brussels – Randstad	25	B	London – Paris	19	C

It can be stated that in general the international connections are served far less frequently than the national lines. Only six connections reach category B. Most of the high frequency international lines are situated along the densely populated borders between Benelux, France, Germany and Switzerland. Furthermore the connection from Munich to Linz is served by a high number of trains per day. The famous London – Paris connection is on 12th place with 19 trains per day in one direction.

Figure 5 shows the connections between metropolises of the European Union with the lowest number of trains per day. Thessaloniki – Sofia is the only intra-EU connection with no train services. Connections with just one train per day are located in the Baltics and between Lisbon and Sevilla. Further connection with very low frequencies of 2 daily trains can be found between Porto and Spain as well around the western slopes of the Pyreneans and along Bucharest – Sofia.

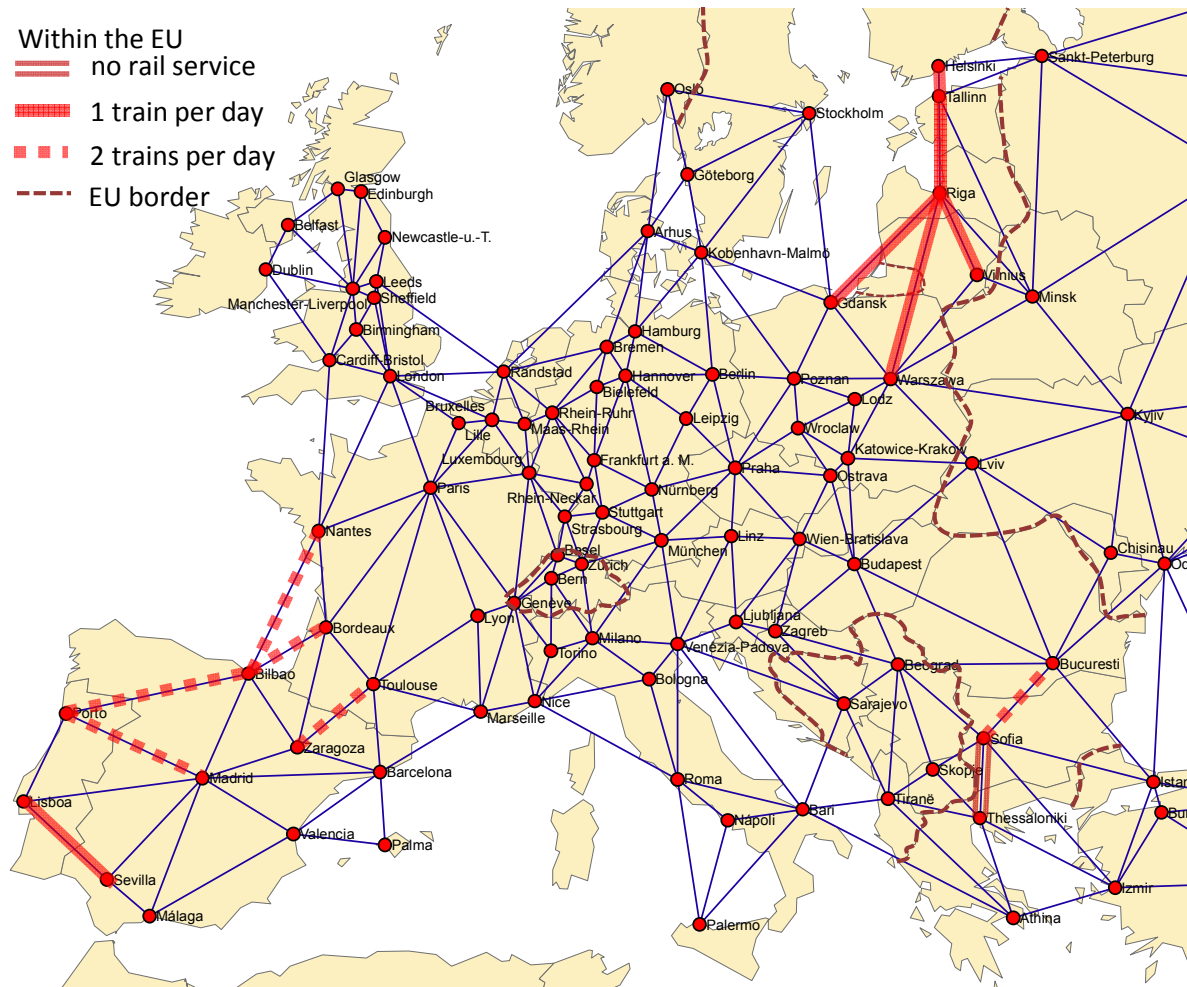


Fig. 5: The connections with the lowest frequencies within the European Union

Figure 6 shows the relation between distance and frequency of trains between two metropolises. As a weak tendency it can be said, that the more distant two metropolises are, the fewer number of trains are offered. Those connections with relatively high or low frequency according to their distance are labelled. The Swiss, Austrian, English, French, Spanish, Ukrainian and Russian main lines have very high frequencies with respect to their distance. All in all Figure 6 shows that distance is not a satisfying explication for frequency which is obviously more influenced by national railway policies.

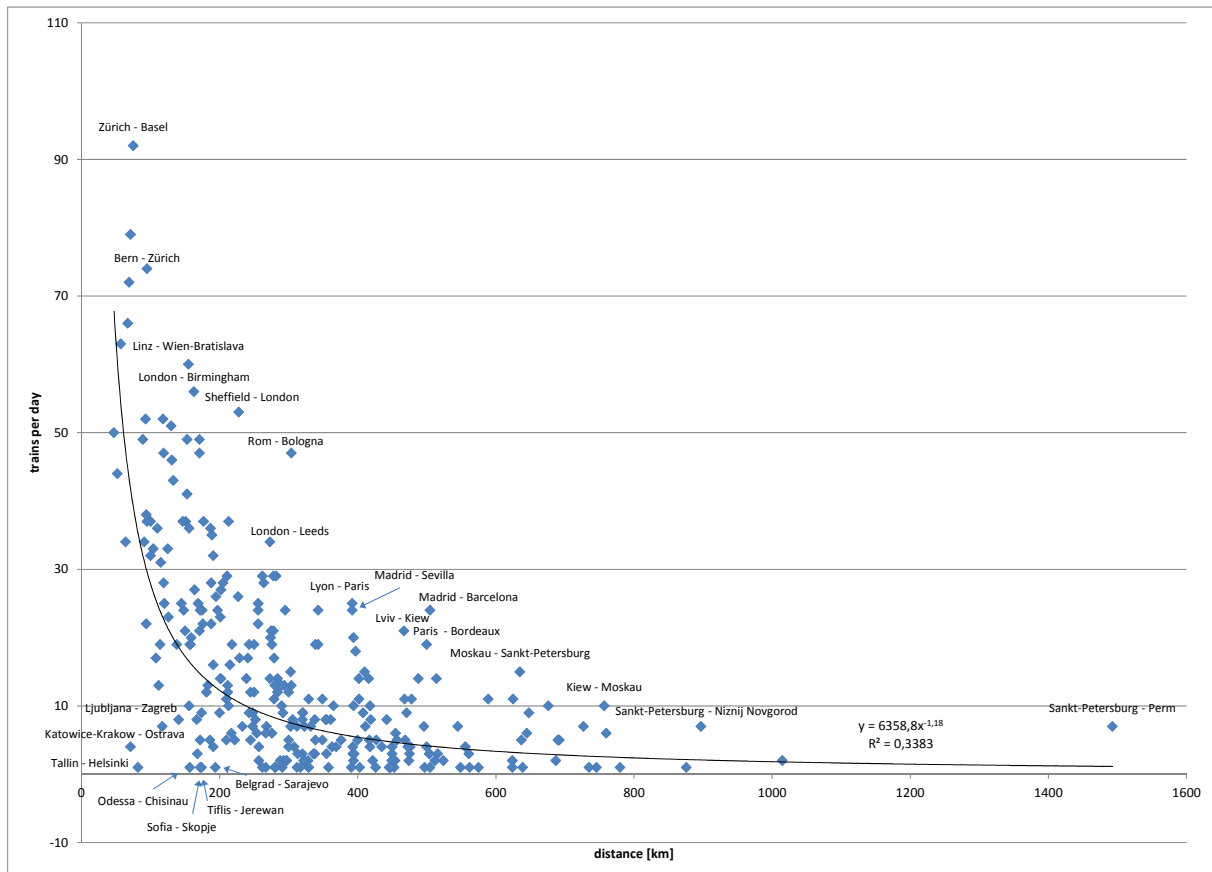


Fig. 6: Relation between distance and frequency

7 MAXIMUM BEELINE SPEED

The second criterion for the analysis is the beeline speed of the services between two metropolises. The beeline speed is calculated by dividing the beeline distance (linear distance) through the travel time (including the waiting time at possible transfers), looked up in the timetables.

In order to assess the infrastructure, in this step only the speed of the fastest connection, i.e. with the shortest travel time, is used and called the maximum beeline speed, thus showing the possibilities of each line and not the average travel time of it.

Figure 7 and 7a shows the maximum beeline speed of the 306 connections in Europe. The thickness and darkness of the lines represent the level of velocity between the metropolises.

maximum beeline speed

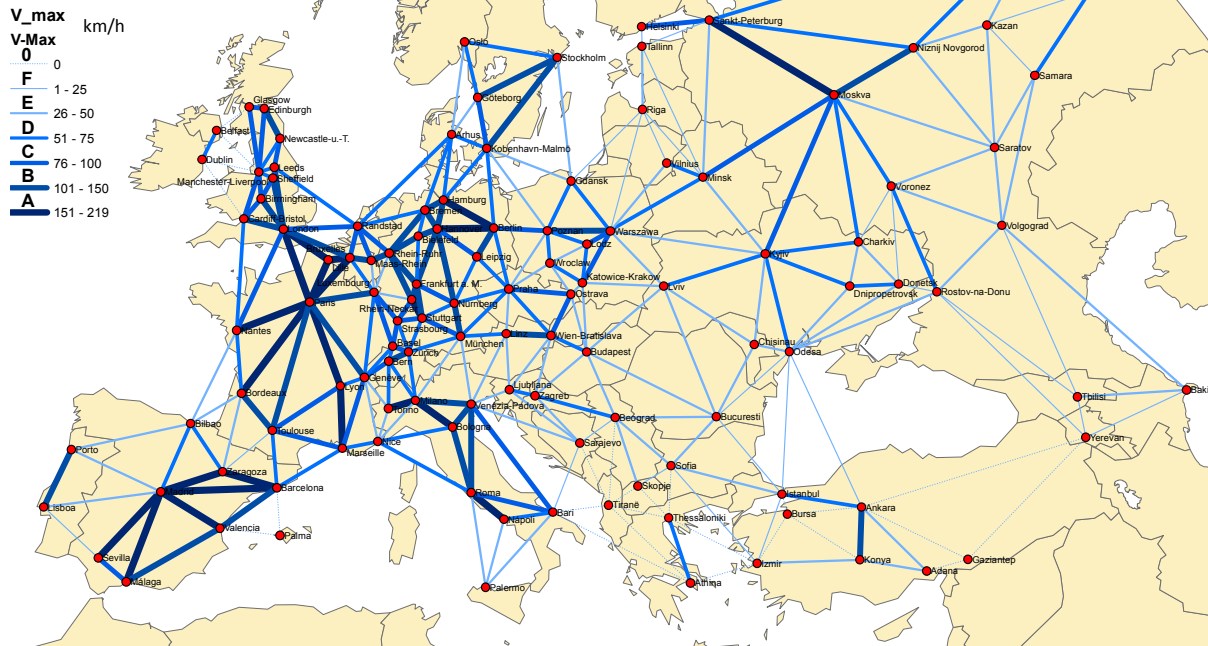


Fig. 7: Maximum beeline speed of the fastest railway connection on Tuesday, 20th of March 2012

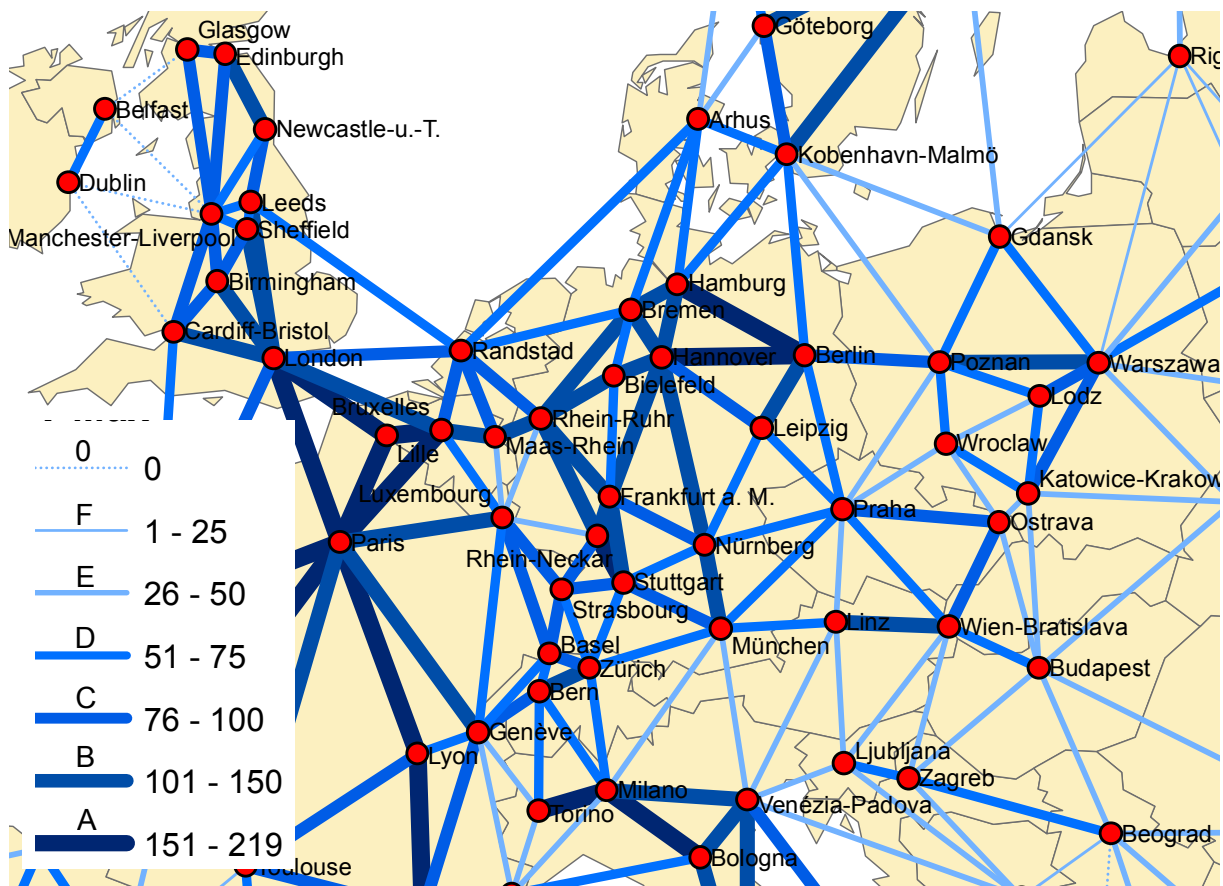


Fig. 7a: Maximum beeline speed of the fastest railway connection on Tuesday, 20th of March 2012
(Central Europe)

Again, we classified the level of service regarding maximum speed in categories of A to F. A stands for a maximum beeline speed of over 150 km/h, while F stands for a velocity of 25 km/h and below. If there are no trains the connection line is dashed and the category is 0.

The connections with the highest maximum beeline speed are shown in Table 3.

Table 3: Connections with the highest maximum beeline speed

Connection	Max. beeline speed (km/h)	Category	Connection	Max. beeline speed (km/h)	Category
Madrid – Zaragoza	219	A	Milan – Bologna	186	A
Madrid – Barcelona	202	A	London – Lille	178	A
Paris – Lyon	201	A	Zaragoza – Barcelona	173	A
Brussels – Paris	198	A	Málaga – Madrid	172	A
Paris – Lille	192	A	Milan – Turin	172	A
Madrid – Valencia	191	A	Lille – Brussels	171	A

The table and figure 7 shows clearly that expectedly the fastest connections between metropolises are found in Spain, France and Italy. Madrid and Zaragoza are connected by an impressive beeline speed of 219 km/h, i.e. the 274 km of distance are made in just 1h15min. Madrid is connected to all Spanish metropolises with a high level velocity of category A, except Bilbao in the Basque country. Similarly the French capital of Paris is connected to almost all neighbouring metropolises including Brussels and London with category A beeline speed. It is interesting to compare the results of the speed analyses with those of the frequency analysis of section 6. Those countries with very high frequencies like Switzerland and the UK have smaller maximum speed levels on their connections, while Spain and France have very high velocity results with lower number of trains per day. Italy also has several sections, like Milan – Bologna and Milan – Turin with very high maximum beeline speeds, but also impressive number of trains per day. In Germany only the comparably long distance connections from Berlin to Hamburg and Hannover have category A speed levels. A further A level speed connection is situated between Moscow and St. Petersburg in Russia. Apart from other main lines in Spain, France, Italy and Germany, category B (101-150 km/h beeline speed) regarding speed can be found in Sweden connecting Stockholm to Gothenburg and Malmö, in Turkey between Ankara and Konya, in Belgium between Brussels and Liège (Maas-Rhine), in Russia between Moscow and Nizhny Novgorod, in Poland between Warsaw and Poznan, in Portugal between Lisbon and Porto and in Austria between Linz and Vienna(-Bratislava).

Again the factor of mountains as the Alps and the Pyreneans and the break of gauge pose a clear limiting factor for the speed levels. Extremely low levels of speed are present on the railway lines connecting Latvia, Lithuania and Poland to each other. For the mere 262 km from Vilnius to Riga travel time is more than 14h with an overnight stop in Daugavpils. For getting from Riga, the largest Baltic metropolis, to the Polish capital with a distance of 562 km you have to travel incredible 26½ hours and change train four times. With a bit more than 20 km/h this represents one of the lowest beeline speed levels in whole Europe although lying in complete lowlands.

To give an overview about the international connections with the highest maximum beeline speed Table 4 is presented.

Table 4: International connections with the highest maximum beeline speed

International connection	Max. beeline speed (km/h)	Category	International connection	Max. beeline speed (km/h)	Category
Brussels – Paris	198	A	Paris – Geneva	132	B
London – Lille	178	A	Brussels – Randstad	99	C
Lille – Brussels	171	A	Marseille – Geneva	93	C
London – Paris	151	A	Luxemburg – Strasbourg	91	C
Brussels – London	139	B	Randstad – Rhine-Ruhr	89	C
Luxemburg – Paris	137	B	Berlin – Poznan	89	C

Unlike regarding the number of trains per day, where no international connection could be found in the top frequency lines, in the case of maximum beeline speed three international lines can be found in the top 12. These are the Thalys and Eurostar based connections Brussels – Paris, London – Lille and Lille – Brussels. London – Paris also narrowly enters category A. The only three lines with category B are Brussels – London and Paris – Luxemburg/Geneva. After those, there is quite a gap to the lines in category C, where five of them enter the top 12. These are four lines connecting France, Switzerland, Belgium, Germany and the Netherlands, as well as Berlin – Poznan, the fastest international Central European railway connection. Other international category C lines in Central and Eastern Europe are Minsk – Moscow, Kiev – Moscow, Helsinki – Saint Petersburg and Ostrava – Vienna-Bratislava.

Figure 8 shows the relation between the average and the maximum beeline speed of the connections. Only some relations can be found far from the regression line. On the one side there are short lines with many regional trains like Lille – Brussels or long lines with just few high speed trains, where the average speed is considerably lower than the maximum speed. On the other side, relations with exclusive use of high speed trains like London – Brussels or Konya – Ankara are marked with little difference between average and maximum speed.

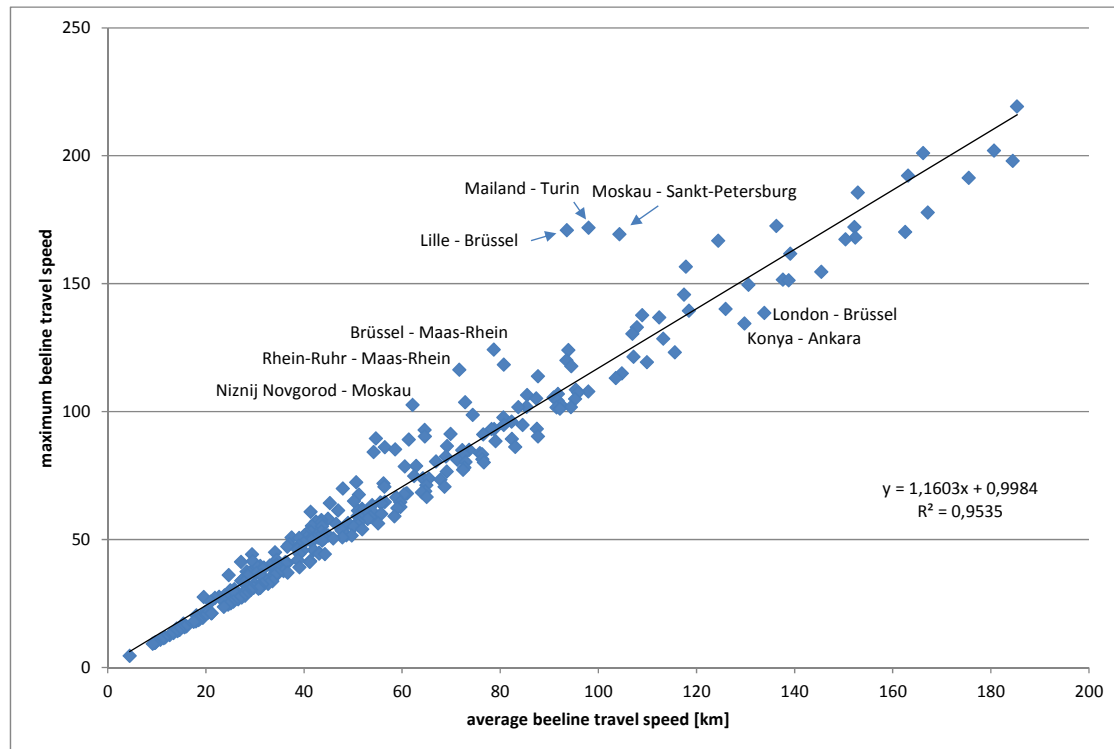


Fig. 8: Relation between average and maximum beeline speed

Table 5 and Figure 9 show the connections between metropolises within the European Union with the lowest maximum beeline speed (below 30 km/h). Sofia – Thessaloniki is the only mainland connection without train services. Tallinn – Helsinki had a speed of just 4 km/h due to extremely high detour factor around the Gulf of Finland. Gdansk – Riga has no geographical barrier but due to extremely slow rail connections, break of gauge and long waiting times at transfer point just reaches a maximum speed of 10 km/h (thus running would be faster!). As described above, the lowest speeds can be found in the Baltics and between Spain and France/Portugal. The low speed levels between Sweden and Poland are a result of high detour factors. The slowest national line is between Palermo and Bari mainly due to railway ferry use.

Table 5: Connection within the European Union with the lowest maximum beeline speed

Intra-EU connection	Max. beeline speed (km/h)	Category	Intra-EU connection	Max. beeline speed (km/h)	Category
Sofia – Thessaloniki	-	0	Stockholm – Gdansk	26	E
Tallinn – Helsinki	4	F	Gdansk – Copenhagen-Malmö	27	E
Gdansk – Riga	10	F	Bilbao – Bordeaux	27	E
Zaragoza – Toulouse	15	F	Bilbao – Nantes	28	E
Vilnius – Riga	18	F	Porto – Bilbao	29	E
Riga – Warsaw	21	F	Palermo – Bari	30	E
Lisbon – Seville	25	F			

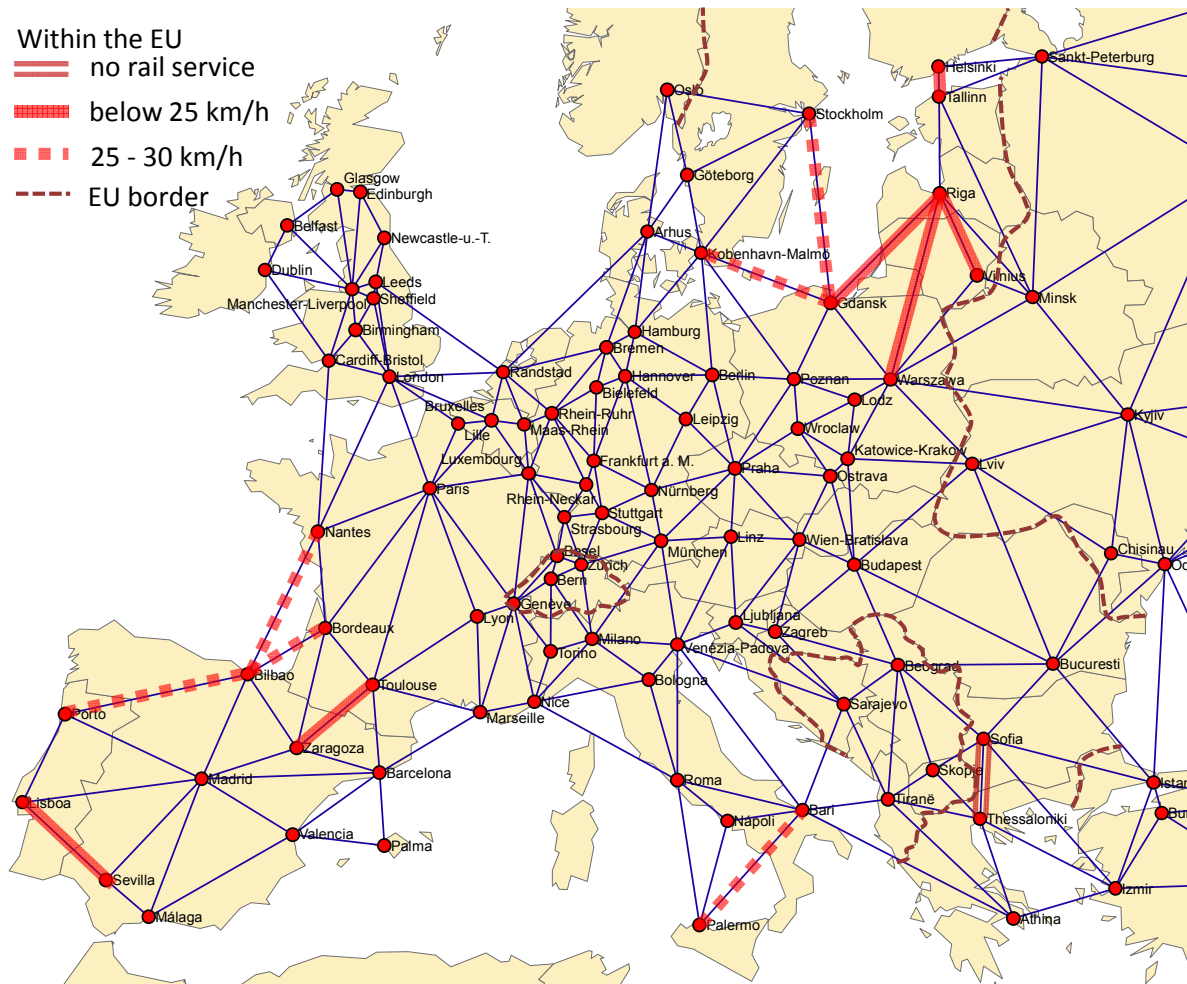


Fig. 9: The connections with the lowest maximum beeline speed within the European Union

Figure 10 shows the relation between distance and the maximum beeline speed between two metropolises. Compared to the distance-frequency relation of Figure 6, in this case virtually no tendency can be uncovered. One could even expect an inverse relation, i.e. connections with larger distance should have higher maximum speed levels. The graph shows that in every distance category there are both connections with very high maximum speeds and those with very low maximum speeds. The weak tendency of lower speed with higher distance can be probably fully explained with less infrastructure investments in sparsely populated areas.

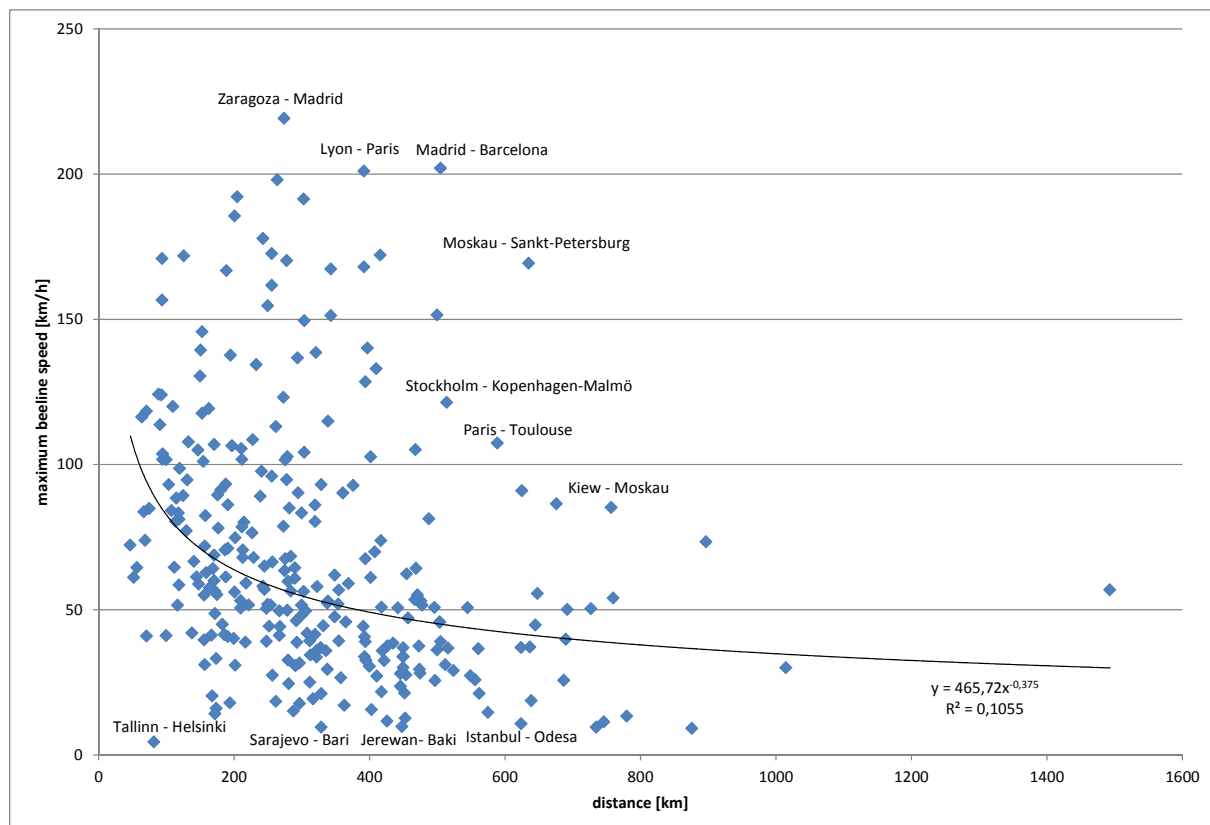


Fig. 10: Relation between distance and maximum beeline speed

8 MINIMAL NUMBER OF TRANSFERS

An additional criterion is the minimal number of transfers needed to get from one metropolis to another. Figure 11 shows the number of transfers between metropolises: the brighter and thicker the line, the more transfers are needed. For the data analyses only connections were taken into account which are not overtaken by a connection which started later at the leaving point. Furthermore, the connection with the minimal number of transfers is not always the fastest connection. Figure 11 shows that most metropolises are connected without need for change of train. Need for transfers are existent on connections across the Pyreneans and to a lesser level on some routes across the Alps. Quite many transfers are needed on more peripheral connections circumnavigating a sea, e.g. the Baltic, the Adriatic and the Black Sea. Connections with no geographical barrier but high number of transfers are found mainly between the Baltic States and Poland or Belorussia, as well as between

Porto and Madrid/Bilbao, Seville and Lisbon, Bremen and Randstad, Nice and Bologna. Again, connections with no trains are displayed by dashed lines.

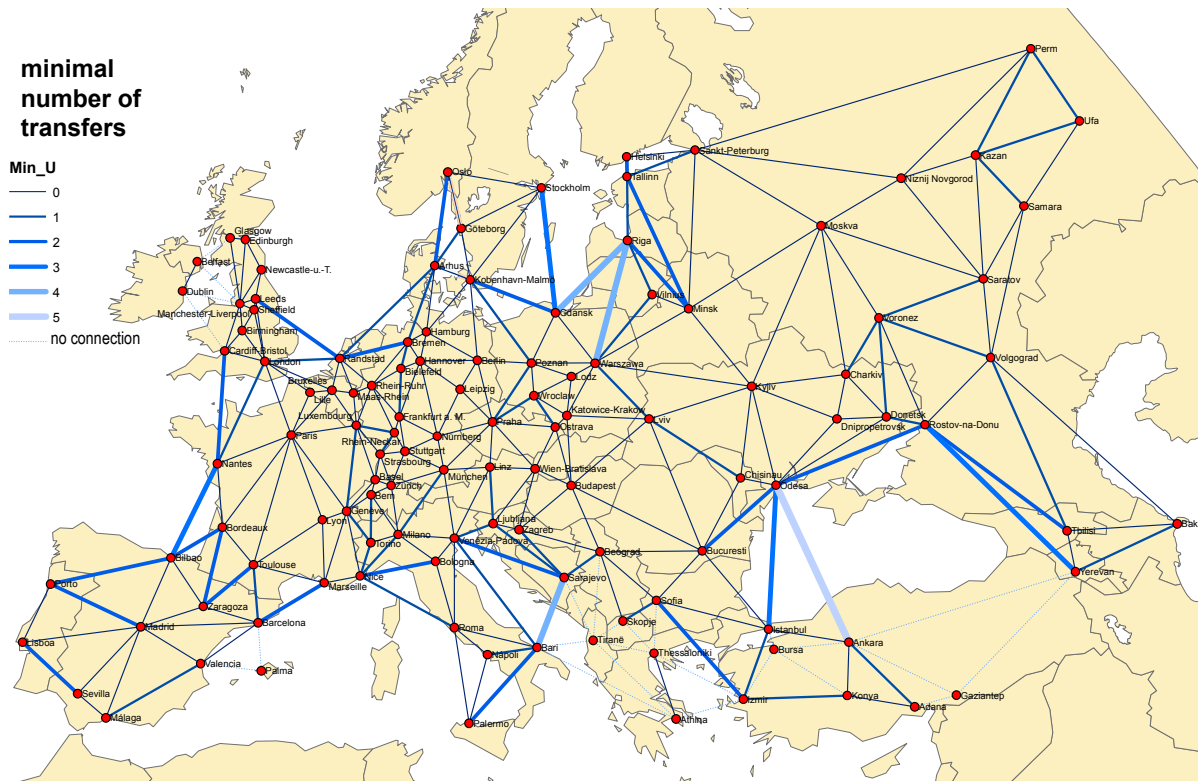


Fig. 11: Minimal number of transfers between metropolises on Tuesday, 20th of March 2012

The following Table 6 shows an overview of the minimal number of transfers on the European connections with existent services. More than 90% of the national connections are served without need of transfer. On the international connections only less than 50% are connected without need for changing trains. Relations with high number of trains (more than 30 per day) but need for one transfer are Bielefeld – Bremen and Bielefeld – Frankfurt. Bremen – Randstad is served by 21 connections per day but needs even 2 transfers (again excluding connections which are overtaken by trains with later departure).

Table 6: Minimal number of transfers necessary between metropolises

Minimal number of transfers	Number of connections	
	national	international
0	143 (90,5%)	60 (47,6%)
1	14 (8,9%)	36 (28,6%)
2	1 (0,6%)	22 (17,5%)
3 or more	0	8 (6,3%)

9 LEVEL OF SERVICE: OVERALL EVALUATION OF CONNECTIONS

In order to get a general analysis of the level of service between European metropolises, an overall evaluation was carried out. For a traveller the most important criteria are the number of trains per day, the overall travel time of the connections and the number of necessary transfers. Ticket prices are not included as these are hardly comparable internationally and price systems are different in each country. Number of seats per train, i.e. capacity, is also excluded, in order to take the individual passenger's point of view. As long as he or she can get a seat on the train it is irrelevant how many total seats the train offers. As only the level of service, i.e. the supply side, was analysed, we did not consider the passenger numbers, i.e. the demand side. A comparison of transport modes concerning travel times would have to include car travel as well as air travel. However, this has not been undertaken as in our study we want to assess the level of service of railway connections between each other, independently of the other transport modes. A further possible criterion is the real travel time and reliability, thus including delays, but due to lack of data and minor relevance this was not carried out.

For our overall evaluation we have chosen to look on the average speed and the frequency of the connections between the metropolises. We therefore multiplied the – below defined – average beeline speed with the number of trains per day. The main aspect of the multiplication is that it ensures that an additional slow train does not lower the overall value of the connection. If for example there are 3 connections from A to B, two of them with 100 km/h and one with just 10 km/h, then the average speed is 70 km/h and the overall evaluation – multiplying average speed and frequency – is $70 \times 3 = 210$. This value must be higher than in the case of just two trains with 100 km/h, where the overall evaluation leads to $100 \times 2 = 200$.

The two criteria, frequency and speed, are equally weighted as it subjectively depends on the traveller whether he prefers short travel times or high number of trains per day. In a further step these two factors could be weighted individually depending on passengers' preferences. A sensitivity analysis is discussed at the end of this section.

The average beeline speed is calculated by dividing the beeline distance by the average travel time. For this the gross travel time of each connection is calculated. It includes the time on the train plus the waiting time during possible transfers. Based on the German guideline of network planning (FGSV 2008) an entry and exit time of 21min is added to the travel time. Furthermore a so called transfer surcharge factor of 15% per transfer is added on the travel time to include the number of needed transfers in the overall evaluation. This is motivated by the fact that e.g. a 3 hours gross travel time with no transfer is more attractive than a 3 hours gross travel time with one transfer. 15% of gross travel time is seen as a realistic transfer surcharge, thus between A and B, a 3h trip with one transfer (180min+27min) is equally scored as a 3h27 trip with no transfer.

This resulting average beeline speed is then modified in order to get a distance dependent quality of speed. For connections with a larger beeline distance, higher speed is needed to get a high quality level. Figure 12 shows this distance dependence of speed quality based on the German guideline of network planning.

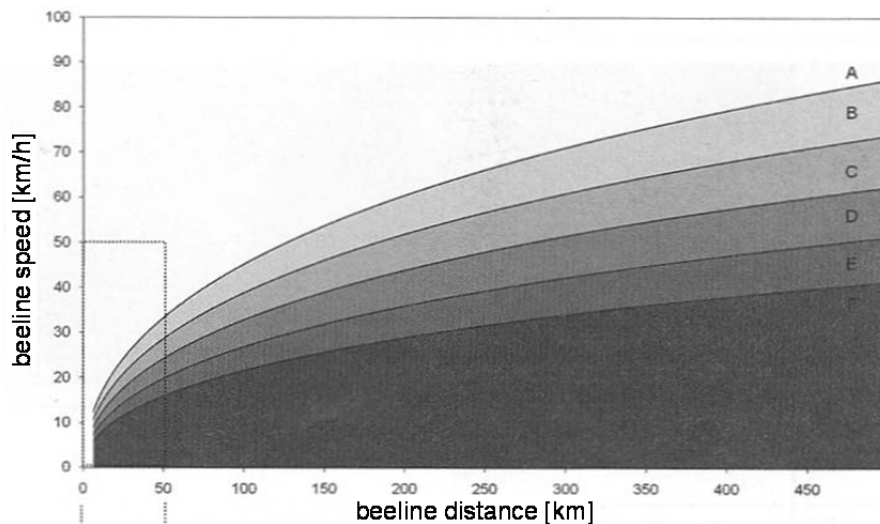


Fig. 12: Distance dependence of quality of speed (abstract value: A-F) on which the calculation is based on (FGSV 2008)

Expressed mathematically, the raw value for the extended quality of speed v_Q is represented by

$$v_Q = v \cdot (22 \cdot d^{-0,5} + 0.37)$$

with v as the gross average speed and d as the beeline distance. Table 7 below shows the abstract values of v_Q and its according categorisation. It must be stressed out that the value v_Q does not represent a speed in km/h, it is an abstract value including transfer surcharge, distance dependency and entry times, as described above.

Table 7: Categorisation of the extended abstract quality of speed

Extended quality of speed v_Q (abstract value)	Categorisation
>117	A
100-117	B
83-100	C
69-83	D
56-69	E
<56	F

Figures 13 and 13a shows the results of the overall evaluation of the connections between the European metropolises. Again, also the overall levels of service are put into 6 categories of A to F and 0 for no connection (dashed).

Quality of connections (overall level of service)

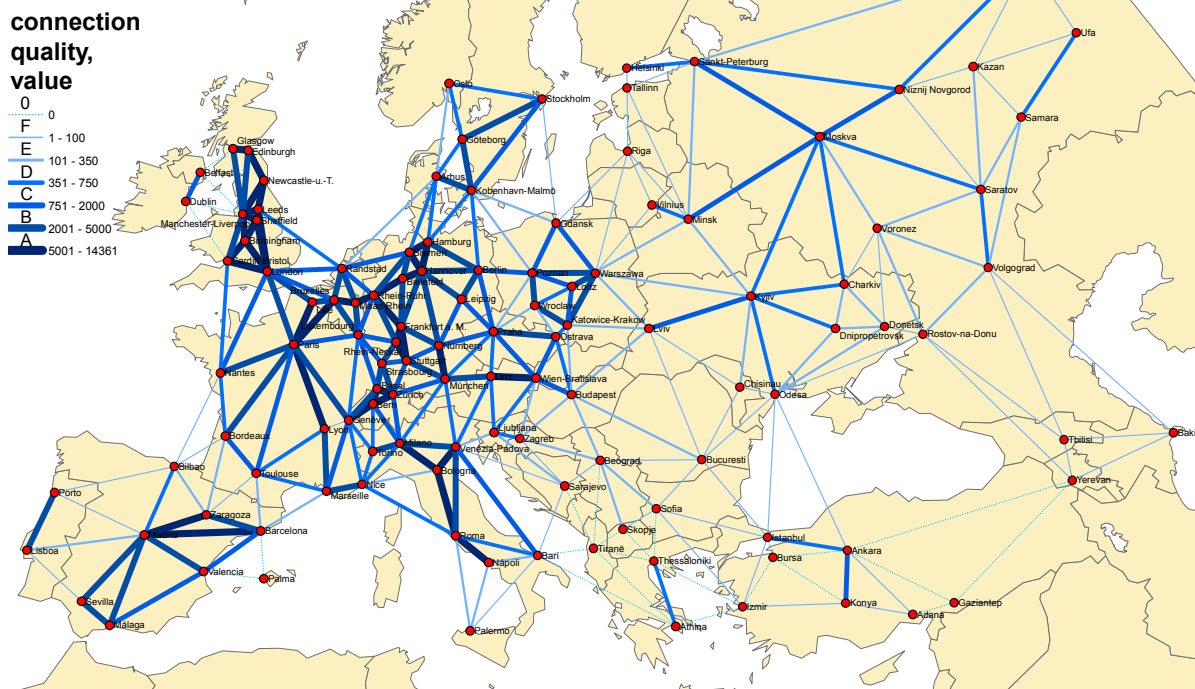


Fig. 13: Overall level of service based on average beeline speed and daily number of trains

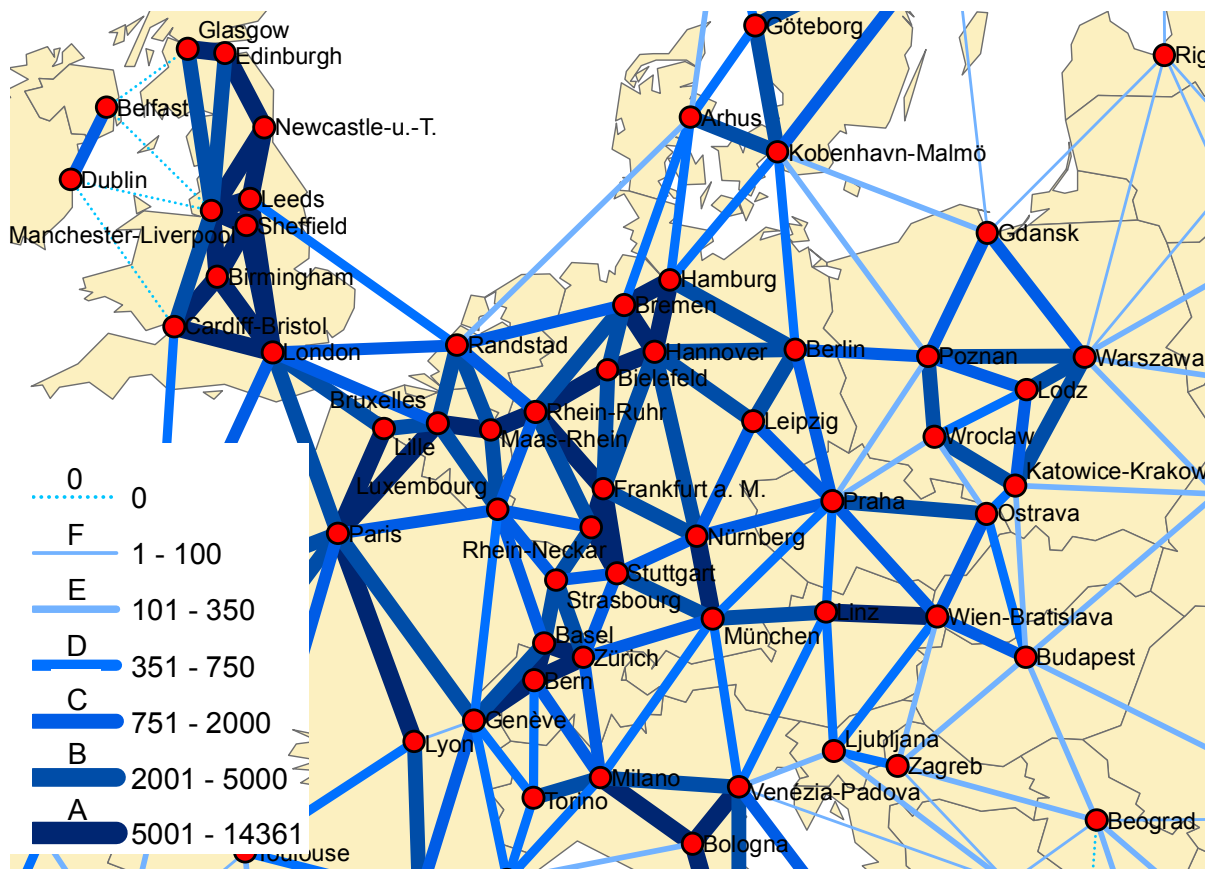


Fig. 13a: Overall level of service based on average beeline speed and daily number of trains
(Central Europe)

The highest level of service is found along the Basel – Zürich – Bern triangle and between Rhine-Neckar and Frankfurt as well as on the British lines of Edinburgh – Glasgow and London – Birmingham. Further high quality connections are in Austria, Germany, Italy and Belgium, as shown in Table 8.

Table 8: Connections with the highest level of service

Connection	Trains per day	Extended quality of speed (abstract value)	Overall level of service (abstract value)	Category
Basel – Zürich	92	A (156)	14361	A
Rhine-Neckar – Frankfurt	79	A (167)	13197	A
Bern – Zürich	74	A (161)	11915	A
Edinburgh – Glasgow	66	A (166)	10933	A
London – Birmingham	56	A (184)	10303	A
Basel – Bern	72	A (138)	9904	A
Linz – Vienna-Bratislava	60	A (163)	9784	A
Frankfurt – Rhine-Ruhr	49	A (192)	9389	A
Rhine-Ruhr – Bielefeld	52	A (178)	9235	A
Manchester-Liverpool – Leeds	63	A (143)	9033	A
Roma – Bologna	47	A (185)	8708	A
Brussels – Maas-Rhine	49	A (162)	7957	A

Several high level sections have a very high number of trains per day, like those in Switzerland and Rhine-Neckar – Frankfurt and the Scottish main line. Other top lines got into the top 12 with high modified average speed values, the so called quality of speed, like London – Birmingham, Frankfurt – Rhine-Ruhr and Roma – Bologna. Other connections with extremely high average speed values did not enter the top 12 due to low frequencies and are described below.

Further category A connections regarding the overall level of service can be found in the UK, in Italy, in Switzerland, in western parts of Germany and along Paris – Brussels/Lille/Lyon and Madrid – Barcelona/Zaragoza.

Apart from mentioned countries, category B connections do also exist along the main lines in the Netherlands, Poland, the Czech Republic, Denmark, Sweden and Portugal.

Category C lines, in above not yet named countries are from Moscow to Saint Petersburg, Niznij Novgorod and Minsk, from Ankara to Konya, from Kiev to Lviv and from Dublin to Belfast.

Figure 14 gives a good overview of the regions with levels of service in category A, B, C and D.

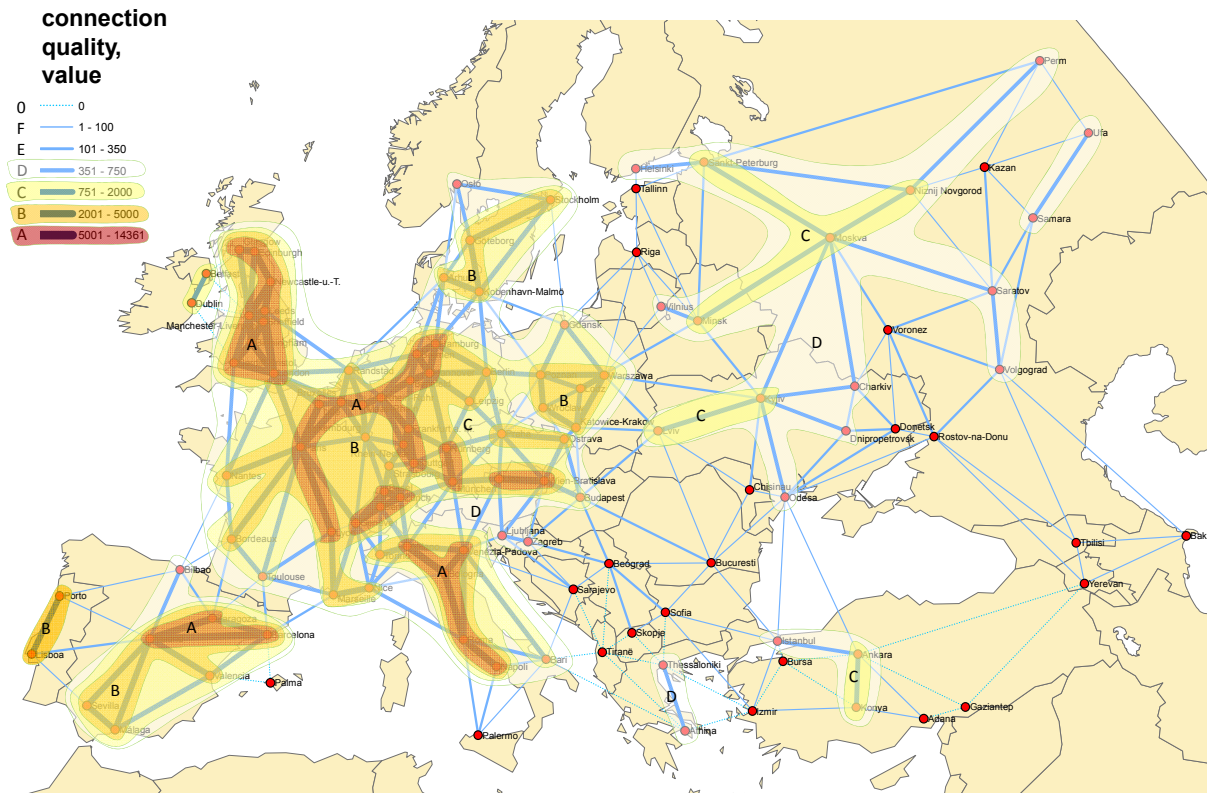


Fig. 14: Overall levels of service. Category A, B, C and D in colours

On international connections only one pair of metropolises is connected with category A, this is Brussels – Paris. Other top international sections are found in Table 9. Some connections have a very high number of trains but a low level of average speed, like Luxemburg – Maas-Rhine (Liège), whereas London – Lille is only connected by 9 daily trains, but with a very high quality of average speed.

Table 9: International connections with the highest level of service

International connection	Trains per day	Extended quality of speed (abstract value)	Overall level of service (abstract value)	Category
Brussels – Paris	28	A (249)	6977	A
Basel – Strasbourg	31	A (148)	4581	B
Brussels – Lille	22	A (174)	3833	B
Brussels – Randstad	25	A (145)	3535	B
London – Paris	19	A (185)	3506	B
Munich – Linz	27	C (98)	2654	B
Luxemburg – Maas-Rhine	32	D (74)	2370	B
Rhine-Neckar – Strasbourg	19	A (118)	2242	B
Strasbourg – Zürich	24	C (90)	2168	B
London – Lille	9	A (240)	2160	B
Brussels – Luxembourg	21	B (103)	2158	B
Paris – Geneva	15	A (135)	2019	B

The lowest overall level of service can again be found across mountain areas like the Pyreneans and the Balkans, the Caucasus region, as well as between Spain and Portugal and along the break of gauge between Lithuania, Belorussia, the Ukraine and Poland, Hungary, Romania. Again the Baltic countries show extremely low levels of railway service between their capitals.

Table 10 and Figure 15 show the relations between metropolises within the European Union with the lowest overall level of service.

Table 10: Connection within the European Union with the lowest level of service

Intra-EU Connection	Trains per day	Extended quality of speed (abstract value)	Overall level of service (abstract value)	Category
Sofia – Thessaloniki	0	0 (-)	-	0
Gdansk – Riga	1	F (8)	8	F
Tallinn – Helsinki	1	F (9)	9	F
Riga – Warsaw	1	F (16)	16	F
Vilnius – Riga	1	F (27)	27	F
Zaragoza – Toulouse	2	F (15)	30	F
Lisbon – Seville	1	F (30)	30	F
Bilbao – Nantes	2	F (19)	38	F
Riga – Tallinn	1	F (46)	46	F
Bilbao – Bordeaux	2	F (25)	50	F
Porto – Bilbao	2	F (26)	52	F
Madrid – Porto	2	F (34)	68	F

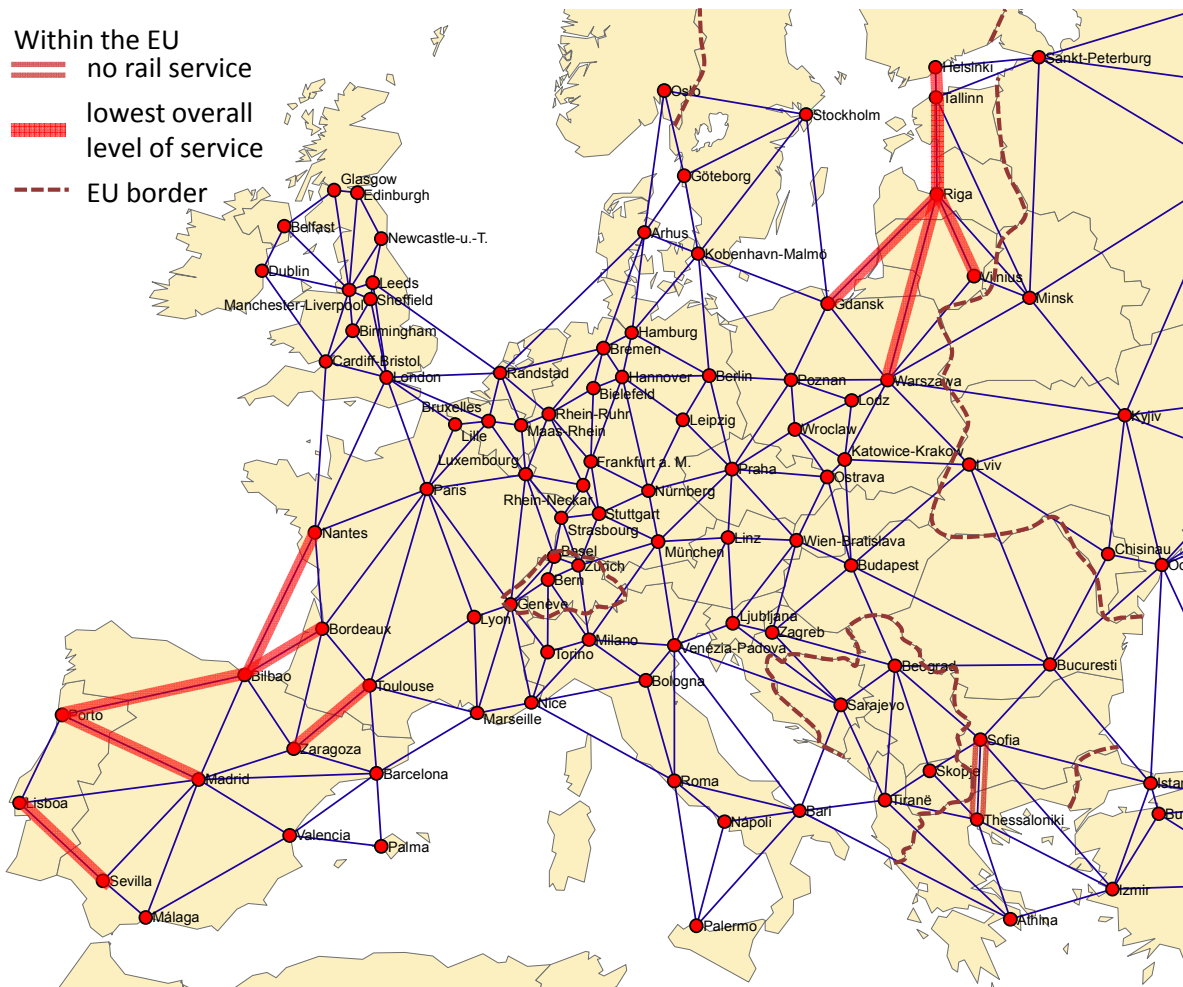


Fig. 15: The 12 connections with the lowest overall level of service within the European Union

Figure 16 presents an alternative analysis of the overall evaluation. It shows the above introduced quality of average speed on the x-coordinate and the number of trains per day (frequency) on the y-coordinate. Each blue dot represents one connection between two European metropolises. The higher the dot lies, the more trains operate on this connection, with Zürich – Basel on the top. The more right the dot lies, the higher is the average beeline speed, including the above mentioned transfer surcharge and distance dependency. Here Zaragoza – Madrid is top. The overall evaluation value is represented by the curved blue lines, showing the limits between the several categories A to F. For example A and B is divided by the line labelled “5000” as it represents pairs of frequency and quality of speed resulting in 5000 if multiplied. The more top-right a dot lies, the higher is its overall evaluation. Some example connections are labelled, also showing the overall evaluation value.

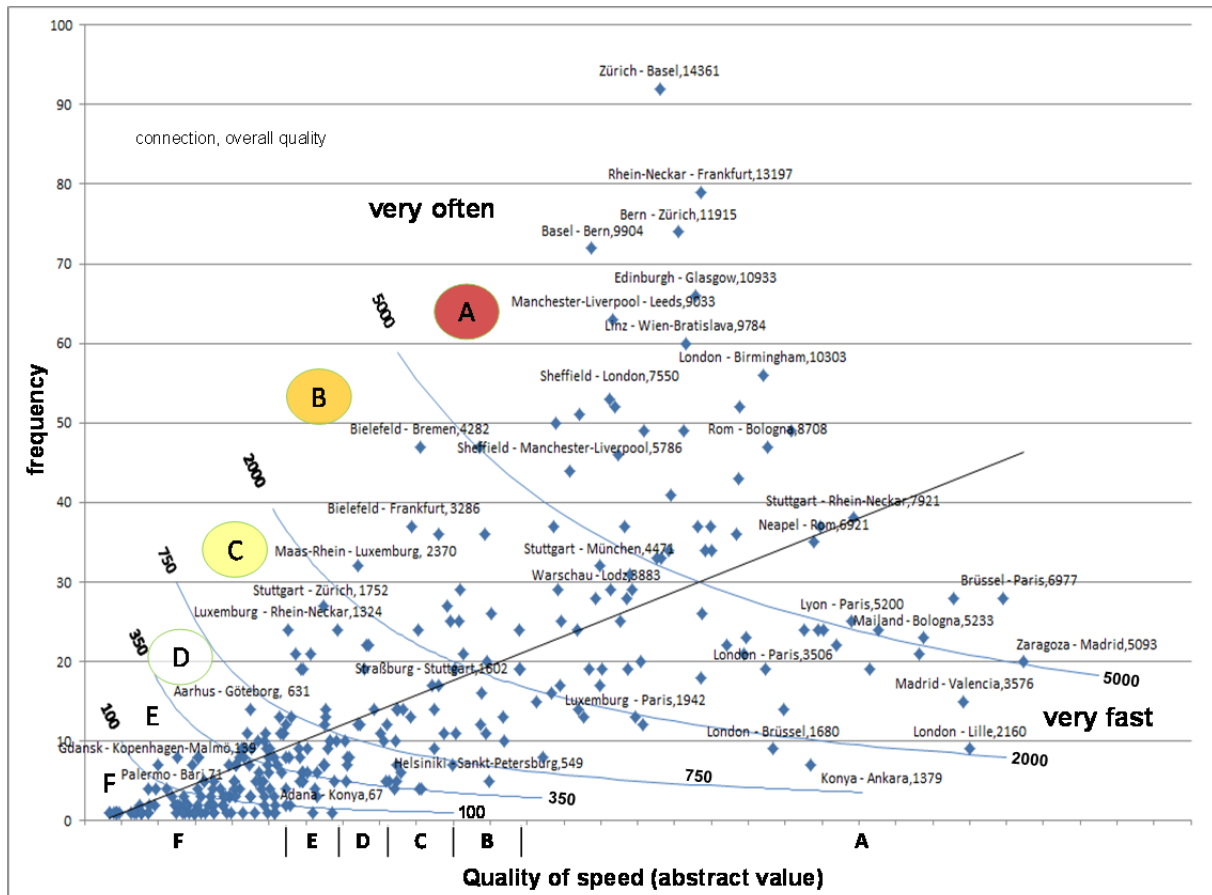


Fig. 16: Frequency and quality of speed of the European connection showing category A to F

Figure 16 also allows identifying connections with relatively fast but infrequent services. For category A, mentioned Zaragoza – Madrid and also Brussels – Paris is very fast but relatively few trains are offered. The other extreme are the Swiss main lines with very high frequencies but not that high average velocity. In category B, Bielefeld – Bremen, Bielefeld – Frankfurt and Maas-Rhine – Luxembourg, are most top-left in Figure 16, and thus have relatively many trains per day, but low average speed. On the other end (fast and seldom) is Madrid – Valencia and London – Lille, latter with only 9 connections per day. Looking to category C, Stuttgart – Zürich and Luxembourg – Rhine-Neckar are served relatively often but slowly, while Konya – Ankara and London – Brussels are made fast and seldom. Within category D, Aarhus – Gothenburg is relatively slow due to geographical constraints, but served quite often, while Helsinki – Saint Petersburg is quite fast but served infrequently.

As mentioned above, the two factors of frequency and speed could be weighted differently. To learn more about the influence of the two factors we performed a small sensitivity analysis. As the overall value is obtained multiplicatively, we have to raise the factor that should get more weight to a certain power. Figure 17 shows the results for a weighting of speed as well as frequency with a power of 2 (dashed lines). If more weight is done to the speed, then the limit line between overall category A and B is rotated clockwise and few connections like Sheffield – Manchester-Liverpool are downgraded, as they are frequent but not that fast. On the other side Madrid – Valencia is entering to category A. If to the contrary, the frequency is weighted stronger the line turns counter clockwise and some inverse changes in the categorisation occurs. All in all, the sensitivity of our calculation is

quite low and thus stable, as we have to include high powers to the factors in order to obtain significant changes in categorization.

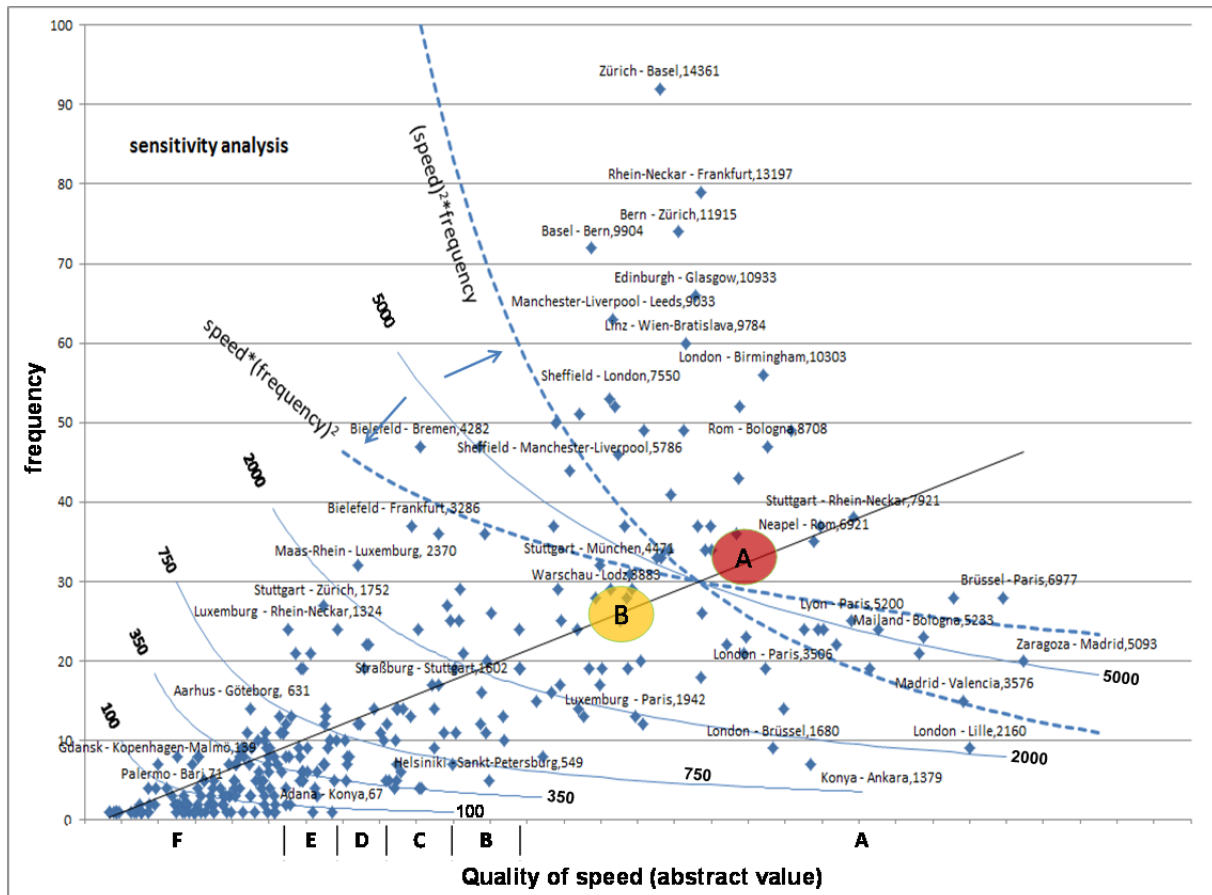


Fig. 17: Sensitivity analysis between category A and B

10 COUNTRY CLUSTERING

Based on the diagram type of Figure 16 the connections of the two top categories A and B were clustered with respect to the country they are located in. Figure 18 shows these connections (compare also Figure 14), where all of them are labelled. The coloured circles include the connections of respective country. It can be seen that the Swiss connections (yellow) have a very high frequency but are not that fast on average. On the other side the Spanish connections (blue) have a very high average speed but quite low frequencies. The UK (green) has connections with quite high frequencies but only some very fast lines. Italy (brown) is between the Swiss and Spanish extreme, it has quite a lot of trains per day and quite high velocities on its metropolitan connections. France (violet) lies between Italy and Spain with often fast but always comparably infrequent connections. In France and also Spain it seems that the improvement of overall level of service is just pursued by increasing speed while not increasing the frequency. The Polish and Czech connections (red) are fast and high frequent and are laying in the middle of the graph. The only Austrian (Linz – Vienna-Bratislava) and Belgian (Brussels – Maas-Rhine) connection is similar to those of the UK. The Scandinavian top connections in Denmark and Sweden vary strongly regarding speed and frequency and resemble more of less the Polish connections, as it does the Porto

– Lisbon and the Dutch Maas-Rhine – Randstad line. The international connections vary in their quality type, whereas the top international line Brussels – Paris resembles the French connections (fast and relatively infrequent). The German connections are not encircled by a coloured line, as the type of them varies strongly. There are almost “French style” connections, like Hannover – Berlin and Berlin – Hamburg, with very high average speed but low frequencies. Then there is the “Swiss style” connection of Rhine-Neckar – Frankfurt and some “UK style” ones, like Rhine-Ruhr – Bielefeld, Hannover – Hamburg or Frankfurt – Stuttgart. Furthermore there are “Italian style” connections with both quite high frequencies and speed as Stuttgart – Rhine-Neckar, Frankfurt – Rhine-Ruhr, Nuremberg – Munich or Hannover – Hamburg. Then, there are the lines of the middle with not that much frequency and speed like Stuttgart – Munich, Bremen – Rhine-Ruhr and the often praised Nuremberg – Hannover main line.

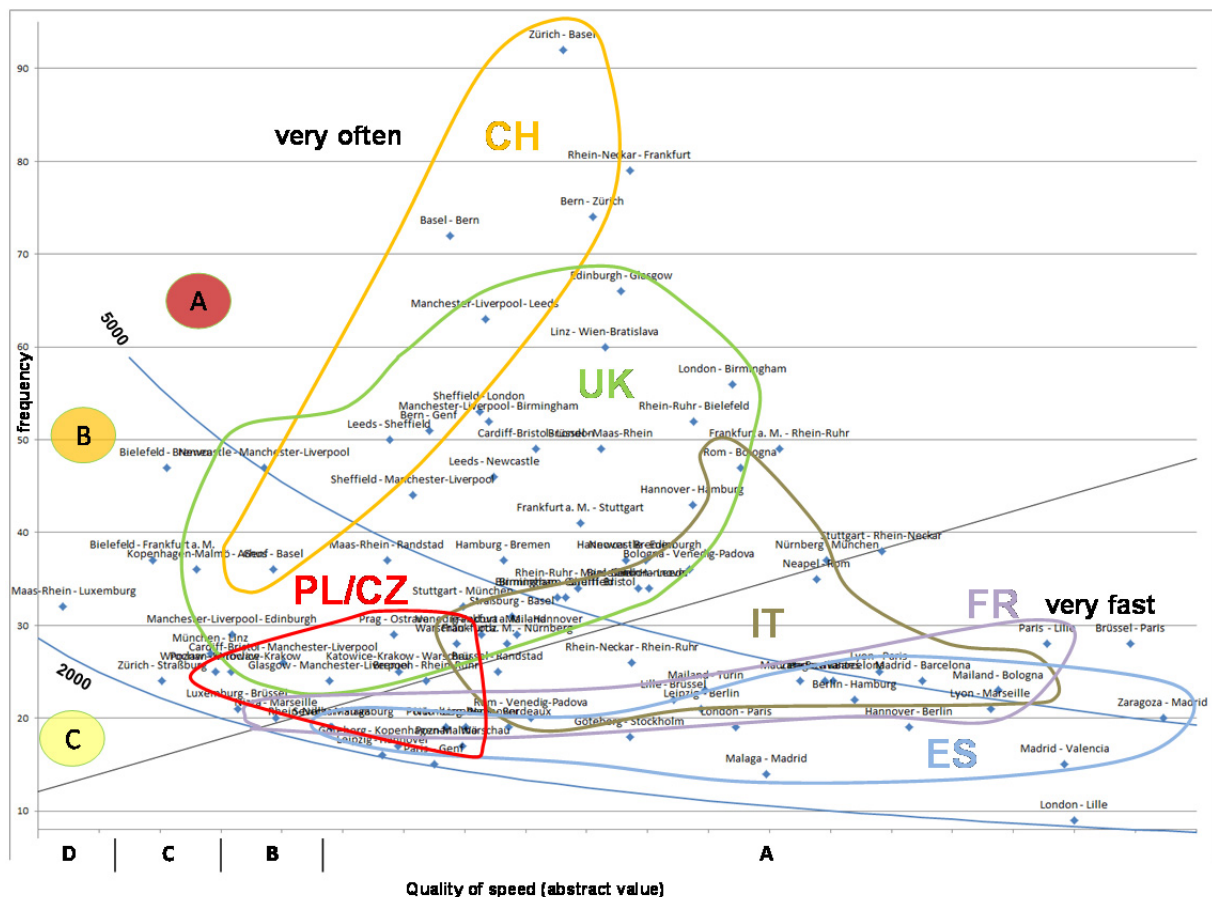


Fig. 18: The main country clusters of overall category A and B connections

11 CONCLUSIONS

In Europe almost every metropolis is connected to the railway network, presenting a huge current and future potential for sustainable transport and mobility. The analysis showed that nevertheless there are enormous differences in the quality of services around Europe. Defining the quality of main railway lines as a result of speed and frequency, the analysis of the level of service exposed that the highest quality of passenger railway connections can be found generally in Switzerland and in some parts of the UK and Germany. Further very high level of service is present in Austria, Italy and Belgium. Also in this category are the main lines in France and Spain.

The good connections in Switzerland and the UK as densely populated countries are mainly a result of high and regular frequencies but with not that high average speeds. On the other hand many Spanish and French metropolises are connected with high speed but not that frequently. Italy's top lines are fast and at the same time high frequent, whereas Germany has a great variety of types of connections, either fast or very frequent.

In general, the international lines crossing borders have significantly lower levels of service; only the metropolises Paris, Brussels and Strasbourg are linked to neighbouring countries in a very high quality. The key factors in limiting level of service of international railway connections are technical (above all break of gauge) or geographical obstacles (as mountains). Finally the Baltic States stand out with very low level of service although having favourable topographic conditions.

Thus, to achieve a fully satisfactory European inter-city-railway system the international connections with a break of gauge need a substantial improvement in order to not lose all passenger traffic to car traffic, long distance buses or air travel. Between the Baltic States, on the Balkans and between Spain and France/Portugal, where rail connections are worst in all Europe, the connections are in need of a fundamental upgrade to provide a better and competitive quality of passenger travel on railways between the metropolises. Furthermore, within Spain and France efforts can be made to increase the frequency of train connections, instead of even more raising the speed with great financial investments. However, relatively sparsely populated and highly urbanized countries with long distances between the major cities obviously have to focus on speed rather than frequency. With regard to the railway transport policy of the European Union a network approach with focus on connecting the metropolises rather than a continuing definition of corridors, still eminent in the new TEN-T concept, can be recommended.

The presented methodology is a further development of a German guideline to assess the level of service on certain lines. It embodies a useful and transparent way to analyse the quality of passenger railway connections between urban centres regarding both speed and frequency to equal shares. As a mean of adjustment the weighting of frequency and speed can be altered and the transfer surcharge can be varied from chosen 15%. The methodology is transferable to other geographical regions as China, India, Japan or the USA with a dense passenger railway network. Furthermore the methodology can be transferred to regional and even local subdivisions by including smaller urban centres as nodes of the network.

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