Deutsches Zentrum
für Luft- und Raumfahrt

Effects of a 400 km/h rail network across Europe with the use of the DLR-developed Next Generation Train (NGT)

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The Next Generation Train (NGT) is a research project for a new type of high speed train. It is developed by DLR (German Aerospace Center), in which 8 institutes with their specialised knowledge are involved. The train is designed for an operational speed of 400 km/h. Due to its light body structure and double-deck concept, it has lower specific energy consumption than a conventional high speed train [1]. The Institute for Transportation Systems develops operational concepts for the train.

1 Object and Background

The object of the study is to analyse the potential for a high speed train of 400 km/h and calculate the figures for an exemplary application to evaluate the benefit of the concept. Within the scope of the project the geography and the present and future rail networks of the western, northern, southern and middle European countries are modeled and an potential NGT network is created in order to verify which effect this speed has on European traffic.

Figure 1: Design study of the NGT 400

A first study was made for the major European relation form Paris to Vienna via Stuttgart and Munich [2]. This analysis revealed the feasibility of switching air transport to rail even for distances up to 1000 km. The NGT covers the way in fewer than 4 hours. Major differences between the European countries are revealed: In Germany more frequent stops create more benefit because of the distributed population. The average speed for the passengers with a direct journey decreases. However the speed for all passengers in the investigation area increases due to the enhanced accessibility to high speed rail.

2 Method for traffic modeling

For the investigation of the European potential, a network is created, which includes the cities, the train routes and frequencies between the modelled cities, the travel times and economic data. The distribution of the traffic demand is created with an elementary gravity model, scaled with real data from Eurostat [3] and the UIC railway statistics [4]. For the assignment a route-based algorithm is used, in which interchanges have a negative influence. Thus the fastest route is not always the best option.

2.1 Network Model

The population coverage is validated with the total population of the NUTS-2 areas [5]. This area definition is used by the European Union and represents smaller federal states or parts of them in Germany, regions in France and Italy and cluster of counties in the UK. The aim is that the cities represent at least 20% of the total population of the NUTS-2 area. In most cases the percentage is much higher. All cities with 80.000 inhabitants and more and also lots of smaller towns are included. Furthermore towns at railway nodes are added, because there are necessary for the network anyway. The limitation to cities and towns follows the concept, that the biggest part of the rail potential lies in cities and not in rural areas.

The rail network is represented by train routes. These are distinguished into high speed, intercity and regional train routes. Also bus and ferry connections are included, if there is no useful connection to the rail network and the feeder potential is important. A special form of intercity train was introduced as IC+. This is for the cases where the strict definition of high speed (considerably higher than 200 km/h) is not fulfilled, but the trains are faster than ordinary intercity trains.

The train route numbering and the train travel times are gathered from the Thomas Cook European Timetable 2010 [6]. Regular stop times are included in the travel time. Average access and interchange times are defined for every city.

2.2 Distribution and Assignment

The gravity model consists of the population of the regarded city pair, the economic power (purchasing power standard per capita in €), the distance and average travel speed. The result is the annual number of rail passengers for every city pair combination. This value is validated with the Eurostat data, where the rail traffic is given in a matrix on the NUTS-2 level. Scaling factors adapt the calculated value. For some relations, especially international and in Eastern Europe, the Eurostat data is missing or the value is not plausible, then the data from the UIC statistics is used. Furthermore a flight factor is introduced, which reduces the value for very long journeys. This factor is necessary as the potential decreases not fast enough for journeys of 4 hours and longer. For these travel times air traffic remains the most attractive mode.

The assignment is based on a train-route oriented routing algorithm. The route with the lowest travel resistance is chosen. The travel resistance consists of access time, travel times, interchange times and the leaving time. The interchange time is scaled with a factor, so that a more comfortable route is preferred compared to a little faster route.

Only long distance traffic with distances of more than 50 km is included in the model. Thus there is a difference with another definition: In Germany, journeys over 50 km in regional trains are not included in the statistics for long distance traffic.

The international traffic is calculated using country-pair scaling variables. The effort for a more detailed study would be too big. It can be stated, that the level of international rail traffic is very different. In eastern European countries even for very long journeys railway is used, so the flight factor has to be reduced. For Western European countries much more traffic volume is expected, but the demand is lower, for example between Germany and the Netherlands.

2.3 Scenarios

Four scenarios are calculated:

- Europe 2010 (for calibration)
- Europe 2025 (forecast with rail lines under construction or planned)
- NGT Maximum Network
- NGT Recommended Network

The NGT Recommended Network is the result of the analysis of the Maximum Network. Only high speed lines which generate 10 million new travellers per year or more are included. The number is a recognized value for high speed lines. A more detailed cost-benefit analysis would require much more effort.

3 Network Model for Europe (2010)

All western, southern, northern and middle European countries are regarded in the model. In the east the Baltic countries, Poland, Slovakia, Hungary, Romania, Bulgaria and Turkey are included. Not included are Iceland (low potential) and the eastern European countries of Russia, Belarus, Moldavia and the Ukraine.

The following numbers define the model network:

- 1904 cities and towns
- 237 Mio. inhabitants included of total 525 Mio.
- 120.000 km rail lines included of total 227.000 km
- Length of high speed route network: 18.400 km
- Length of intercity and IC+ route network: 66.100 km
- Length of regional train route network: 75.600 km

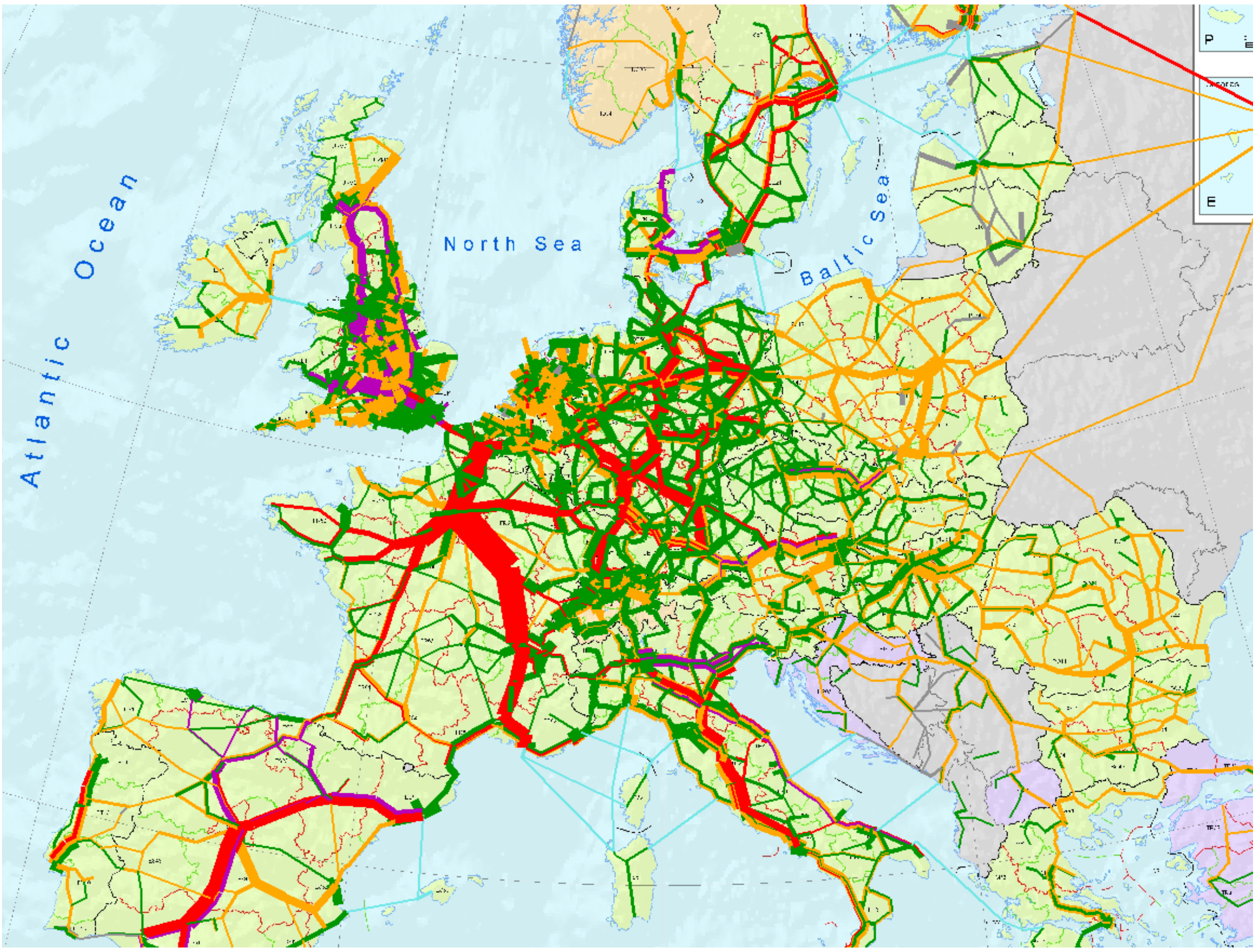

Figure 2: Rail Network for Europe 2010 (Red = High Speed, Violet = IC+, Orange = IC, Green = Regional Trains, Thickness = Line frequency)

3.1 Focus on Great Britain

For Great Britain and Northern Ireland 202 cities and towns with a population of 32 Mio are included, that is 52% of the total population. London is then biggest city and represents the biggest part of the metropolitan area. The metropolitan areas of Manchester, Liverpool, Birmingham and Tyne & Wear are fragmented. The population in these areas is represented by the administrative city regions or boroughs. Some of the outer bouroughs are connected with urban transport systems to the central stations of the big cities, e.g. the Manchester Metrolink connects Altrincham to Manchester.

High Speed Traffic exists only on the line “High Speed One” form the Channel Tunnel to London. The speed on the main lines to Scotland, the West and East is 125 mph, which is 201 km/h. So it is not high speed traffic following the strict definition. The long-distance trains on these lines are categorized as IC+. The trains reach a very high average speed of 123 km/h. So they are faster than the ICE trains in Germany, which reach an average speed of 114 km/h. The reason for this is that ICE routes follow old upgraded lines for long sections and have speed limits in node areas. Yet another reason for the high average speed in Britain is the high train density, which allows the skipping of stops. A 20-minute train interval is offered between London and Manchester. Not all trains stop at all intermediate stations, nevertheless Milton Keynes, Stoke-on-Trent, Macclesfield and Crewe are served at least hourly. Furthermore the long-distance-trains from London to Scotland do not have to stop at Birmingham or Manchester because theses cities have their own regular and fast connection to Scotland. In general all the lines have a high train frequency. Together with Switzerland and the Netherlands, Britain has the highest passenger train density in Europe.

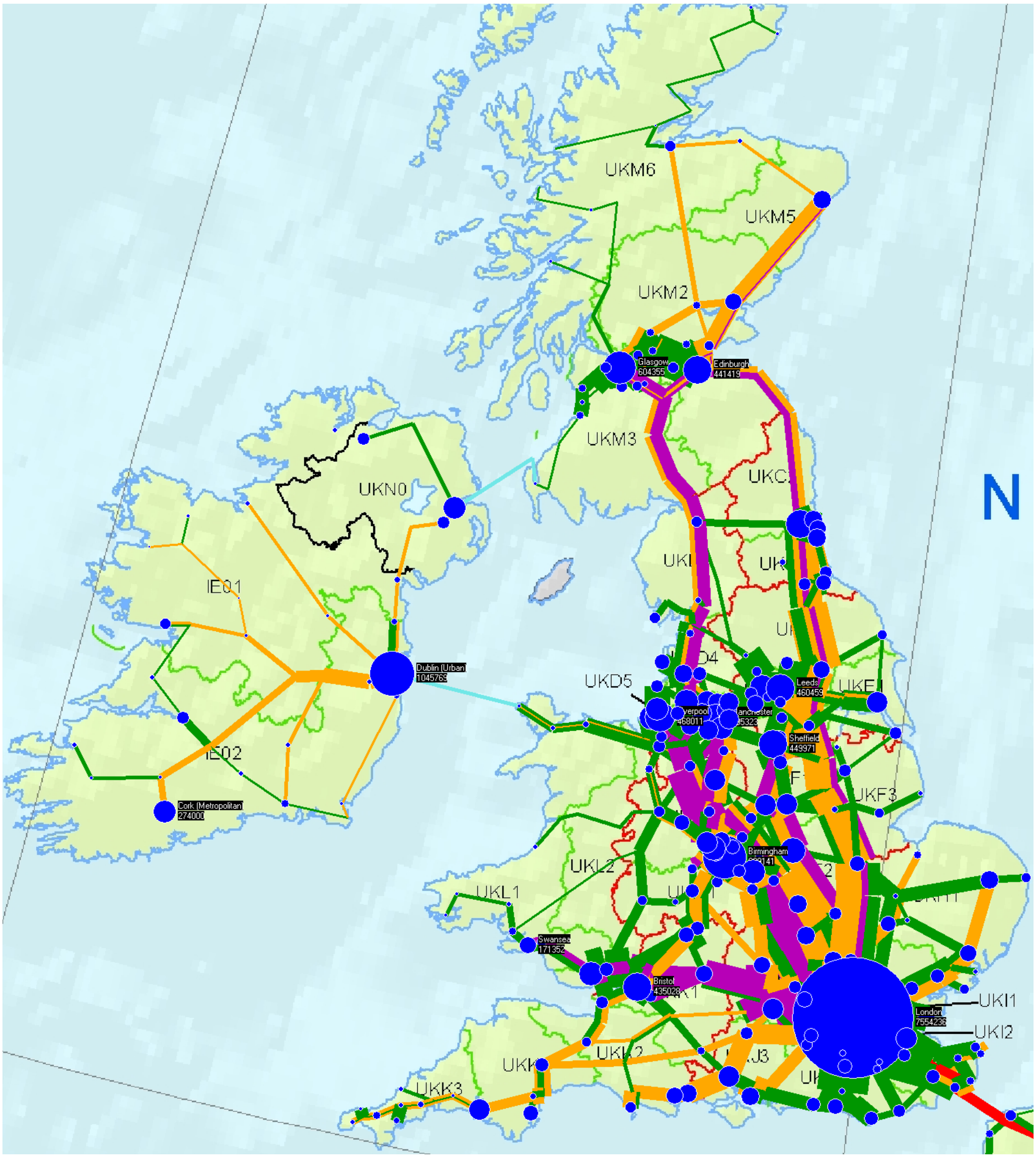

Figure 3: Train Network Model for Great Britain and Ireland (Blue circles represent the population of the cities)

10.100 km (63%) of the total 16.100 km of rail network is included in the model. That value allows the conclusion, that there are not much secondary lines with lower importance. For instance the model of the Czech Republic contains only 35% of the total rail network. So it can be stated, that there are many secondary lines with lower importance for the connection of the modelled cities.

All modelled cities in the UK are connected to the rail network and there are no major gaps in the network. Exceptions are the area north of London, where there is a lack of cross-connections and along the coast. The low density of rail lines in Wales, Scotland and Northern Ireland does not have a negative impact on this connectivity evaluation because there is a low population density with low traffic demand.

3.2 Comparison of European Countries

The model is analysed to allow a comparison of the European countries. One key figure is the average population per city. This value has a statistical meaning because in every region the percentage of the population covered is similar. Countries with a big value have the tendency of better conditions for high speed rail because more people are living in cities and the distance to the next long-distance train is low (see Figure 4). Spain seems to have the best conditions, followed by France. The low value for Switzerland shows, that the population is wide-spread, which requires a high-density network with good connections. In the case of Ireland or Finland the value shows the bigger number of smaller cities, which creates lower demand and generate challenges to provide a good rail transport supply.

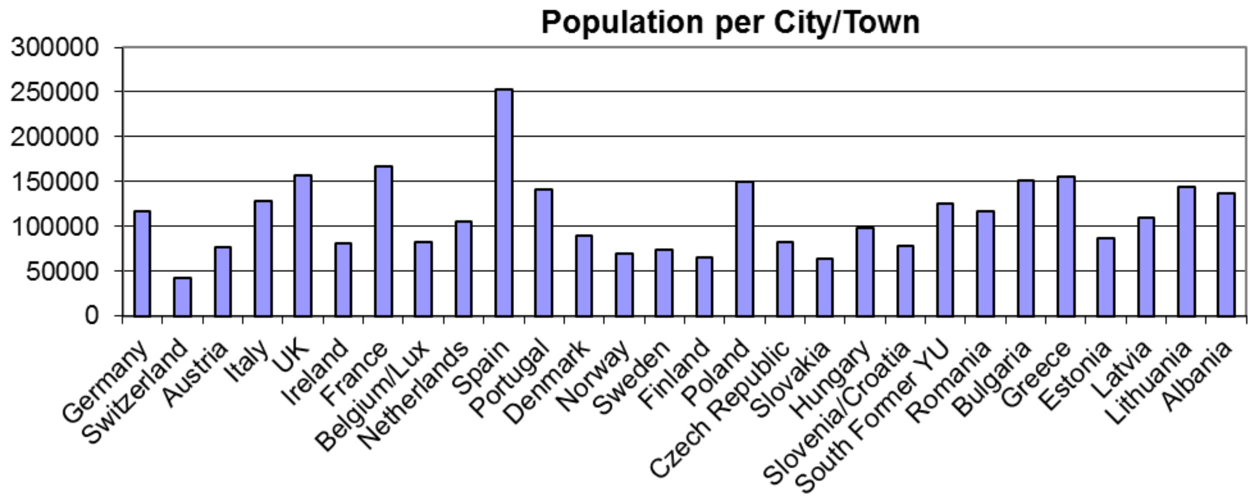

Figure 4: Population per City/Town

In the above section the modelled percentage of the total network was mentioned. In Figure 5 the highest value can be found in the Netherlands where almost the whole network has importance for the passenger transport. A high value means that there are not much secondary lines or in the model are many smaller towns included, which have to be connected to the network. The first meaning can be assigned to the UK, Ireland, Spain, Denmark, Estonia and Greece. The second one is the cause for the high value in Switzerland.

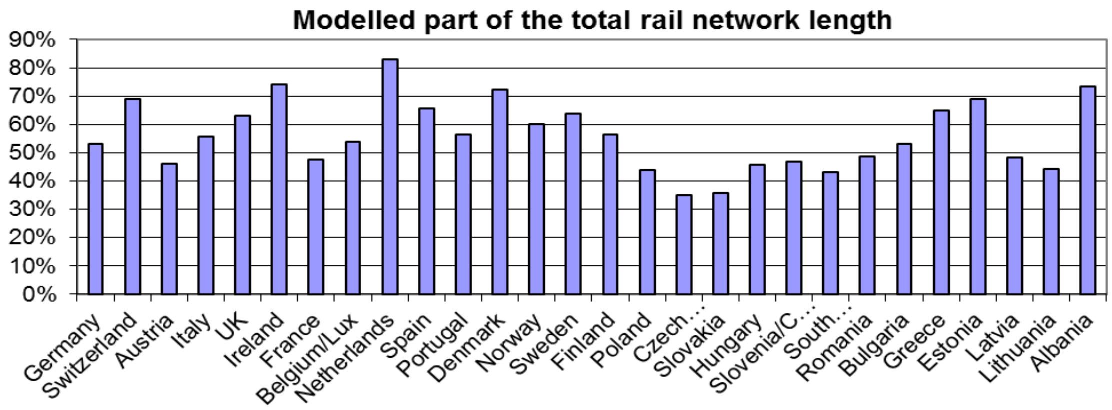

Figure 5: Modelled part of the total rail network length

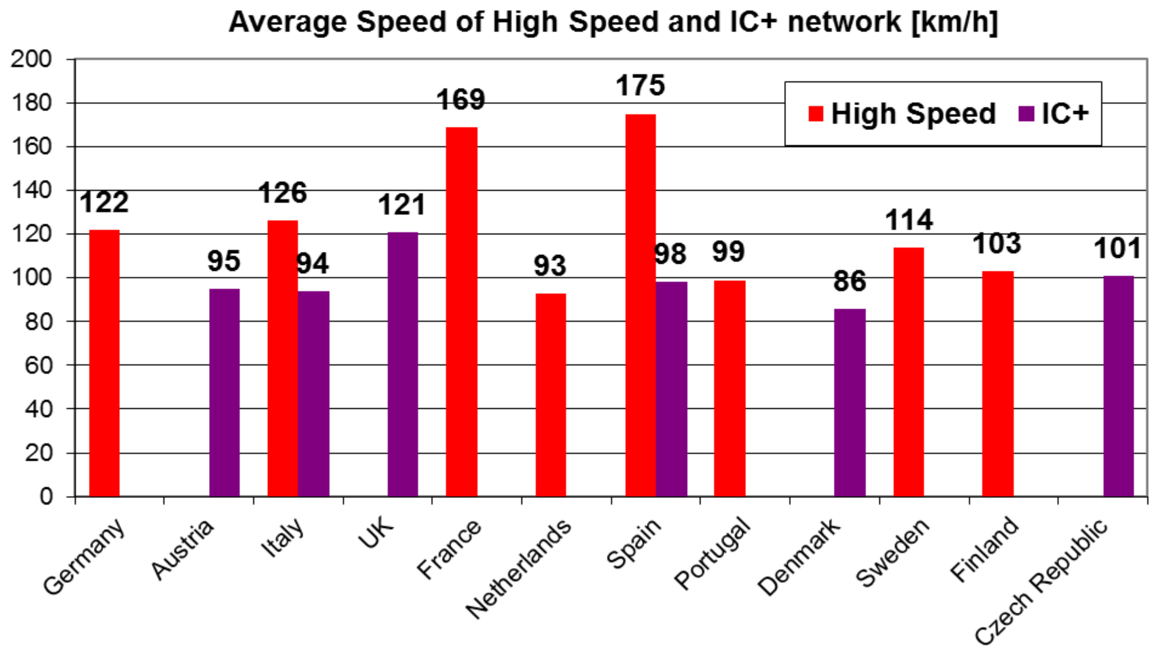

Figure 6: Average Speed of High Speed and IC+ network

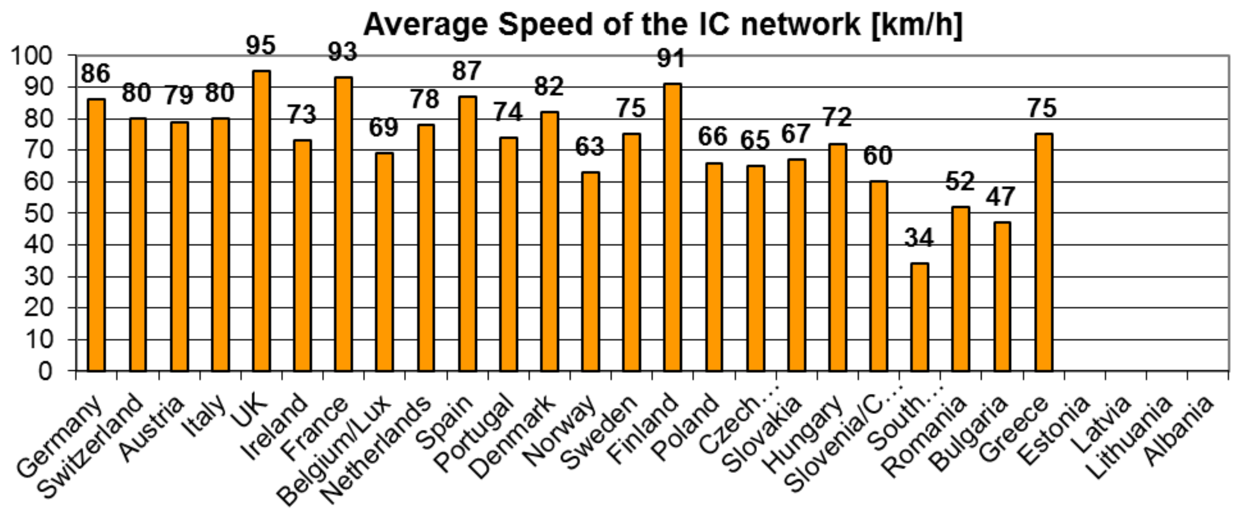

Figure 7: Average Speed of the IC network

In Figure 6 and Figure 7 the average speed of the model train types is displayed. It is weighted with the train running performance (train-km), but not the traffic performance (Pkm). The fastest high speed train routes can be found in Spain. This includes only AVE trains, gauge-changing trains partially using high speed lines are assigned as IC+. Because of the Eurostar also Great Britain has a high value. The French value is lower because of the large proportion of old lines TGV trains are running on. The same reason causes the low average speed of the German ICE. Even there are few high-speed line sections, the speed standard in the Scandinavian countries of Sweden and Finland is very high. The reason amongst others is the low number of stops on very long distances. The speed level for IC traffic moves around 80-100 km/h in Western Europe. Britain has a higher level because of the limitation of stops allowed by the high train density. France and Finland have a low rural population density which reduces the number of intermediate stops. The difficult topography of Norway reduced the average speed there. A lower speed level in the formerly Eastern Bloc countries can be determined. The level is extraordinary low in former Yugoslavia except Slovenia and Croatia and Albania (no trains assigned as IC).

4 Scenario 2010

Currently most of the railway passengers have a national destination. In Figure 8 national traffic is displayed in blue, whereas international traffic in red.

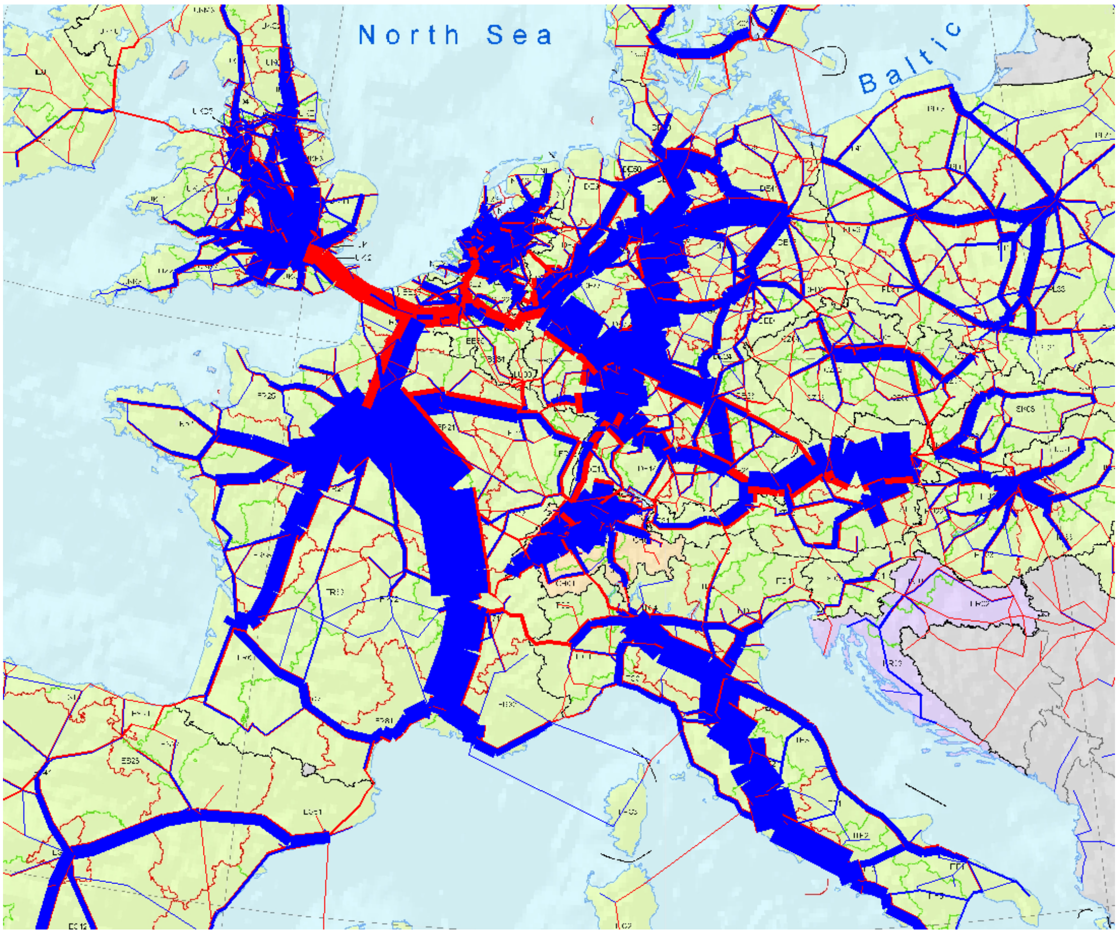

Figure 8: Passenger long distance traffic 2010 in Central Europe

The highest passenger numbers are obtained mainly on the core high speed network. These are the following lines (only voyages for 50 km and longer, both directions):

Line	Passengers per day	Inter-national
Paris – Dijon / Lyon	95.000	5%
Paris – Atlantique	80.000	1%
Paris – Lille	50.000	40%
London – Rugby (West Coast Main Line)	50.000	5%
London – Peterborough (East Coast Main Line)	35.000	2%
Utrecht – Eindhoven	45.000	1%
Frankfurt – Mannheim	80.000	11%
Köln – Frankfurt	60.000	10%
Göttingen – Kassel	65.000	3%
Zürich – Olten	85.000	5%
Wien – St. Pölten	65.000	10%
Stockholm – Katrineholm	25.000	2%
Milano - Bologna	40.000	3%
Firenze - Roma	55.000	1%
Madrid - Cordoba	15.000	0%
Madrid - Barcelona	15.000	2%

With almost 100.000 passengers a day the LGV line from Paris to the Southeast is the most used high speed line in Europe with a high train frequency of 4-5 minutes. The map clarifies the fact that international rail traffic stands on a low level in Europe.

The calibration of the international traffic shows the different significance in different parts of Europe. The biggest intensity is between the Czech Republic and Slovakia. The calibration factors are on a level which is stronger than the inner German rail transport. Additionaly the flight factor has to be reduced, so the passengers use the railway despite the long travel times. The traffic between Austria and Germany is on the same level as the inner German. Very strong connections are also between Germany and Switzerland, France and Switzerland, France and Italy and France and Luxemburg. The flight factor has to be reduced especially between Austrian and Italy, Czech Republic and Poland, Spain and Portugal. A possible explanation for this amongst others is an intensive usage of night trains. The level of international traffic in the model is low between Germany and the Netherlands, France and the Netherlands and the UK and France. Nevertheless the strongest international connection in Europe is the Eurostar between London and Paris. However the population, economic power and the short distance leads to expectations of much more traffic than there currently is. This is approved by the passenger numbers: The Eurostar couldn’t fulfil the expectations the first years of its existence [7].

The number of relations with at least one passenger per day per inhabitant can serve as a value for the complexity of the traffic. Germany has the most complex origin-destination arrangement. Britain has the secondmost complex traffic (56% of the German value), followed by Italy (46%), Switzerland (44%). Less complex the traffic is in France (22%) and Spain (12%). The more complex the traffic relations are the more difficult is it to offer a good high speed rail to major parts of the population.

5 Scenario 2025

For 2025 a forecast has been made, which takes the realisation of all rail lines now under construction or planned lines as a basis. Important new or upgraded line projects are amongst others:

- Germany: Leipzig – Erfurt – Nürnberg, Stuttgart – Ulm
- Austria: Western Corridor, Koralm Corridor
- Switzerland: Gotthard Base Tunnel
- UK: High Speed 2 (London – Rugeley)
- France: LGVs: Bretagne, Bordeaux, Toulouse, Rhin-Rhone, Mediterranean
- Spain: all major cities in coastal areas connected with Madrid
- Italy: Milano – Venezia
- Sweden: Stockholm – Malmö (partially)
- Poland: CMK Line (Warszawa – Krakow/Katowice)
- Turkey: Istanbul / Bursa – Ankara, Izmir – Ankara, Ankara – Sivas

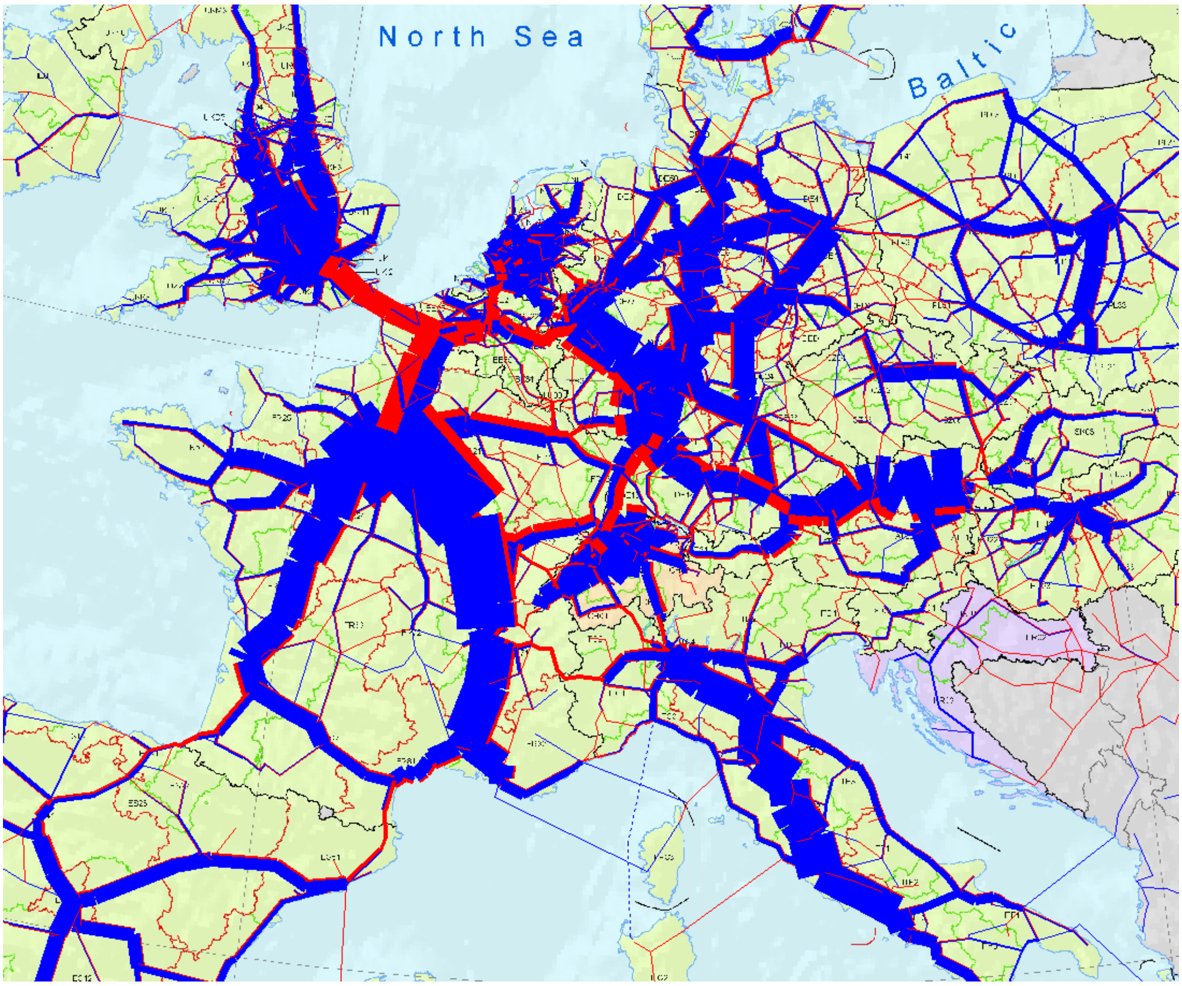

Figure 9: Passenger long distance traffic in 2025

With the realisation of these projects the sum of the national traffic performance rises from 227 bn. Pkm in 2010 to 257 bn. Pkm in 2025. The passenger numbers rise from 909 to 986 Mio. The international traffic performance rises from 20 to 27 bn. Pkm, passenger numbers from 48 to 61 Mio.

The biggest increase is realised in Spain. The performance rises about 50% from 10.4 to 15.7 bn. Pkm. Even more new passengers can be attained in Turkey. The high speed lines revolutionize the passenger rail transport in Turkey. The performance rises from 2.4 to 10.7 bn. Pkm, passenger numbers from 9.5 to 30.6 Mio. Further high increases are calculated for Austria (+16%), France (+14%) and Greece (+25%), if the new sections of the Athens-Thessaloniki line are finished.

The biggest incrase of the performance for international traffic is realised between Spain and France (+1300 Mio Pkm), Switzerland and France (+880 Mio Pkm), Switzerland and Germany (+572 Mio Pkm), France and Italy (+395 Mio Pkm) and Germany and Italy (+229 Mio Pkm).

6 Scenario NGT Maximum Network

The initial question for this work package of the NGT project was to identify the potential for a train with an operational speed of 400 km/h in Europe. The approach is to create a complete new network which allows railway operation at this high speed for almost the whole line. The existing network acts as a feeder network.

To create this new network, strict rules are followed. These rules help to set the same scale to all regions of Europe regardless of the topography or established traffic corridors. The first rule classifies the cities. All cities from 500.000 inhabitants should have a direct connection to the network, for cities from 200.000 the high speed station should not be farther than 50 km away, for all cities from 80.000 inhabitants not farther than 100 km. The network itself follows some rules: parallel lines should have a distance of at least 100 km, the distance between stopping stations should be at least 50 km, the detour factor should not exceed 1,5. The lines should be connected with the existing central stations in the city center to avoid the increase of access and egress times. The operational speed within the city borders is reduced to allow the usage of the existing lines. In addition to the urban slow zones the travel time was increased by a factor to consider the exceeded line length which will occur in the detailed planning. Therefore the maximum network includes not the shortest theoretical travel times. The resulting network is shown in Figure 10.

The maximum network is 77.000 km long and has 434 stations. Three longer subsea tunnels are investigated: under the Irish Sea from Holyhead to Dublin under the Baltic Sea from Stockholm to Turku and from Helsinki to Tallinn. The tunnel under the Fehmarn Strait is already incuded in the 2025 scenario.

The traffic performance would increase from 285 to 678 bn. Pkm. The part of the international traffic would rise from 11% to 37%. Countries with an extraordinary growth of national rail traffic are Poland (39 bn. Pkm), Romania (15 bn. Pkm) and Turkey (37 bn. Pkm). These countries have a big potential, founded by an optimal size and a number of big cities spread over the country. Among the western European countries Germany would take the first place with 91 bn. Pkm heeling France (78 bn. Pkm). This figure shows that there is much undeveloped potential for high speed in Germany. The relative growth in France would be lower than in other countries due to the well developed high speed network in 2025. The same situation can be found in Spain. Smaller countries have low benefit with high speed lines, so the growth rates are low for example in Switzerland, then Netherlands, Belgium and Denmark.

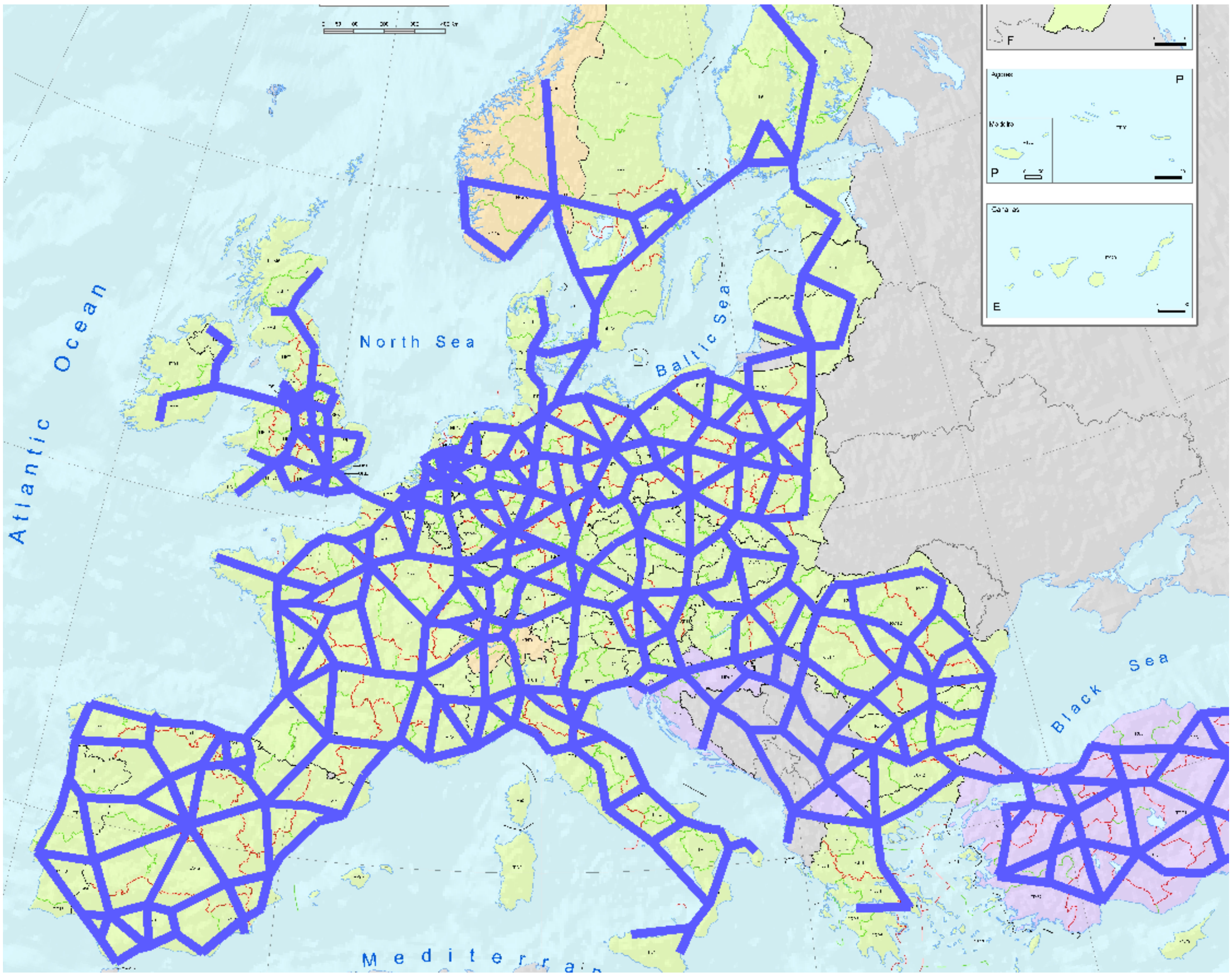

Figure 10: NGT Maximum Network

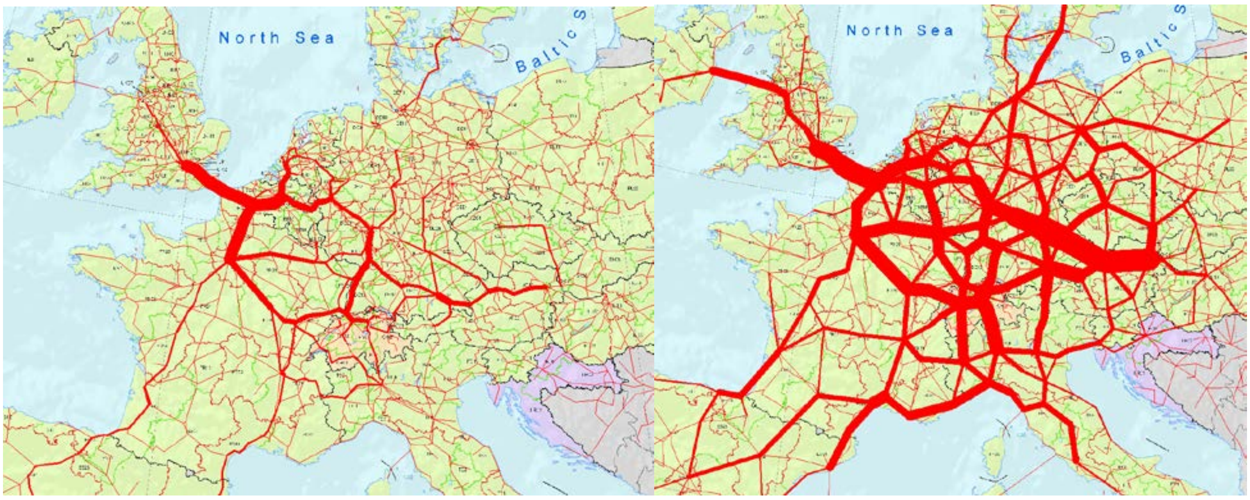

Figure 11: Development of the international rail traffic from 2025 (left) to NGT Maximum scenario

The most important international connections develop between Austria and Germany (25 bn. Pkm), France and Italy (17 bn. Pkm) and Germany and Italy (11 bn. Pkm). Even long distances are rail-relevant so the connection Spain – Italy (8 bn. Pkm) and Spain – Germany (3 bn. Pkm).

7 Scenario NGT Recommendable Network

The maximum scenario remains theroretical because most of the lines have no national economic benefit exceeding the effort. Even the operations would not be profitable on most lines. A detailed cost-benefit analysis would go beyond the scope of this work. But it is possible to calculate the attained passengers per line section. The loss on the old lines has to be taken in account. So this analysis is neither a cost-benefit analysis nor it takes capacity effects for instance for freight traffic into account.

For high speed lines a number of 10 Mio new passengers per year on the line profile is said to fulfil the economic requirements to generate benefit [8]. The whole maximum network was analysed. The result is a network of 13.500 km, which is recommendable and further 9.000 km which have to be analysed deeper to come to a substantiated recommendation.

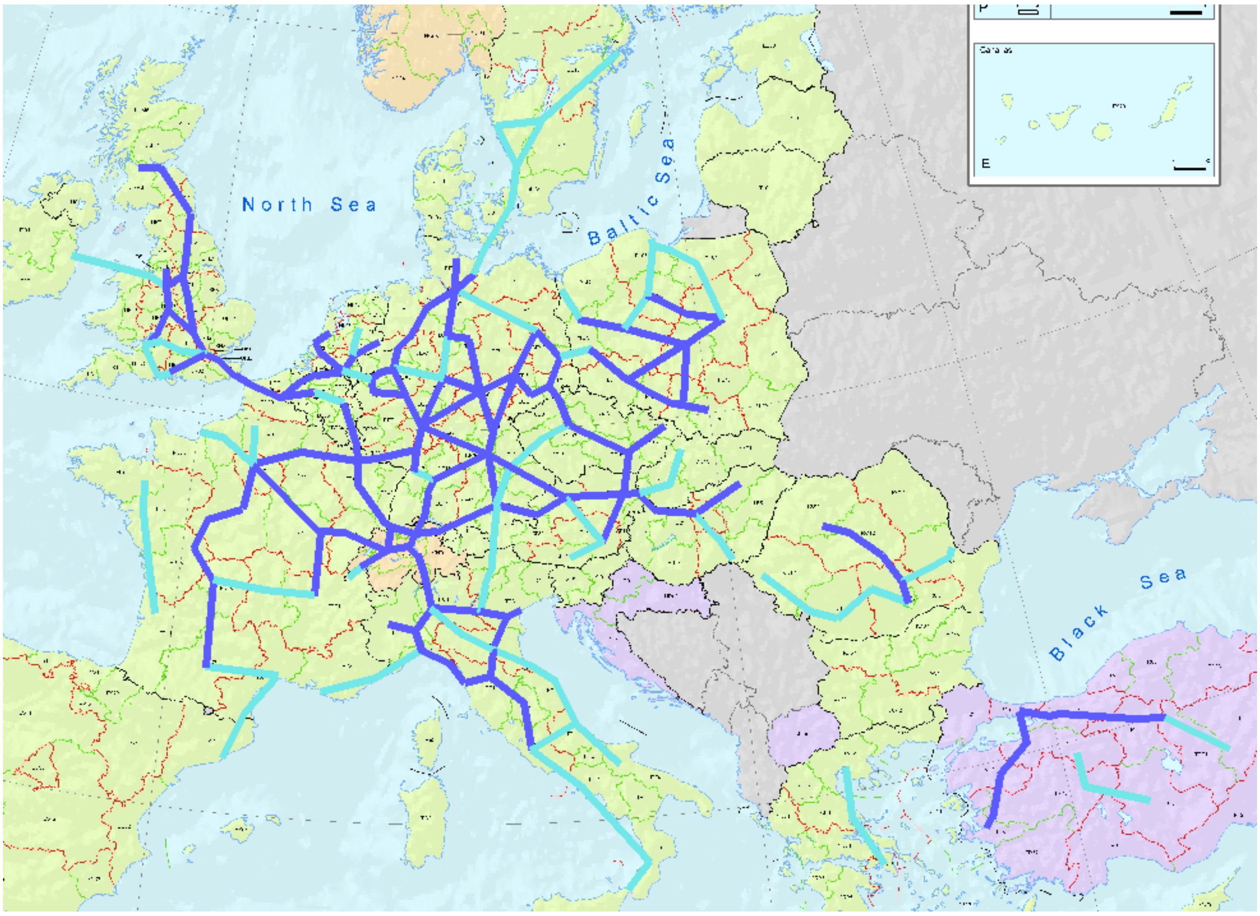

Figure 12: Recommendable NGT Network (Dark blue = high probability for good benefit-cost-value, light blue = to investigate)

To have a look at the three subsea tunnels: Only the tunnel under the Irish Sea has potential (22.000 passengers/day). The Baltic tunnels have a too low demand (1000 passengers/day). Most of the recommended network is placed in Germany. Apart from the unused national potential an explanation is the central location with a noteworthy value of transit traffic. Examplary connections are Benelux-Austria or France/Benelux-Poland/Czech Republic. In France and Italy the recommended network consists basically of additional lines to the existing core network. With the exception of the Paris-Lyon line, which has extraordinary demand (150.000 passengers/day), these are lines along the Atlantic coast or through Central France and in Italy connections of Genova. In Britain connections to Scotland and around London are recommendable. A second channel tunnel with 400 km/h could increase the demand from 28.000 to 50.000 passengers a day. In the Czech Republic only international connections generate enough benefit to connect also national destinations to Prague. A lot of profitable lines seem to exist in Poland. The recommendable networks for Hungary and Romania have the design of a star with the capital as the origin. In Turkey a new line from Ankara to Istanbul would generate much more traffic than the high speed line under construction now. Also a connection from Istanbul to Izmir generates high benefit. It is noticeable that there are no recommendable lines in Spain. The network of 2025 is that much expanded that all the rail potential is captured and enhancement of the speed to 400 km/h does not have a significant effect.

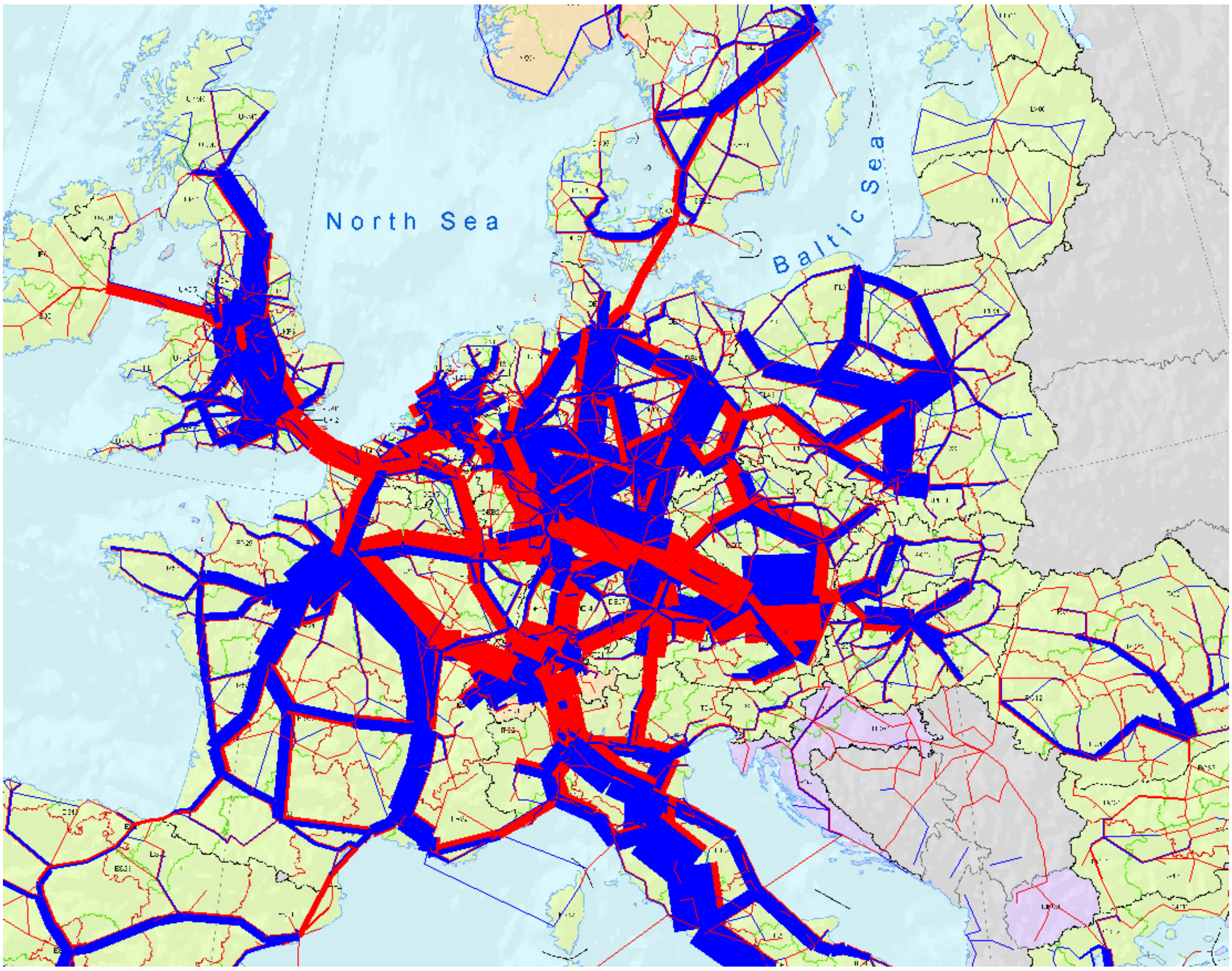

Figure 13: Passenger long distance traffic on the NGT Recommendable network

8 Summary

In the context of the project Next Generation Train (NGT) of the German Aerospace Center (DLR) the potential for a European-wide high speed network for 400 km/h was calculated. The traffic model was calibrated with origin-destination data from Eurostat. The result is a recommendable network, in which the lines can reach a positive benefit-cost-value. The largest increase of traffic volume is realised in Central Europe, but also in Poland, Romania and Turkey. The international rail connections would grow most: the traffic performance increases by factor 7.

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