Escola Tècnica Superior d'Enginyers de Camins, Canals i Ports de Barcelona
UNIVERSITAT POLITÈCNICA DE CATALUNYA

PROJECTE O TESINA D'ESPECIALITAT

Títol

Introduction to high speed railway services in the Czech Republic

Autor/a

Miquel Morata Royes

Tutor/a

Andrés López Pita

Departament

Infraestructura del transport i del territori

Intensificació

Transports

Data

1 de juliol de 2009

Life is like riding a bicycle,
to keep your balance you must keep moving.
Albert Einstein

GRATITUDES

My gratitude to Andrés López Pita for giving me the chance to do this minor thesis abroad and Leoš Horníček for helping me with his time and very useful information.

Thanks to my family who has helped me to persist on my work.

INTRODUCTION TO HIGH SPEED RAILWAY SERVICES IN THE CZECH REPUBLIC

Author: Miquel Morata Royes
Tutor: Andrés López Pita

ABSTRACT

This minor thesis tries to be a study of the introduction to the high speed railway services in the Czech Republic, attending to the constructive and technological aspects at the same time that the strategic aspects of the study phase, such as the offer and the demand analysis, the affectation on the territory and the current existing network, the relations with other means of transport and the connection with the neighboring countries. Likewise, an economic analysis of the proposal will be done to study the viability of the investment, without forgetting the environmental impact that the infrastructure would cause. At all time one refers to the traffic of passengers and goods, in order to do an exhaustive and complete study.

The European high speed is present in the most developed Western countries in a constantly growth phase. With the annexation of the countries of the East and Central Europe to the European Union, an expansion and a still major growth is being expected, as it is an investment of a more sustainable and competitive transport for average distances, as much on passengers traffic as on freight. The unification of the technical criteria at the moment of constructing high speed railway facilitates the international traffic, increasing the commercial speed due to the no need of having to stop in the frontiers. The above mentioned motive is especially relevant in the freight traffic, since it provides a greater capacity and makes it very competent against the road transport.

The Czech Republic has not remained passing by in the improvement of the transport network and the Czech Department of Transport and Infrastructures is already on the study phase of the construction of a high speed railway. Given the strategic position that the Czech Republic occupies in the Europe's center, the construction of a high speed railway in this country supposes a very important step towards the high speed railway conquest of the rest of the continent, besides opening the doors to the neighbor countries lacking in such infrastructures to follow the same steps to achieve a high speed railway transport network that would improve their communications.

PLANIFICACIÓN DE LOS SERVICIOS DE ALTA VELOCIDAD EN LA REPÚBLICA CHECA

Autor: Miquel Morata Royes
Tutor: Andrés López Pita

RESUMEN

Esta tesina pretende ser un estudio sobre la planificación de los servicios ferroviarios de alta velocidad en la República Checa, atendiendo tanto a los aspectos constructivos y tecnológicos de la misma como los aspectos estratégicos de la fase de estudio, entendiendo por ello el análisis de la oferta y la demanda, la afectación sobre el territorio y la red actual existente, las relaciones con otros medios de transporte y la conexión con los países limítrofes. Asimismo, se trata de hacer un análisis económico de la propuesta para estudiar la viabilidad de la inversión, sin dejar de lado el impacto ambiental que dicha infraestructura ocasionaría. En todo momento se hace referencia al tráfico de pasajeros y de mercancías, con objeto de realizar un estudio exhaustivo y completo.

La alta velocidad europea se encuentra presente en los países occidentales más desarrollados en una fase de continuo crecimiento. Con la anexión de los países de la Europa central y oriental a la Unión Europea, es de esperar un crecimiento aún mayor, al tratarse de una inversión en un modo de transporte más sostenible y competitivo para distancias medias, tanto en el tráfico de viajeros como de mercancías. La unificación de los criterios técnicos a la hora de construir líneas ferroviarias de alta velocidad facilita los trayectos internacionales, aumentando la velocidad comercial al no deberse efectuar paradas en las fronteras necesariamente. Dicho motivo es especialmente relevante en el tráfico de mercancías, ya que lo dota de una gran capacidad y lo hace muy competente frente al transporte por carretera.

La República Checa no se ha quedado atrás en la mejora de la red de transportes y el Ministerio de Transportes e Infraestructuras checo ya dispone en fase de estudio la construcción de una línea de alta velocidad. Dada la posición estratégica que ocupa la República checa en el centro de Europa, la construcción de una línea de alta velocidad en este país supone un paso adelante muy importante hacia la conquista ferroviaria del resto del continente, además de abrir las puertas a los países vecinos carentes de tales infraestructuras a seguir sus pasos para lograr una red de transporte ferroviario que mejore sus comunicaciones.

INDEX OF CONTENT

GRATITUDES I
ABSTRACT II
RESUMEN III
INDEX OF CONTENT IV
INDEX OF FIGURES VI
INDEX OF TABLES IX

1. INTRODUCTION AND OBJECTIVES 1

2. HIGH SPEED NEED IN THE CZECH REPUBLIC 3
  2.1. General information of the Czech Republic 3
  2.2. Czech transport infrastructure 4
  2.3. Czech railway infrastructure 6
  2.4. European context 9
  2.5. Benefits and disadvantages expected from high speed railway in the Czech Republic 12

3. OFFER AND DEMAND ANALYSIS 13
  3.1. Offer analysis 14
    3.1.1. Railway offer in the Czech Republic 14
    3.1.2. Railway offer in Central Europe 19
    3.1.3. Proposed model for the study 22
  3.2. Demand analysis 27
    3.2.1. Trip generation and attraction 27
      3.2.1.1. Society and demography 27
      3.2.1.2. Economy 32
      3.2.1.3. Trip generation and attraction estimation 38
    3.2.2. Trip distribution 40
    3.2.3. Modal split 43
      3.2.3.1. Influence of the price of the service and substitute services 43
      3.2.3.2. Influence of the accessibility of the service 44
      3.2.3.3. Influence of travel time and frequency of the service 45
      3.2.3.4. Influence of the quality of the service 46
      3.2.3.5. Modal split estimation 46
    3.2.4. Route assignment 50

4. PROPOSED NETWORK AND SERVICES 52
  4.1. Origin of the studies of high speed railway in the Czech Republic 52
  4.2. Network design and frontier connections 57
    4.2.1. Previous analysis 57
    4.2.2. Designed national route 63
    4.2.3. Frontier connections 65
    4.2.4. Stations 67
    4.2.5. Construction stages 70
    4.2.6. Consideration of freight transport 73
  4.3. Construction and technology 74
    4.3.1. New constructed lines 75
    4.3.2. Upgraded lines 79

4.4. General features of the service 83
4.4.1. Commercial speed..83
4.4.2. Operating high speed lines and their frequency 84
4.4.3. Fares 87

5. AFFECTATION TO THE TERRITORY AND THE CURRENT NETWORK ...88
5.1. Affectation to the accessibility of the network 88
5.2. Affectation to the travel time...89
5.3. Affectation to the commercial speed 93
5.4. Estimated changes of the transport modal distribution 96
5.5. Affectation to the freight transport 99

6. ECONOMICAL STUDY AND INVESTMENT VIABILITY 101
6.1. Expenses...101
6.1.1. Construction costs 101
6.1.2. Exploitation costs..103
6.2. Incomes...105
6.3. Investment viability analysis 107

7. ENVIRONMENTAL IMPACT ASSESSMENT...111
7.1. Occupation and affectation of soil 111
7.1.1. Description of the impact 111
7.1.2. Measures to reduce the impact 114
7.2. Energy consumption...114
7.2.1. Description of the impact 114
7.2.2. Measures to reduce the impact 116
7.3. Pollution...116
7.3.1. Description of the impact 116
7.3.2. Measures to reduce the impact 118
7.4. Noise and vibrations...118
7.4.1. Description of the impact 118
7.4.2. Measures to reduce the impact 120
7.5. Other impacts...120
7.5.1. Description of the impacts 120
7.5.2. Measures to reduce the impacts 121

8. CONCLUSIONS...122

9. REFERENCES 124

INDEX OF FIGURES

2. HIGH SPEED NEED IN THE CZECH REPUBLIC

Figure 2.1. Regions in which the Czech Republic is divided [E] 3
Figure 2.3. Distribution of transport modes. Own elaboration from data of [6] 5
Figure 2.5. Evolution of Czech rail transports in the last six years. Own elaboration from data of [6] 7
Figure 2.6. Main railway corridors in the Czech Republic [C] 8
Figure 2.7. Evolution of Czech rail passengers in the last years. Own elaboration from data of [6] 9
Figure 2.8. European high speed rail network in June 2008 [3] 10
Figure 2.9.a. Length of high speed lines over 250 Km/h at the end 2004 [3] 11
b. Length of high speed lines over 160 km/h to 250 Km/h at the end 2005 [3]..11
Fig 2.10. Development of high speed traffic in Europe (billion-passenger-Km) [3] 12

3. OFFER AND DEMAND ANALYSIS

Figure 3.1. View of Pendolino [B] 15
Figure 3.2. Czech Republic rail map [F] 16
Figure 3.7. Main rail corridors in Central Europe, with links to the surrounding territory [1] 20
Figure 3.8. Length of operated lines in EU and number of vehicles in 2005. Own elaboration from data of [6] 21
Figure 3.9. Map of Europe with the selected study zone [I] 22
Figure 3.10. Map of Central Europe separated by zones with their centroides and railway connections. Own elaboration 23
Figure 3.14. Density of population of the Czech Republic in 1996 [O] 28
Figure 3.16. Settlement and main population corridors of the Czech Republic [7] 29
Figure 3.18.a. Population of the biggest agglomerations in Central Europe in 2006. b. Population of the biggest cities in Central Europe in 2006. Own elaboration from data of [7] 31
Figure 3.19. Settlement and main population corridors of Central Europe [7]...32
Figure 3.20. Employment rates in the Central European countries in 2005 [E].33
Figure 3.23. Central European airports sorted according to their performance in 2006. Own elaboration from data of [7] 35
Figure 3.25. Goods transport flows exported and imported from/into the Czech Republic in 2007. Own elaboration from data of [6] 37

4. PROPOSED NETWORK AND SERVICES

Figure 4.1. High speed network proposal for the Czechoslovak Republic in 1990 [14] 53
Figure 4.2. Trans-European Transport Network [10] 54
Figure 4.3. Topographic map of the Czech Republic [O] 58
Figure 4.4. Geologic map of the Czech Republic [O] 59

Figure 4.5. Annual precipitation rates of the Czech Republic in mm [Q] 60
Figure 4.6. Forests in the Czech Republic [O]...61
Figure 4.7. Agricultural land in the Czech Republic [O] 62
Figure 4.9. High speed railway proposal for the inner Czech Republic. Own elaboration 64
Figure 4.10. High speed proposal in 2020 [14]...66
Figure 4.11. High speed railway proposal for the Czech Republic and its connections with the neighboring countries. Own elaboration...........................67
Figure 4.12. Virtual reproduction of the high speed stretch Praha – Beroun [1]71
Figure 4.13. Construction stages of the high speed railway proposal for the Czech Republic and frontier connections. Own elaboration 72
Figure 4.14. High speed railway network proposal for the Czech Republic with its stations. Own elaboration...74
Figure 4.15. Spatial layout of the high speed railway superstructure [1] 76
Figure 4.16. Disposition of the switches next to a high speed railway station [1] 76
Figure 4.17. Layout of a high speed bridge [1] 77
Figure 4.18. Cross section of the Soumagne high speed railway tunnel [19]....78
Figure 4.20. Upgrading works of a railway line [R] 81
Figure 4.21. Tilting train near Hokuto (Japan) [E]...83
Figure 4.23. Proposed high speed operating lines. Own elaboration 85

5. AFFECTATION TO THE TERRITORY AND THE CURRENT NETWORK

Figure 5.1. Rail map of the study zone before the introduction to high speed railway. Own elaboration from data of [3] 88
Figure 5.2. Rail map of the study zone after the introduction to high speed railway. Own elaboration from data of [3] 89
Figure 5.3. Isochrones for every hour of travel time from Praha before the introduction to high speed. Own elaboration 90
Figure 5.5. Isochrones for every hour of travel time from Praha after the introduction to high speed. Own elaboration 92
Figure 5.6. Isochrones of the differences in travel time from Praha before and after the introduction to high speed. Own elaboration 93
Figure 5.9. Inter-regional public transport modal distribution in the Czech Republic. a) Before introduction high speed. b) After introduction to high speed. 97
Own elaboration...97
Figure 5.10. Inter-regional public transport modal distribution in the study zone in Central Europe. a) Before introduction high speed. b) After introduction to high speed. Own elaboration 98
Figure 5.11. Current modal distribution of freight transport in the Czech Republic. Own elaboration from data of [6] 99

6. ECONOMICAL STUDY AND INVESTMENT VIABILITY

Figure 6.1. Evolution of investment expenditure in transport infrastructure in the Czech Republic in Czech Crowns (CZK) [1]..101

Figure 6.2. Comparison of unit investment costs for the construction of roads and high speed railway. Own elaboration from data of [1]...............................102
Figure 6.3. Comparison between investments of high speed railway and road infrastructures in the Czech Republic [1] 103
Figure 6.7. Estimated expenses and incomes for the high speed railway services in the Czech Republic. Own elaboration 106

7. ENVIRONMENTAL IMPACT ASSESSMENT

Figure 7.1. High speed railway cut in the line Madrid – Valladolid [T] 112
Figure 7.2. High speed railway bridge in the line Madrid – Valladolid [T] 113
Figure 7.3. Comparison of the energy consumption by transportation mode [21] 115
Figure 7.4. Comparison of CO_2 emissions by transportation mode [21]..........117
Figure 7.5. Noise protection walls in an urban space [U] 119

INDEX OF TABLES

2. HIGH SPEED NEED IN THE CZECH REPUBLIC

Table 2.2. Regions of the Czech Republic and their population in 2008 [E]........4
Table 2.4. Extension of rail lines in the Czech Republic (Km) [6]........................6

3. OFFER AND DEMAND ANALYSIS

Table 3.3. Basic economic indicators of Czech railway transport in 2006 [6]....17
Table 3.4. Breakdown of employees of railway main operators in 2006 [6] 18
Table 3.5 Locomotives in the Czech Republic by source of power in 2007 [6] .18
Table 3.6 Number of passenger vehicles and wagons in the Czech Republic in 2007 [6]...18
Table 3.11. Railway distances among all the centroides. Own elaboration from data of [G] and [H]..24
Table 3.12. Travel time among all the centroides. Own elaboration from data of [G] and [H]...25
Table 3.13. Railway commercial speed among all the centroides. Own elaboration from data of [G] and [H] 26
Table 3.15. Major areas of population concentration in the Czech Republic in 2007 [7]...28
Table 3.17. Basic demographic data of Central European countries in 2007 [7] 30
Table 3.21. GDP per capita in the Czech Republic’s regions in € in 2008. Own elaboration from data of [E] and [K] 33
Table 3.22. Cities over 100 thousand population in Central Europe exceeding 50% of the EU 27 GDP per capita average [7] 34
Table 3.24. National good transport flow in 2007 in thousand tonnes [7]..........36
Table 3.26. International tourism of the Czech Republic in 2006 [6] 38
Table 3.27. Trip generation and attraction estimation per year (as a function of K). Own elaboration from [E], [K] and all the previous data..............................39
Table 3.29. Trip distribution matrix in thousand trips per year. Own elaboration 41
Table 3.30. Trips by public transport mode in the Czech Republic in 2007 [6]..42
Table 3.31. Total departing / arriving trips for region sorted from most to least. Own elaboration...42
Table 3.32. Ranking of quality indicators by transportation mode. Own elaboration 46
Table 3.36. Probability matrix for high speed railway election among the studied zones. Own elaboration 48
Table 3.37.Trip distribution matrix for high speed railway in thousand trips per year. Own elaboration...49

4. PROPOSED NETWORK AND SERVICES

Table 4.8. High speed trip distribution in the Czech Republic in thousand trips. Own elaboration...63

Table 4.22. Considered commercial speeds for the high speed network. Own elaboration 84
Table 4.24. Proposed frequencies for every high speed operating line. Own elaboration 86
Table 4.25. Prices (in €) of the proposed high speed service. Own elaboration87

5. AFFECTATION TO THE TERRITORY AND THE CURRENT NETWORK

Table 5.4. Travel time for every connection in the study zone. Own elaboration 91
Table 5.7. Commercial speed of the railway lines in the study zone after the introduction to high speed in the Czech Republic. Own elaboration 94
Table 5.8. Differences of the commercial speed for every connection in the study zone before and after the introduction to high speed in the Czech Republic. Own elaboration....95

6. ECONOMICAL STUDY AND INVESTMENT VIABILITY

Table 6.4. Passenger·Km per year for the high speed railway service in the Czech Republic. Own elaboration 104
Table 6.5. Estimated exploitation costs for the high speed railway in the Czech Republic per year. Own elaboration from previous data and [S] 105
Table 6.6. Expected high speed railway income per year in the Czech Republic due to ticket issuing. Own elaboration 106
Table 6.9. Estimated coverage of the high speed railway services in the Czech Republic per year. Own elaboration 109

1. INTRODUCTION AND OBJECTIVES

This minor thesis tries to be a study on the introduction to the high speed railway services in the Czech Republic. It has to be noticed that high speed signifies at least 250 Km/h, therefore it means that special trains and dedicated lines will be needed, in addition to in cab signaling, rolling stock, operation rules, marketing, financing, maintenance systems, station emplacements… An upgrade of existing lines and classic trains must be done to operate up to about 200 Km/h. Moreover a lot of new features will have to be studied, such as reliability, comfort, accessibility, price, safety, frequency, time of travel, commercial speed, etc.

The Czech Republic high speed railway would suppose advantages for the whole society, as it offers a higher capacity of transport, reduces traffic congestion, helps economic development, promotes logical territory structure and helps to contain urban sprawl, respecting the environment and making an efficient use of land and energy.

Because of the generality of this study, several analysis and studies will need to be done. That is why the whole study has been divided into six main parts, which are the aims of this minor thesis:

1. High speed need in the Czech Republic
2. Offer and demand analysis
3. Proposed network and services
4. Affectation to the territory and the current network
5. Economical study and investment viability
6. Environmental Impact Assessment

First of all we will talk about the high speed need in the Czech Republic, according to the current transportation system and whether a introduction to high speed is necessary or not, explaining its general benefits and disadvantages.

Secondly we will try to make an offer and demand analysis so that we can estimate the demand of high speed railway regarding the current railway offer and other transportation modes. We will always talk about the Czech Republic and Central Europe, talking basically about the passenger transport but also referring to freight transport.

Then it will be possible to design a network in the national territory and its connections to the neighbor countries, according to the offer and demand analysis. The most important features of the new services will be explained, such as the constructive aspects, frequency, commercial speed, technology, fares, etc.

We will then study the affectation of the proposed high speed network to the territory and the current network, this means, the improvement of connections and relationships among national and international regions, the expected changes in the transport modal distribution and the affectation to the freight transport.

Moreover, we will make an economical study to know the expected incomes and expenses, besides doing an investment viability analysis to know whether the introduction to high speed railway in the Czech Republic is a profitable project or not.

In the same way, we will do an Environmental Impact Assessment analysis to explain all kinds of impacts the whole infrastructure would cause, giving some measures to reduce them.

Finally we will draw several conclusions about the introduction to high speed railway in the Czech Republic.

2. HIGH SPEED NEED IN THE CZECH REPUBLIC

Before doing a study of the introduction to high speed in the Czech Republic it is essential to know whether it is something needed or not, analyzing its benefits and disadvantages. To answer this question we will talk about some general information about the Czech Republic, the current transport infrastructure, focusing on its railway, at the same time that studying the European context of high speed railway.

2.1. General information of the Czech Republic

The Czech Republic is a landlocked country in Central Europe. The country borders Poland to the northeast, Germany to the west, Austria to the south and Slovakia to the east. The capital and largest city is Praha. The country is composed of the historic regions of Bohemia and Moravia, as well as parts of Silesia. The Czech Republic has been a member of NATO, since 1999 and the European Union, since 2004. As of 1 January 2009, the Czech Republic holds the Presidency of the Council of the European Union. [E]

The Czech landscape is quite varied. Bohemia, to the west, consists of a basin drained by the Elbe and the Vltava rivers, surrounded by mostly low mountains, such as the Krkonoše range of the Sudetes. The highest point in the country, Sněžka at 1,602 m, is located here. Moravia, the eastern part of the country, is also quite hilly. It is drained mainly by the Morava River, but it also contains the source of the Oder River. Water from the landlocked Czech Republic flows to three different seas: the North Sea, Baltic Sea and Black Sea.

Since 2000, the Czech Republic is divided into thirteen regions and the capital city of Praha. Each region has its own elected Regional Assembly and president. In Prague, their powers are executed by the city council and the mayor. [E] The regions are the followings:

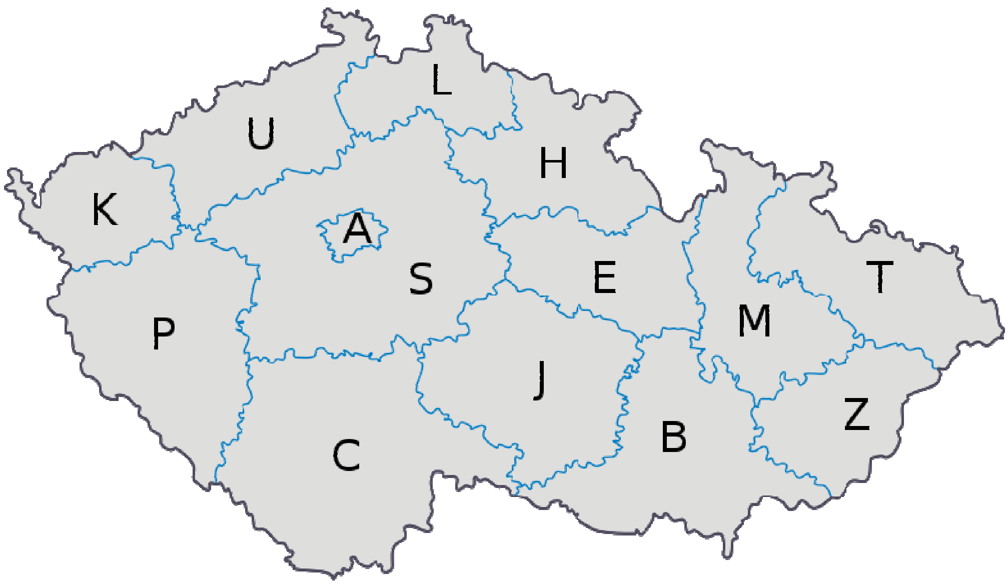


Figure 2.1. Regions in which the Czech Republic is divided [E]

The names of the regions and their population are shown below:

(Lic. plate)	Region	Capital	Population
A	Praha, the Capital City		1.223.368
S	Central Bohemian Region	Offices located in Praha	1.214.356
C	South Bohemian Region	České Budějovice	634.408
P	Plzeň Region	Plzeň	565.029
K	Karlovy Vary Region	Karlovy Vary	308.450
U	Ústí nad Labem Region	Ústí nad Labem	835.260
L	Liberec Region	Liberec	435.755
H	Hradec Králové Region	Hradec Králové	553.503
E	Pardubice Region	Pardubice	513.949
M	Olomouc Region	Olomouc	641.897
T	Moravian-Silesian Region	Ostrava	1.250.066
B	South Moravian Region	Brno	1,143.389
Z	Zlín Region	Zlín	591.026
J	Vysočina Region	Jihlava	514.470

Table 2.2. Regions of the Czech Republic and their population in 2008 [E]

As it can be seen in the table, the population is quite well distributed around the whole country, though it is true that a big part of it is concentrated in Praha and its surroundings.

The older 76 districts including three 'statutory cities' (without Praha, which had special status) lost most of their importance in 1999 in an administrative reform; they remain as territorial divisions and seats of various branches of state administration.

2.2. Czech transport infrastructure

Regarding its density, the Czech transport infrastructure is comparable with other EU states. Currently, investments into the technical upgrading of the transport infrastructure are in progress together with plans to expand the continuity of the infrastructure into the European transport routes. After 1992, the main focus in the Czech Republic has been on building the motorways and speed roads and the urban area bypasses. Investment into infrastructure increased after the Czech Republic entered the EU, especially as a result of the possibility to utilize financial means from EU Structural Funds.

In the Czech Republic, there are more than 55.000 Km of roads and motorways, from which 2.601 Km are E type (European road networks). By the end of 2004, 546 Km of motorways and 336 Km of speed communications were built. Up to now, the motorway network has achieved one-third of its planned extent. The density of the regional road network is sufficient. The density of the roads and motorways in the Czech Republic reaches 0,737 Km/Km^2 (in the rest of Europe it is 0,389 Km/Km^2), but the motorway density is only 0,006 Km/Km^2 (EU 0,015 Km/Km^2). [6]

The Czech Republic, compared to other EU countries, is insufficient in independent traffic lanes for non-engine transport, i.e. bike lanes. The adverse development is influenced by achieving a high level of motorization comparable with other West European countries.

Regarding the traffic volume, the number of passengers in the second half of the 90’s stagnated, nevertheless, the means of transport structure changed significantly. The number of passengers using public roads and the railway transport decreased for the benefit of individual automobile transport. Similar changes were recorded in the area of transport capacity, where the total indicator increased, but the capacity of public roads and railway transport dropped for the benefit of individual automobile transport. In the '90s, the capacity of freight traffic significantly shifted from railways to road transport, when the total goods freight transport rate dropped and the total freight transport capacity grew 50%. [6] Traffic volume on the roads and local connections increased significantly. In the next picture it can be seen the current distribution of transport modes in the Czech Republic:

Modal transport distribution

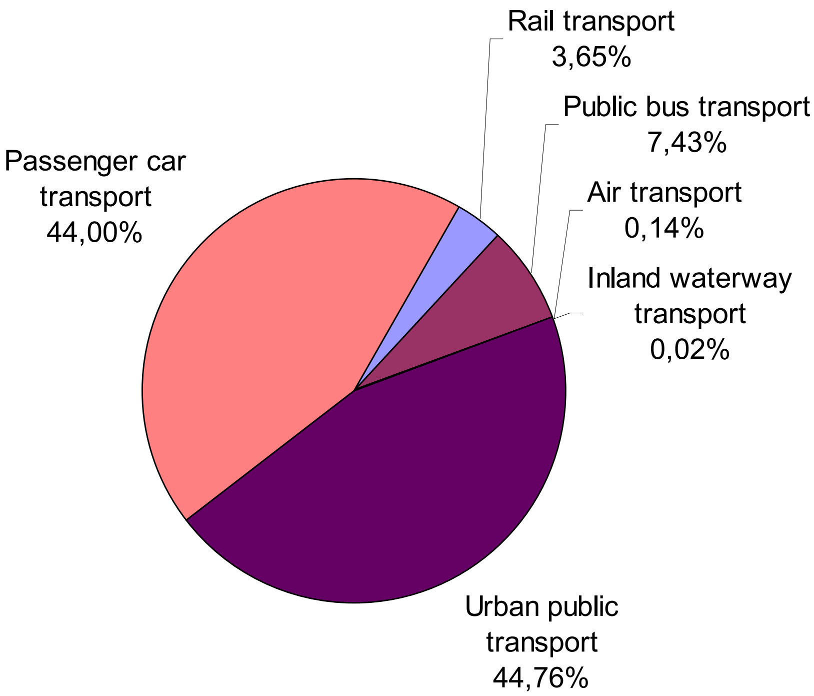


Figure 2.3. Distribution of transport modes. Own elaboration from data of [6]

So it is easily seen that the most used transport modes are urban public transports (for urban routes) and private car. The rail transport supposes a very little percentage in the daily traffic of the Czech Republic.

The length of utilized waterways in the Czech Republic is 664 Km, of which 303 Km are navigable rivers suitable for long-distance water transport. Water transport takes a relatively small portion of the transport capacity, which is partially due to being the only connection of the country to the Labe. [6]

Currently, the fastest growing transport system is aviation transport. There are 87 civilian airports in the Czech Republic, nine of which are public international airports. The vast majority of operations are performed at Praha - Ruzyně Airport, which provides over 94% of the overall performances in public transport and over 84% of aviation freight transport. Other airports are Brno - Tuřany, Ostrava-Mošnov and Karlovy Vary. The capacity of these smaller airports is not utilized frequently. In 1993, 1.358 million people went through customs in the Czech Republic; in 2004, that number increased to 10.125 million people. [6]

In the period after 1992, the technical infrastructure improved. Almost 90% of people used water from the public waterways. Regional differences also exist. For example, in Prague, 99.3%, and in the Central Bohemian region only 68.4% of inhabitants are connected to drains. Almost two-thirds of inhabitants are connected to gas supplies. The highest number of apartments connected to a gas supply is in the South Moravian region (82.2%), while in South Bohemia it is only 35.7%. [6]

2.3. Czech railway infrastructure

Concerning to the Czech railway infrastructures, it is to be said that there are 9,612 Km of railway network, all of them in operation, from which 1,866 Km are double-rail and multi-rail ways. The country is outstanding regarding the railway network density, because it has 0.120 Km of railways per Km2, while EU has only 0.047 Km/Km2). [6] Trains are accessible even in mountain areas, and the connections are relatively comfortable and easily accessible in terms of the railway station infrastructure and prices. However, passenger railway transport still must undergo some development to better accommodate the needs of passengers and link it to public transport, where no railways are available yet.

The extension of the Czech railways in the last few years is shown below:

	2003	2004	2005	2006	2007
Length of operated lines	*9.602*	*9.612*	*9.614*	*9.597*	*9.588*
by number of tracks					
single track	7.757	7.746	7.746	7.746	7.719
double tracks and more	1.845	1.866	1.868	1.851	1.869
by gauge of tracks					
standard gauge	9.500	9.511	9.512	9.495	9.486
narrow gauge	102	101	102	102	102
by nature of traffic					
passenger only	486	47	47	11	10
goods only	211	230	309	249	152
passenger and goods transport	8.905	9.335	9.258	9.337	9.426
Total non-electrified lines	***6.659***	***6.630***	***6.617***	***6.556***	***6.528***
Total electrified lines	***2.943***	***2.982***	***2.997***	***3.041***	***3.060***

Table 2.4. Extension of rail lines in the Czech Republic (Km) [6]

As it can be seen, the extension has remained almost constant, despite the electrified lines are slowly growing up against the non-electrified ones. In addition to that, it can also be seen that the multi-operability lines (passengers and goods) are becoming more common in the rail traffic.

Passenger transport is 99% provided by Czech Railways, which belongs to the largest companies in the Czech Republic and offers railway transport on the territory of Bohemia, Moravia and Silesia. The other most significant companies are Viamont, OKD Transport and Unipetrol Transport. [6]

More than 7,000 trains run daily on Czech railways, transporting on average about half a million passengers every day. In annual terms, over 178 million passengers and over 100 million metric tons of goods are transported, being the average transport distance of passengers over 170 Km. [6] The share of goods transport increases in the long term for private railway transporters. It is predominantly used to transport bulky and powdery goods. Its benefit is relative speed and independence from the unpredictable situation on highways. On the other hand, railway freight carriers are limited by the extent of the railway.

On the next graph, it can be seen the present situation of passenger and goods rail traffic in the Czech Republic:

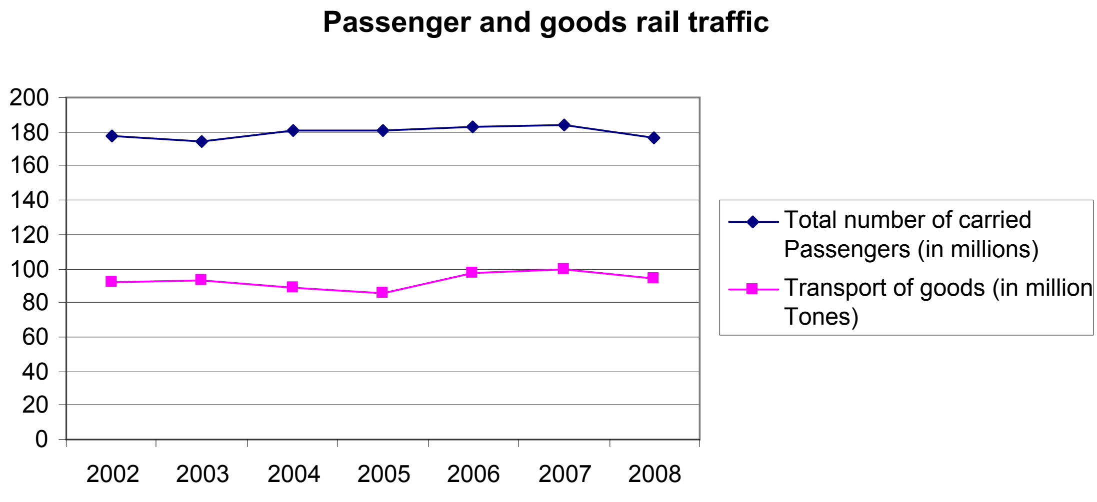


Figure 2.5. Evolution of Czech rail transports in the last six years. Own elaboration from data of [6]

The Czech Republic has defined four main railway corridors that are undergoing a priority modernization, which can be seen in the picture below:

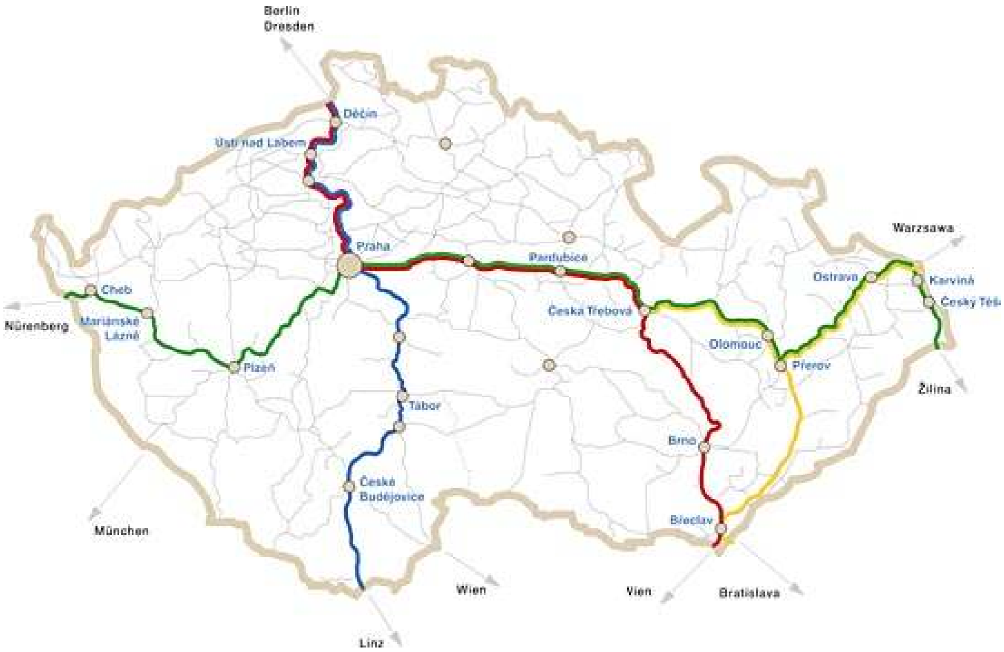


Figure 2.6. Main railway corridors in the Czech Republic [C]

These corridors are:

1. German/Czech border - Děčín - Praha - Česká Třebová - Brno - Břeclav - Czech/Austrian border
2. Břeclav - Přerov - Karviná including Přerov - Česká Třebová
3. German/Czech border - Cheb - Plzeň - Praha - Česká Třebová - Czech/Slovak border, overlapping in the section Přerov - Dětmarovice with the Second Corridor
4. German/Czech border - Děčín - Praha - Tabor – České Budejovice – Czech/Austrian border, overlapping in the Děčín - Praha section with the First Corridor.

The modernization targets of these four corridors result from international treaties that Czech Republic concluded and from Czech Railways´ actions such as the connection of core railways to main European railway lines, meet the requirements of the Czech Republic’s integration into European structures (EU, NATO), decrease the negative effects on the living environment, improve the safety with more elaborated technological devices, increase commercial speed in passenger railway transport, improve the reliability and periodicity in goods transport and get a wider offer of services for transporters (international combined transport).

After the Czech Republic's accession to the European Union, railway transport lost one major advantage over road transport: the ability to cross international borders relatively quickly. Before EU entry, diesel trucks had to wait long hours before passing into the Czech Republic. Rail freight carriers now have to find a new way to compete. While freight transport through the Czech Republic has recently increased, the railway freight carriers, unlike highway freight carriers, weren't able to profit.

On the graph below it can be seen the decline of transport passenger services in the nineties because of the transition to road transport:

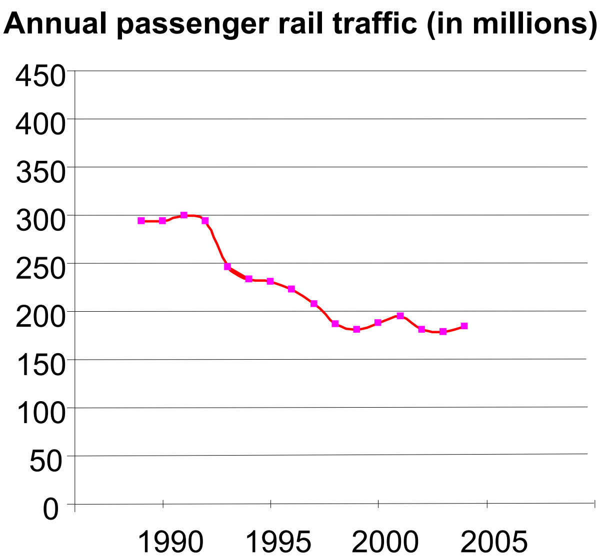


Figure 2.7. Evolution of Czech rail passengers in the last years. Own elaboration from data of [6]

A development after 2000, though, is quite stable at around 180 million people. It is expected that with the introduction to high speed the tendency changes into a better rail use rate.

2.4. European context

Regarding the European railway situation, it is to be mentioned that Common Transport Policy is a crucial component of the EU's Single Market. Major strides in the development of high speed railways in Europe galvanize interest in the integrative potential of the high speed railway services. Plans for establishing a high speed network include extension of some 35,000 km, of which 20,000 km are new dedicated tracks. [3]

While high speed trains shall connect all continental EU Member States and Britain, common high speed network with new tracks with speed over 250 km/h shall interconnect crucial EU areas. In this year, segments of a high speed network are set to open in six countries across Western Europe.

The next picture shows the current European rail network, where different speed railways are specified:

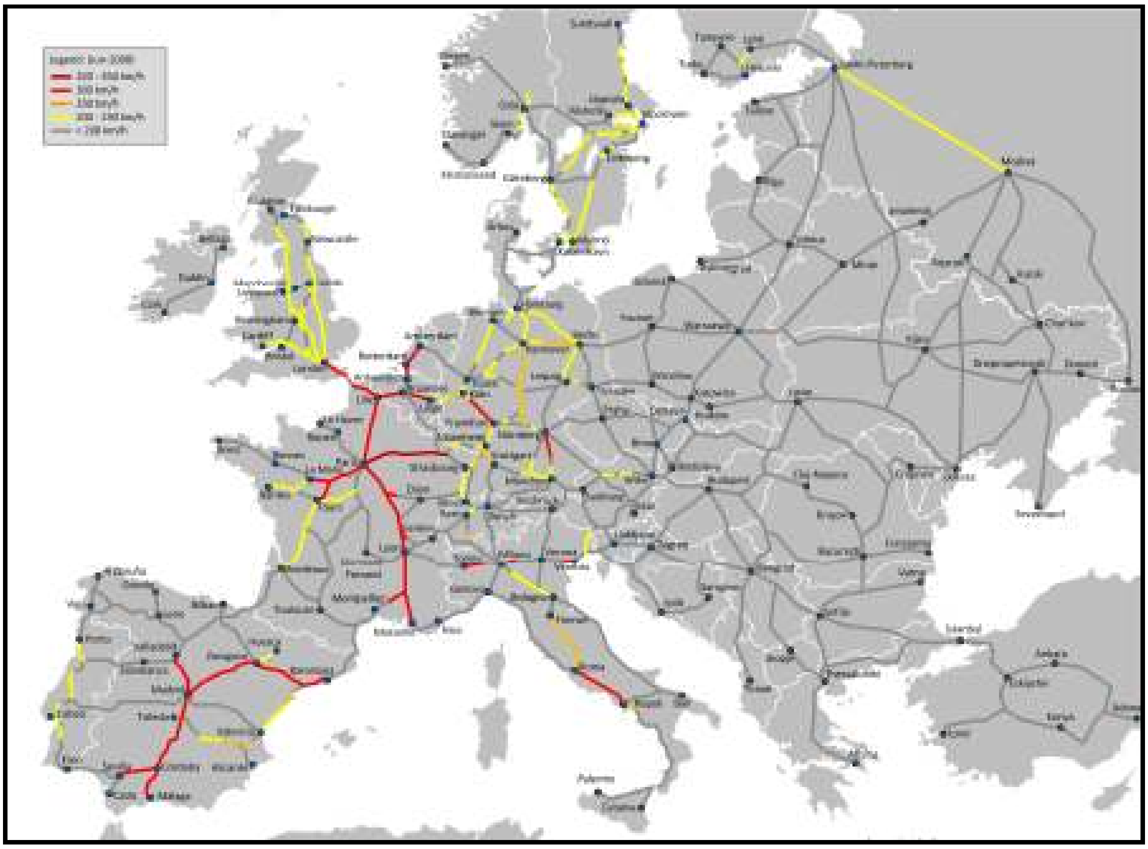


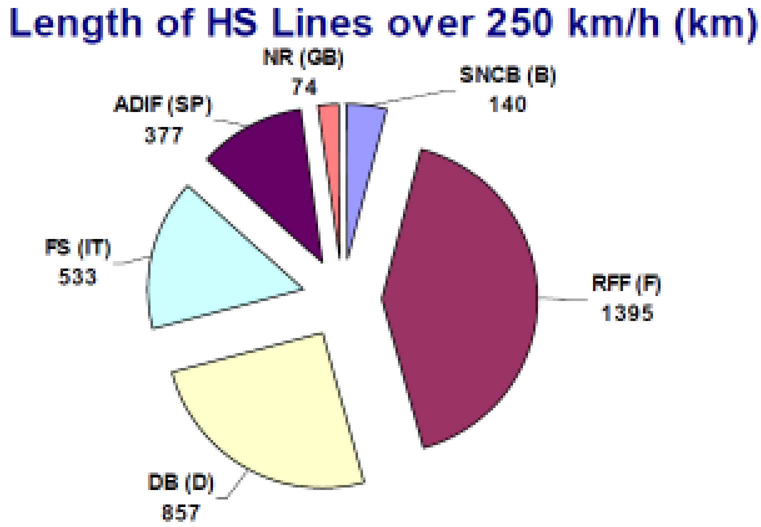
Figure 2.8. European high speed rail network in June 2008 [3]

Priorities in planning, development and funding of a high speed network were established in a series of reports at the beginning of the 1980's. In late 1990's, following a formal Commission proposal, the EC Council of Ministers established an action programme designed to complete the Single Market in European transport. One of its five objectives is 'the provision of high-quality links between the major urban centers, including high speed links'. This act established the notion of 'Declaration of Community Interest', which opens the door to EU funding of projects considered essential to the Community as a whole. The unexpected financial and social success of TGV helped attract international attention to rapid rail as both a hi-tech and a solid component of transport infrastructure. [3]

Europe's emerging high speed network combines new lines built over the past twenty years with conventional routes upgraded for 160 Km/h or 200 Km/h operations. Actually, the top European high speed trains are designed to operate at up to 350 km/h in commercial service. They include French TGV POS for 320 km/h, German ICE 3 for 330 Km/h and Siemens' class 103 for Spanish RENFE for up to 350 Km/h. [3]

European high speed traffic has tripled in the space of ten years. Market share increased strongly, with the situation completely overturned in some markets. For journey times up to 2 1/2 hours, rail's share of the rail/air market is over 75%, with 50% up to 4 hours. [3]

Next diagrams show the length of high speed lines in the western countries of Europe, both lines over 250 Km/h as from 160 Km/h to 250 Km/h:



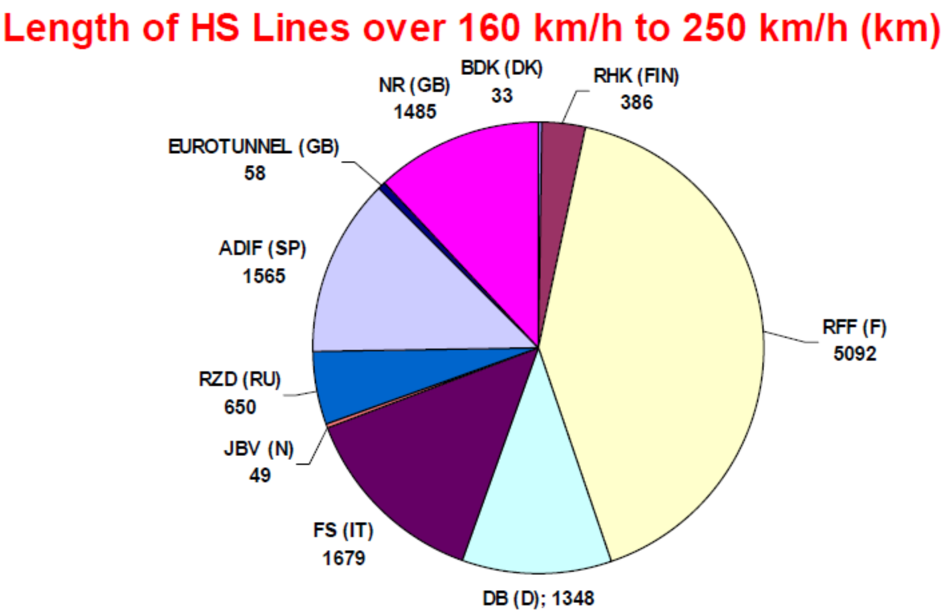


Figure 2.9.a. Length of high speed lines over 250 Km/h at the end 2004 [3]
b. Length of high speed lines over 160 km/h to 250 Km/h at the end 2005 [3]

Investments in expensive high speed rail lines are really only justified for links with very heavy traffic flows. Despite it, new lines are difficult to obtain in some areas (densely populated ones, sensitive cultural or natural environments). Fast train technology, geared for substantially higher speeds on conventional main line tracks, involves the application of active (Fiat) or passive (Talgo) car body tilt technology for increased passenger comfort in curves by means of compensation of lateral acceleration and soft suspension bogies (ABB). In case of soft suspension bogies, the main importance lies in bogie’s design featuring reduced dynamic forces. As opposed to traditional bogies, this ABB´s concept allows wheel axles to respond to curves and achieves 40% higher speed through curves. [3]

A recent study *Étude Trafic Passagers 2010-2020* [3] reveals that by 2010 high speed will have gathered an extra 51 billion passengers-km, two thirds of which will have come from other transport modes.

On the next graph it can be seen the increase of the high speed traffic in Europe within the last few years:

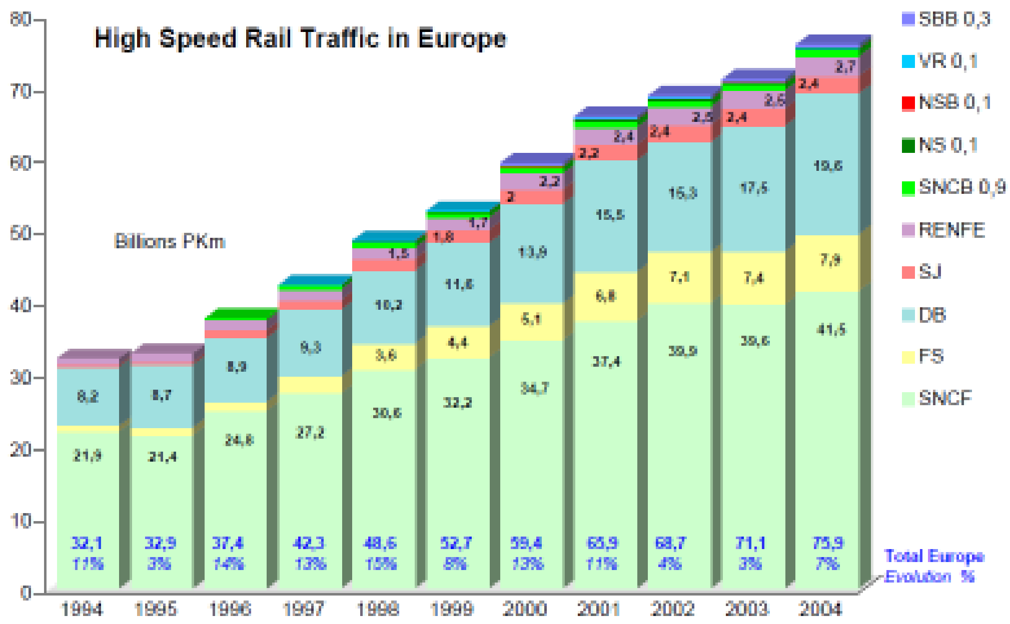


Fig 2.10. Development of high speed traffic in Europe (billion-passenger-Km) [3]

With the incorporation of several other countries to the high speed network, it is clearly visible that high speed railway is winning the battle of passenger transportation in medium distances in all Europe.

2.5. Benefits and disadvantages expected from high speed railway in the Czech Republic

Social viability of high speed railway in the Czech Republic is based on two arguments. One is that a high speed railway will draw peripheral regions closer to the EU's geographic, political and economic centre. This is especially crucial for the Czech Republic and peripheral regions in Eastern Europe where the main impetus for development will have to come via political initiative rather than existing economic demand. Another social argument in favor of high speed railway is that they serve the public interest as an environmentally sound alternative to road or air travel, reducing motorways and air traffic and therefore decreasing the pollution levels.

Studies show that high speed links maximize profitability in medium distance travels, it means between 200 and 500 Km, requiring large population density at either end, high existing market demand based on current and projected traffic flows and journey times under 3 or 4 hours duration, beyond which they can no longer compete successfully with airlines for business passengers. This is especially interesting for the Czech Republic, because of its medium territory extension and the market distribution based on its strategic situation in Central Europe.

Due to the fact that the development of a modern motorway network in the Czech Republic continues being successful and builds on the European network, a majority of trucks from the Balkans, Austria, Slovakia and Poland go solely through the Czech territory causing unprecedented environmental degradation, frequent environmental accidents and other problems. Instead, high speed railways offer larger superiority in terms of economy and ecology, as its land occupation is about 25 meters width, while highways require over 100 meters. Moreover, high speed railway is 8 times less toxic than private cars and 30 times less toxic than trucks. Its application in the mainland and Europe scale represents an optimal solution of transport systems in relation to transport by road, water and air modes.

High speed lines may indirectly facilitate the flow of goods, by freeing up more regular rail capacity on conventional lines. Thus, there will be a gain against road transport, which had been increasing due to the entrance of the Czech Republic into the EU. The effect of high speed railway will be to increase the flow of national and international passenger traffic bringing a visible and direct benefice to the increased mobility of the Czechs and Europeans, even if the majority of those still serve the domestic markets. High speed introduction may also change the tendencies in the transport modal use in the Czech Republic (see fig. 2.3).

Moreover, development of high speed railway offers intriguing possibilities for successful commercial application of advanced technologies, which would increase the transport alternatives and convenience for millions of Czechs and Europeans. Its integrative potential is determined by implementation of technical standards of interoperability and high development costs. Instead of traditional neglect of railways, high speed rail can help the EU endeavor to maximize the advantages of the Single Market.

The main disadvantages of the introduction to the high speed railway in the Czech Republic are the construction and operation costs, which suppose a big part of the general budgets of the State, as well as the ticket prices travelers and companies would have to pay. In addition to that, the environmental impact should be taken into account due to its great dimensions, considering not only the construction impacts but the noise emissions, the energy consumption, the vibrations and the landscape barriers.

Because of all the previous cited reasons, high speed railway in the Czech Republic is something that would contribute more benefits rather than disadvantages for the whole Czech community, in addition to satisfy the faster transport needs of goods and passengers.

3. OFFER AND DEMAND ANALYSIS

Once we are sure of the necessity of the introduction to high speed in the Czech Republic, next step is to do an offer and demand analysis so that we can know which cities should be connected and where would the railway better go through, as well as to plan the whole service. Both the offer and demand analysis are very important due to the fact that while passenger traffic studies are mainly based on their demand, goods traffic is more dependent to the offer.

Offer and demand are always highly related, being the current demand influenced by the offer, making it very difficult to estimate. However, we will try to find the potential demand of high speed in the Czech Republic with sequential models, studying the main factors that take part on them. As passengers require better services than goods, we will focus more on passengers demand rather than on freight's. In all cases one refers to the Czech Republic and the closest Central Europe, due to its strong influence.

3.1. Offer analysis

To talk about the offer of the Czech railways we need to describe the current railway network and its features, as in the national territory as in Central Europe. Most general information has been explained in the previous chapter, such us the Czech rail lines extension (see fig. 2.4), the passenger and goods rail traffic (see fig. 2.5), the main railway corridors in the Czech Republic (see fig. 2.6) and the high speed corridors in Europe (see fig. 2.8).

We will talk now about other important features of the railway offer in the Czech Republic, like the categories of Czech trains, the main railway services, general fares, the network interconnection and territorial scope of the service, railway safety and security, some basic economic indicators, the number of employees working in the whole service, the number of locomotives, passenger vehicles and wagons in the Czech Republic railways and some other technical information. Moreover, we will analyze the Central European network and its features, including the existing high speed lines, and we will analyze the global offer regarding distances, travel times and commercial speeds of the railway service with a proposed model for the study.

3.1.1. Railway offer in the Czech Republic

Like in all the countries, there are several categories of trains, depending on their scope, commercial speed, distances, etc. The categories of Czech trains sorted from slow to fast are [A]:

• Osobní (Os) - local train that stops everywhere.
• Spěšný (Sp) - local train that usually skips little villages.
• Rychlík (R) - regional train, with stops in major towns. They are commonly used for longer distances.
• Express (Ex) - faster regional train.

• Intercity, Eurocity (IC, EC) - pretty modern longer distance train, with stops in major cities only.
• Supercity (*Pendolino*) - fastest new trains, which operate between biggest cities and need compulsory reservation.

One of the last investments of the Czech railway vehicles has been the *Pendolino,* which goes up to 230 Km/h, though due to the Czech Republic's maxim speed restriction, it goes only at 160 Km/h. Since December 11th of 2005, passengers can use their comfortable and modern units. These trains depart from Prague on two lines. For the line that goes from Prague to Vienna and Bratislava, the *Pendolino* is linked to the higher quality EC or IC routes. On these trains, passengers pay the usual price for transport as in other trains with higher quality EC or IC. For the line that joins Prague and Ostrava, the *Pendolino* line is classified as SuperCity and carries the name "SC *Pendolino*".

Figure 3.1. View of Pendolino [B]

Czech Railways provide international, long-distance domestic, regional and suburban services, sleepers and couchette coaches, dining cars, carriage of handicapped passengers, besides carriage of baggage and bicycles.

Regarding the fares, prices for train tickets are tariffs determined according to the number of kilometers covered. A domestic ordinary adult ticket for a 100-kilometer trip costs about CZK 190. For international travel, passengers would pay from CZK 1,350 for a train between Prague and Berlin. A ticket on the *Pendolino* for an adult costs around CZK 400 (1-150 Km in second class) to CZK 750 (301–450 Km in first class). For all types of connections, trains usually offer significant discounts for children up to 15 years, seniors and disabled persons. A 25% discount on regular tickets is given to In-card/Rail plus holders. [A]

Looking into detail the Czech Republic rail map we can see the national territorial scope of its railways and their interconnections:

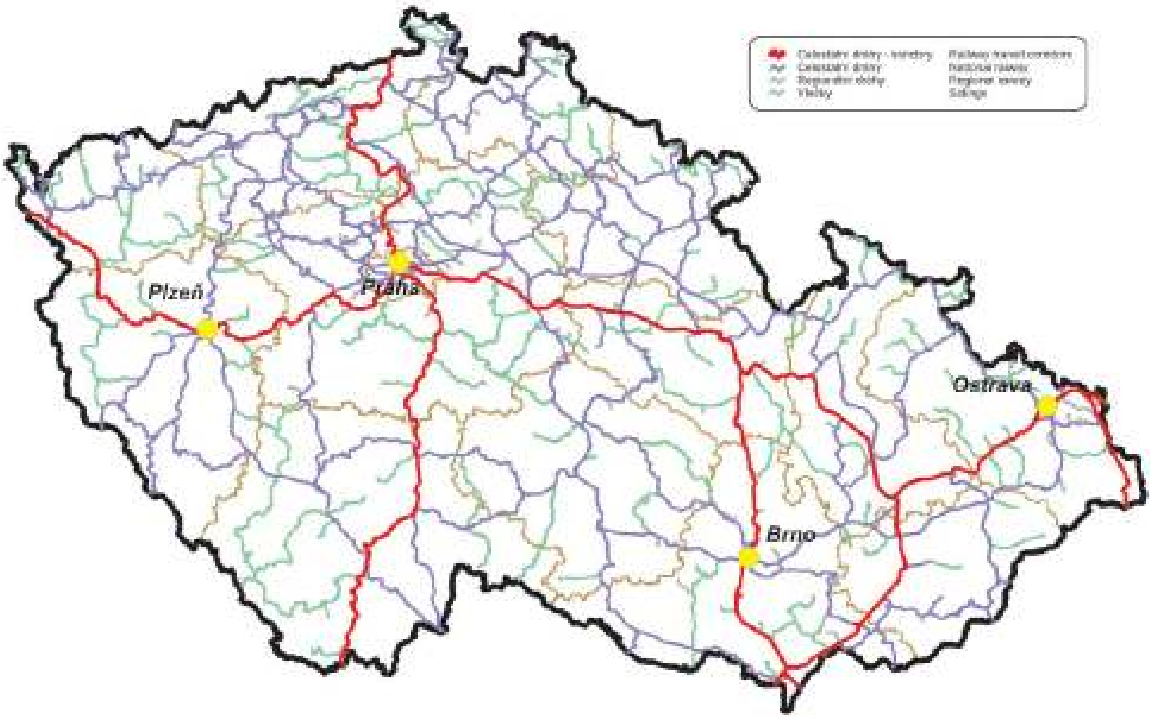


Figure 3.2. Czech Republic rail map [F]

As it can be seen on the map, the territorial scope of the Czech railway is excellent; despite most of the rail lines are single and non-electrified. The main corridors are shown thicker, and it can be noticed the importance of Prague, Brno and Břeclav's (in the south of Brno) junctions. The northern and eastern part of the country has a major density of railways, according to the population distribution (see fig. 2.2), being Prague and the Central Bohemian region the densest ones. However, the southern-western part of the Czech Republic has good rail communications too, not having any point of the territory further than 50 Km to any railway.

Prague is the main railway centre. The most important train stations are:

• Hlavní nádraží (Main Station), which is the biggest station. It has ticket offices, a train information centre and a Prague Information Service.
• Nádraží Holešovice (Holešovice Station) is usually the terminus for trains from Berlin and other destinations to the north.

Regarding the security of Czech railways, it should be said that grade crossings are not very safe. Most of the existing 8,511 grade crossings are unsecure (drivers are only alerted with the warning cross). Only 826 grade crossings are equipped with automatic lightning devices and crossing barriers - the highest level of crossing safety. Investments provided by the Ministry of Transport are preferentially intended for improvement of safety on grade crossings. [A]

To describe the offer of the Czech railway it is essential to talk about its economic dimensions. Thus, some basic indicators are shown below:

Enterprises	55
Employees (actual persons)	62.517
Wages excluding other personnel expenses (mill. CZK)	15.631
Other personnel expenses (mill. CZK)	803
Average monthly gross wage per actual person (CZK)	20.853
Revenues (mill. CZK)	55.203
of which:	
Sales (mill. CZK)	43.520
of which:	
Sales of own goods (mill. CZK)	863
Sales of services (mill. CZK)	42.429
Sales of goods for resale (mill. CZK)	228
Outputs, including trade margin (mill. CZK)	43.985
Book value added (mill. CZK)	16.556
Expenses (mill. CZK)	55.305
of which:	
Production consumption (mill. CZK)	27.429
Expenses of goods sold (mill. CZK)	160
Equity capital, 31 Dec (mill. CZK)	40.826
Acquisition of fixed assets (mill. CZK)	6.158
of which:	
Tangible fixed assets (mill. CZK)	5.898
Intangible fixed assets (mill. CZK)	260
Tangible fixed assets at net book value, 31 Dec (mill. CZK)	42.830
Intangible fixed assets at net book value, 31 Dec (mill. CZK)	619
Inventories, 31 Dec (mill. CZK)	2.074
Book value added per worker (thousand CZK)	265
Percentage of production consumption in outputs (%)	62,36

Table 3.3. Basic economic indicators of Czech railway transport in 2006 [6]

From the table can be extracted that we are talking about 55.000 mill. CZK of expenses and revenues, over 40.000 mill. CZK of fixed assets, and over 60.000 employees. All these indicators show not only the big size of the Czech railway enterprises, but also its good performance. The employees of the Czech railways can divided into several categories, which are:

General Administration - management	5.223
Train crews and station staff	27.961
Locomotive crews and rolling stock maintenance	15.949
Other activities	13.384
Total	**62.517**
of which	
Females	18.084
Males	44.433

Table 3.4. Breakdown of employees of railway main operators in 2006 [6]

Besides the Czech railways companies organization and economical information explained above, some other technical information such us the type and number of locomotives, passenger vehicles and wagons should be mentioned. Thus, the current locomotives in the Czech Republic are:

	Number of locomotives	**Traction power (thousand kW)**
Electric	971	2.530
Diesel	1.416	1.158
Steam	27	18
Total	**2.414**	

Table 3.5 Locomotives in the Czech Republic by source of power in 2007 [6]

As it can be seen, though electric locomotives traction power is the highest, the most used are the diesel ones, because of its lower prices. There are still some steam locomotives, clearly obsolete.

The passenger vehicles and good transport wagons existing in the current rail network are:

Passenger cars	2.215
Trailers to railcars	2.255
Couchette coaches, sleeping cars	103
Dinning cars	43
Total number of passenger vehicles	**4.616**
Privately owned wagons	9.487
Wagons owned by the commercial rail operators	*38.172*
of which	
covered wagons	6.412
high sided wagons	22.150
flat wagons	6.255
other wagons	3.355
Total number of wagons	**47659**

Table 3.6 Number of passenger vehicles and wagons in the Czech Republic in 2007 [6]

In the table we can see that the major part of the Czech rail traffic is due to goods transport, as the number of wagons is over 10 times the number of passenger vehicles. In addition to that, most of the wagons are owned by commercial rail operators, though about a 20% are private, being most of them high sided wagons.

3.1.2. Railway offer in Central Europe

Regarding the European railway offer affecting the Czech Republic, it is to be said that our interest is in most part of Central Europe due to Czech Republic position. The transport corridors in Central Europe are divided in three main categories: north-south routes, west-east routes and significantly diagonal routes. [1]

The main north-south routes are:
• Amsterdam - Brussels - Lille - Paris - Lyon - Marseille
• Amsterdam / Hamburg - Köln - Frankfurt - Basel - Bern / Zürich - Milan
• Hamburg - Hannover - Nürnberg - München - Innsbruck - Verona
• Berlin - Leipzig - Erfurt - Nürnberg - München - Innsbruck – Verona
• Berlin - Leipzig - Erfurt - Nürnberg - München - Salzburg - Ljubjana - Trieste
• Berlin - Dresden - Prague - Linz - Graz - Zagreb
• Berlin - Dresden - Prague - Vienna / Bratislava
• Gdansk - Warsaw - Katowice - Ostrava / Zilina - Břeclav / Bratislava - Vienna

The main west-east routes are:
• London - Lille - Brussels - Cologne - Dortmund - Hannover - Berlin - Poznan - Warszawa
• Frankfurt - Erfurt - Leipzig - Dresden - Wroclaw - Katowice - Krakow
• Nürnberg - Linz - Wien - Budapest
• Paris - Saarbrücken - Mannheim - Frankfurt - Leipzig - Berlin - Poznan - Warszawa
• Paris - Saarbrücken - Mannheim - Frankfurt - Leipzig - Dresden - Wroclaw - Krakow
• Paris - Strasbourg - Karlsruhe - Stuttgart - Munich - Salzburg - Vienna - Budapest
• Lyon - Torino - Milan - Verona - Venezia - Trieste - Zagreb

Significant diagonal routes are:
• Hamburg - Berlin - Prague - Bratislava - Budapest
• Warsaw - Katowice - Brno / Bratislava - Vienna - Villach - Venezia
• Amsterdam - Cologne - Frankfurt - Nürnberg - Linz - Wien
• Paris - Dijon - Bern - Milan
• Lyon - Geneva - Zürich - München - Regensburg - Prague - Ostrava - Krakow

On the next figure all these corridors in Central Europe are shown:

Figure 3.7. Main rail corridors in Central Europe, with links to the surrounding territory [1]

Some parts of this rail network, especially in the western countries, are high speed railways (see fig. 2.8). As it can be seen, the highest railway density takes place in Germany, while in the Czech Republic there are only four main rail corridors (see fig. 2.6). There are two main routes, one from north to south connecting Austria to northern Germany and another significantly diagonal connecting Poland to eastern Germany. They are crossed in the capital, Prague.

Some of the routes have sections under construction of high speed, such as: [1]

• Leipzig – Erfurt of the route Berlin – Frankfurt / Nürnberg
• Erfurt – Ebenfeld of the route Leipzig – München
• Stuttgart – Ulm of the route Karlsruhe / Mannheim – München
• Wien – St. Pölten of the route Wien – Linz

Analysing the high speed network one can see where the biggest lack of high speed railway in Central Europe is located. The main deficits are: [1]

• Erfurt – Eisenach – Fulda of the route Berlin – Frankfurt
• München – Salzburg of the route München – Wien
• München – Zürich of the route München – Milano
• München – Praha
• Dresden – Praha

Thus, two of the biggest deficits of high speed routes are connections between Germany and the Czech Republic, as long as the expansion to the eastern part of Central Europe is something interesting, what we have clearly seen in the previous chapter.

The most important region close to the Czech Republic is the conurbation of Munich, through which links can be realized both to northern Italy, and through Strasbourg to Paris. Linking Prague to Munich also allows (in Regensburg) link to the Danube corridor and therefore be linked to the route Frankfurt - Nürnberg - Linz - Wien. Similarly important are the links to Prague via Dresden with directions Leipzig - Frankfurt and Berlin - Hamburg. By the way, Brno is an important connection to the Danube corridor in the area of Vienna and Ostrava from the corridor Dresden - Katowice - Krakow.

In the next graph the length of railway lines and the number of vehicles in most of the EU countries are shown, most to least:

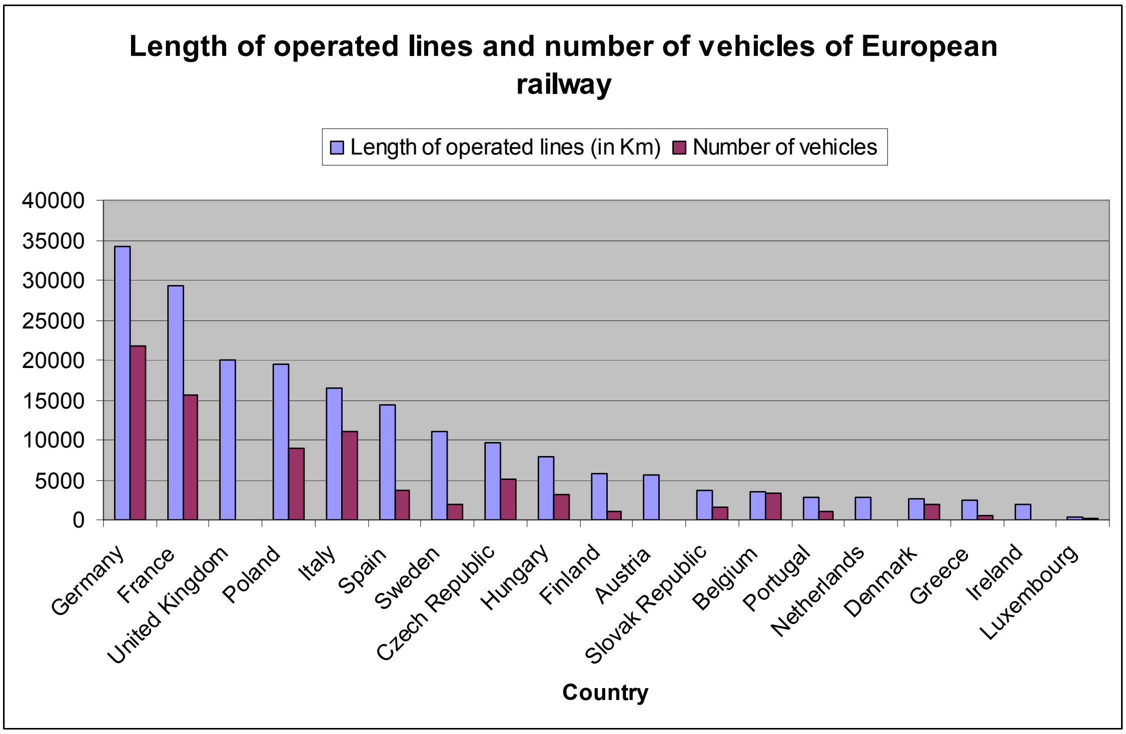


Figure 3.8. Length of operated lines in EU and number of vehicles in 2005. Own elaboration from data of [6]

As it can be noticed, Germany is the EU country with more length of operated lines, being followed by France, the UK and Poland, though Italy has more vehicles on its railways than Poland. The Czech Republic, despite being a relatively small country, has much more operated rail lines than many other countries in the EU, even some of the biggest ones. The same happens with the number of vehicles, making it clear that it is one of the countries in the EU with highest railway density.

3.1.3. Proposed model for the study

To study the global railway offer, we have divided our study zone in several parts. Each of these parts will have a centroid, which we will use as the representative point of that part. We have tried to choose a sufficient number of zones, well distributed in the territory, considering the most important cities of them. The chosen points from the Czech Republic and Central Europe are:

1. Praha
2. Pardubice
3. Ústí nad Labem
4. Plzeň
5. České Budejovice
6. Dresden
7. Olomouc
8. Brno
9. Linz
10. Leipzig
11. Wroclaw
12. Nürnberg
13. Ostrava
14. Berlin
15. Bratislava
16. Wien
17. Salzburg
18. Erfurt
19. München
20. Katowice
21. Trenčín
22. Stuttgart
23. Hannover
24. Frankfurt
25. Innsbruck
26. Graz
27. Budapest
28. Lodz
29. Warszawa
30. Zürich

In the next maps, the location of the study zone is shown, as well as the 30 parts in which we have divided it with their centroides and railway lines:

Figure 3.9. Map of Europe with the selected study zone [I]

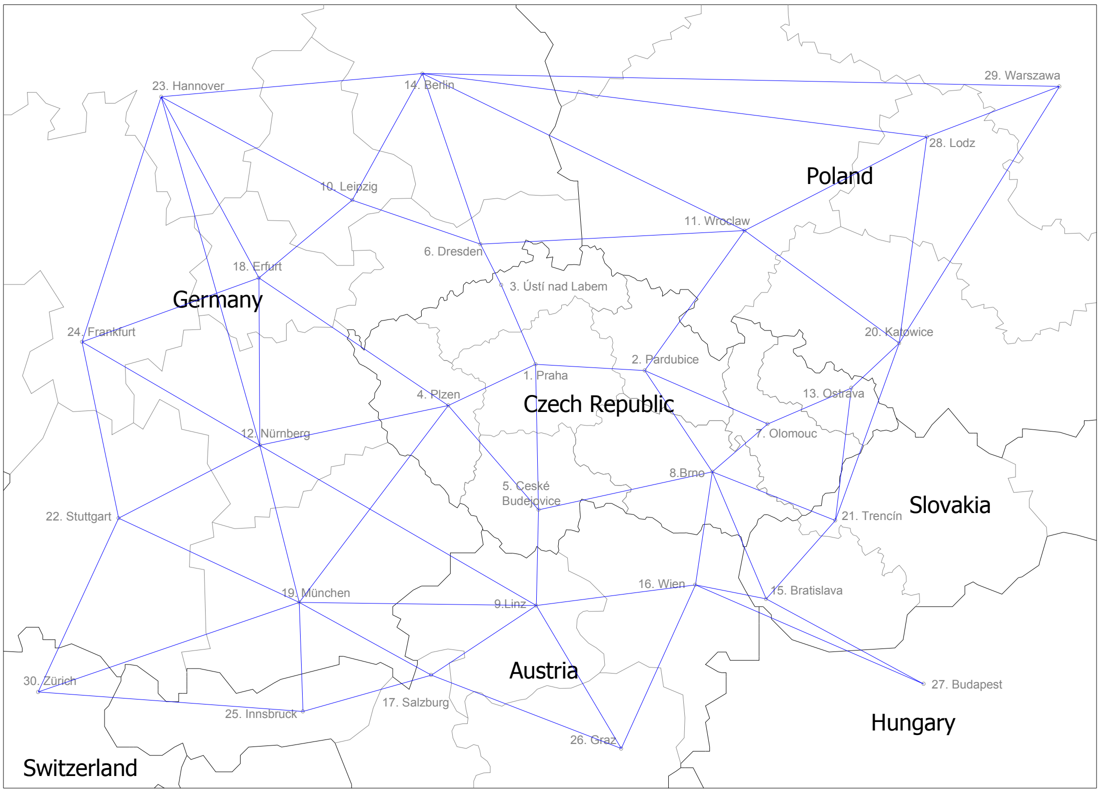


Figure 3.10. Map of Central Europe separated by zones with their centroides and railway connections. Own elaboration

The eight parts into which we have divided the Czech Republic are well distributed along the whole national territory, and their cities are the most populated and important in their respective regions. The parts into which we have divided the neighbor countries are a little bit bigger, as much as they are less populated and further away from the Czech Republic. The represented regions must not be confused with real regions of the Central European countries, though some of them are coincident.

Regarding the railway network shown in the second map, what we have represented is a graph with the lines we are considering in our study. These lines have been drawn in a schematic way, connecting the centroides with a straight line. All the information we are going to extract from our proposed study model has been considering this graph.

Considering the railway distances among all the cited points we have the following table (the numbers represent the number of the centroid):

Railway distances (in Km) among the 30 centroides

Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	0	104	106	114	169	192	250	255	294	309	348	355	356	366	396	404	421	426	440	458	477	681	574	588	612	544	650	600	705	755
2	104	0	210	218	273	296	146	151	398	413	244	459	252	470	292	300	525	530	544	354	373	785	678	692	716	510	546	496	601	859
3	106	210	0	220	275	86	356	361	400	203	357	461	462	260	502	510	527	320	546	547	583	777	468	577	718	650	756	609	736	861
4	114	218	220	0	136	306	364	369	261	423	462	241	470	480	510	451	388	491	326	572	591	567	688	474	498	511	699	714	819	641
5	169	273	275	136	0	361	336	236	125	478	517	377	442	535	377	315	252	595	405	544	458	646	743	610	447	375	563	769	791	705
6	192	296	86	306	361	0	442	447	486	117	271	381	548	174	588	596	613	234	573	461	669	691	382	491	745	736	842	523	650	888
7	250	146	356	364	336	442	0	100	439	559	390	605	106	616	241	249	566	676	690	208	293	931	824	838	761	459	495	439	455	1005
8	255	151	361	369	236	447	100	0	339	564	395	610	206	621	141	149	466	681	619	308	222	860	829	843	661	359	395	539	555	919
9	294	398	400	261	125	486	439	339	0	603	642	325	545	660	268	190	127	575	280	647	391	521	795	558	322	250	438	878	894	580
10	309	413	203	423	478	117	559	564	603	0	388	367	665	165	705	713	712	117	559	578	786	574	265	374	731	853	959	640	734	799
11	348	244	357	462	517	271	390	395	642	388	0	652	292	353	536	544	769	505	788	190	463	962	609	762	960	754	790	252	379	1103
12	355	459	461	241	377	381	605	610	325	367	652	0	711	532	593	515	345	250	192	813	716	433	470	233	364	575	763	904	1031	507
13	356	252	462	470	442	548	106	206	545	665	292	711	0	645	310	355	672	782	796	102	187	1037	901	944	867	565	564	333	349	1111
14	366	470	260	480	535	174	616	621	660	165	353	532	645	0	762	770	787	282	724	543	816	739	256	539	896	910	1016	510	569	964
15	396	292	502	510	377	588	241	141	268	705	536	593	310	762	0	78	395	822	548	396	123	789	970	826	590	288	254	627	643	848
16	404	300	510	451	315	596	249	149	190	713	544	515	355	770	78	0	317	765	470	457	201	711	978	748	512	210	248	688	704	770
17	421	525	527	388	252	613	566	466	127	712	769	345	672	787	395	317	0	595	153	774	518	394	815	578	195	301	565	1005	1021	453
18	426	530	320	491	595	234	676	681	575	117	505	250	782	282	822	765	595	0	442	695	903	457	245	257	614	825	1013	757	851	682
19	440	544	546	326	405	573	690	619	280	559	788	192	796	724	548	470	153	442	0	898	671	241	662	425	172	454	718	1040	1145	315
20	458	354	547	572	544	461	208	308	647	578	190	813	102	543	396	457	774	695	898	0	273	1139	799	952	969	667	650	231	247	1213
21	477	373	583	591	458	669	293	222	391	786	463	716	187	816	123	201	518	903	671	273	0	912	1051	949	713	411	377	504	520	971
22	681	785	777	567	646	691	931	860	521	574	962	433	1037	739	789	711	394	457	241	1139	912	0	541	200	413	695	959	1214	1308	225
23	574	678	468	688	743	382	824	829	795	265	609	470	901	256	970	978	815	245	662	799	1051	541	0	341	834	1045	1224	766	825	766
24	588	692	577	474	610	491	838	843	558	374	762	233	944	539	826	748	578	257	425	952	949	200	341	0	597	808	996	1014	1108	425
25	612	716	718	498	447	745	761	661	322	731	960	364	867	896	590	512	195	614	172	969	713	413	834	597	0	496	760	1200	1216	258
26	544	510	650	511	375	736	459	359	250	853	754	575	565	910	288	210	301	825	454	667	411	695	1045	808	496	0	458	898	914	754
27	650	546	756	699	563	842	495	395	438	959	790	763	564	1016	254	248	565	1013	718	650	377	959	1224	996	760	458	0	881	897	1018
28	600	496	609	714	769	523	439	539	878	640	252	904	333	510	627	688	1005	757	1040	231	504	1214	766	1014	1200	898	881	0	127	1355
29	705	601	736	819	791	650	455	555	894	734	379	1031	349	569	643	704	1021	851	1145	247	520	1308	825	1108	1216	914	897	127	0	1460
30	755	859	861	641	705	888	1005	919	580	799	1103	507	1111	964	848	770	453	682	315	1213	971	225	766	425	258	754	1018	1355	1460	0

Table 3.11. Railway distances among all the centroides. Own elaboration from data of [G] and [H]

The railway distances shown here are the shortest distances following the rail network. As it can be seen, the largest distance in our study zone is between Zürich and Warszawa, corresponding to 1460 Km. The average distance between two random points is 560 Km. Praha is the city which is nearest to all the other points in our study zone, being 412 Km to all the other centroides in average while Zürich is the furthest one, being at 800 Km in average.

Considering the travel time among all the cited points we have the following table:

Travel time (in hours) among the 30 centroides																														
Zone	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
1	0,00	1,00	1,25	1,75	2,75	2,25	2,25	2,75	5,00	3,50	5,75	5,00	3,50	4,50	4,25	4,50	6,00	4,75	6,00	5,50	5,50	8,25	6,25	7,00	8,00	7,00	7,00	8,75	8,25	10,25
2	1,00	0,00	2,25	2,75	3,75	3,25	1,25	1,75	5,00	4,50	5,00	6,00	2,50	5,50	3,25	3,50	6,00	5,75	7,00	4,50	4,50	9,25	7,25	8,00	8,00	6,00	6,00	7,75	7,25	11,25
3	1,25	2,25	0,00	3,00	4,00	1,00	3,50	4,00	6,25	2,25	4,50	5,50	4,75	3,25	5,50	5,75	7,25	3,50	6,50	6,75	6,75	7,00	5,00	5,75	8,50	8,25	8,25	9,25	9,00	9,75
4	1,75	2,75	3,00	0,00	2,00	4,00	4,00	4,50	4,25	5,25	7,50	3,25	5,25	6,25	6,00	5,75	5,25	6,25	4,25	7,25	7,25	6,50	6,25	5,25	6,25	7,25	8,50	10,50	10,00	8,50
5	2,75	3,75	4,00	2,00	0,00	5,00	5,00	4,50	2,25	6,25	8,50	5,25	6,25	7,25	4,75	3,75	3,25	7,50	4,75	8,25	6,00	7,00	8,25	7,25	5,25	5,25	6,50	11,50	11,00	9,00
6	2,25	3,25	1,00	4,00	5,00	0,00	4,50	5,00	7,25	1,25	3,50	4,50	5,75	2,25	6,50	6,75	7,00	2,50	5,50	6,25	7,75	6,00	4,00	4,75	7,50	9,25	9,25	8,25	8,00	8,75
7	2,25	1,25	3,50	4,00	5,00	4,50	0,00	1,50	4,75	5,75	6,00	7,25	1,25	6,75	3,00	3,25	5,75	7,00	7,25	3,25	4,25	9,50	8,50	9,25	7,75	5,75	5,75	6,50	6,00	11,50
8	2,75	1,75	4,00	4,50	4,50	5,00	1,50	0,00	3,25	6,25	6,75	6,50	2,75	7,25	1,50	1,75	4,25	7,50	5,75	4,75	2,75	8,00	9,00	8,50	6,25	4,25	4,25	8,00	7,50	10,00
9	5,00	5,00	6,25	4,25	2,25	7,25	4,75	3,25	0,00	7,50	10,00	3,25	6,00	8,00	2,50	1,50	1,00	6,25	2,50	8,00	3,75	4,75	6,25	5,25	3,00	3,00	4,25	11,25	10,75	6,75
10	3,50	4,50	2,25	5,25	6,25	1,25	5,75	6,25	7,50	0,00	4,75	4,25	7,00	1,25	7,75	8,00	6,75	1,25	5,25	7,50	9,00	4,75	2,75	3,50	7,25	10,50	10,50	7,75	7,00	7,50
11	5,75	5,00	4,50	7,50	8,50	3,50	6,00	6,75	10,00	4,75	0,00	8,00	4,75	5,75	8,25	8,50	10,50	6,00	9,00	2,75	8,25	9,50	7,50	8,25	11,00	11,00	11,00	4,75	5,50	12,25
12	5,00	6,00	5,50	3,25	5,25	4,50	7,25	6,50	3,25	4,25	8,00	0,00	8,50	4,75	5,75	4,75	2,50	3,00	1,00	10,50	7,00	3,25	3,00	2,00	3,00	6,25	7,50	11,25	10,50	5,25
13	3,50	2,50	4,75	5,25	6,25	5,75	1,25	2,75	6,00	7,00	4,75	8,50	0,00	8,00	4,25	4,50	7,00	8,25	8,50	2,00	3,75	10,75	9,75	10,50	9,00	7,00	7,00	5,25	4,75	12,75
14	4,50	5,50	3,25	6,25	7,25	2,25	6,75	7,25	8,00	1,25	5,75	4,75	8,00	0,00	8,75	9,00	7,25	2,50	5,75	8,50	10,00	5,50	1,75	4,25	7,75	11,00	11,50	6,50	5,75	8,25
15	4,25	3,25	5,50	6,00	4,75	6,50	3,00	1,50	2,50	7,75	8,25	5,75	4,25	8,75	0,00	1,00	3,50	8,75	5,00	6,25	1,25	7,25	8,75	7,75	5,50	3,50	2,75	9,50	9,00	9,25
16	4,50	3,50	5,75	5,75	3,75	6,75	3,25	1,75	1,50	8,00	8,50	4,75	4,50	9,00	1,00	0,00	2,50	7,75	4,00	6,50	2,25	6,25	7,75	6,75	4,50	2,50	2,75	9,75	9,25	8,25
17	6,00	6,00	7,25	5,25	3,25	7,00	5,75	4,25	1,00	6,75	10,50	2,50	7,00	7,25	3,50	2,50	0,00	5,50	1,50	9,00	4,75	3,75	5,50	4,50	2,00	4,00	5,25	12,25	11,75	5,75
18	4,75	5,75	3,50	6,25	7,50	2,50	7,00	7,50	6,25	1,25	6,00	3,00	8,25	2,50	8,75	7,75	5,50	0,00	4,00	8,75	10,00	3,50	2,25	2,25	6,00	9,25	10,50	9,00	8,25	6,25
19	6,00	7,00	6,50	4,25	4,75	5,50	7,25	5,75	2,50	5,25	9,00	1,00	8,50	5,75	5,00	4,00	1,50	4,00	0,00	10,50	6,25	2,25	4,00	3,00	2,00	5,50	6,75	12,25	11,50	4,25
20	5,50	4,50	6,75	7,25	8,25	6,25	3,25	4,75	8,00	7,50	2,75	10,50	2,00	8,50	6,25	6,50	9,00	8,75	10,50	0,00	5,50	12,25	10,25	11,00	11,00	9,00	9,00	3,25	2,75	14,75
21	5,50	4,50	6,75	7,25	6,00	7,75	4,25	2,75	3,75	9,00	8,25	7,00	3,75	10,00	1,25	2,25	4,75	10,00	6,25	5,50	0,00	8,50	10,00	9,00	6,75	4,75	4,00	8,75	8,25	10,50
22	8,25	9,25	7,00	6,50	7,00	6,00	9,50	8,00	4,75	4,75	9,50	3,25	10,75	5,50	7,25	6,25	3,75	3,50	2,25	12,25	8,50	0,00	3,75	1,25	4,25	7,75	9,00	12,00	11,25	2,75
23	6,25	7,25	5,00	6,25	8,25	4,00	8,50	9,00	6,25	2,75	7,50	3,00	9,75	1,75	8,75	7,75	5,50	2,25	4,00	10,25	10,00	3,75	0,00	2,50	6,00	9,25	10,50	8,25	7,50	6,50
24	7,00	8,00	5,75	5,25	7,25	4,75	9,25	8,50	5,25	3,50	8,25	2,00	10,50	4,25	7,75	6,75	4,50	2,25	3,00	11,00	9,00	1,25	2,50	0,00	5,00	8,25	9,50	10,75	10,00	4,00
25	8,00	8,00	8,50	6,25	5,25	7,50	7,75	6,25	3,00	7,25	11,00	3,00	9,00	7,75	5,50	4,50	2,00	6,00	2,00	11,00	6,75	4,25	6,00	5,00	0,00	6,00	7,25	14,25	13,50	3,75
26	7,00	6,00	8,25	7,25	5,25	9,25	5,75	4,25	3,00	10,50	11,00	6,25	7,00	11,00	3,50	2,50	4,00	9,25	5,50	9,00	4,75	7,75	9,25	8,25	6,00	0,00	5,25	12,25	11,75	9,75
27	7,00	6,00	8,25	8,50	6,50	9,25	5,75	4,25	4,25	10,50	11,00	7,50	7,00	11,50	2,75	2,75	5,25	10,50	6,75	9,00	4,00	9,00	10,50	9,50	7,25	5,25	0,00	12,25	11,75	11,00
28	8,75	7,75	9,25	10,50	11,50	8,25	6,50	8,00	11,25	7,75	4,75	11,25	5,25	6,50	9,50	9,75	12,25	9,00	12,25	3,25	8,75	12,00	8,25	10,75	14,25	12,25	12,25	0,00	1,50	14,75
29	8,25	7,25	9,00	10,00	11,00	8,00	6,00	7,50	10,75	7,00	5,50	10,50	4,75	5,75	9,00	9,25	11,75	8,25	11,50	2,75	8,25	11,25	7,50	10,00	13,50	11,75	11,75	1,50	0,00	14,00
30	10,25	11,25	9,75	8,50	9,00	8,75	11,50	10,00	6,75	7,50	12,25	5,25	12,75	8,25	9,25	8,25	5,75	6,25	4,25	14,75	10,50	2,75	6,50	4,00	3,75	9,75	11,00	14,75	14,00	0,00

Table 3.12. Travel time among all the centroides. Own elaboration from data of [G] and [H]

The travel time is the minimum of the fastest connections. It has to be said that some of the connections may have train changes, with the corresponding time increase, that have not been considered here. Nevertheless, most of the connections are direct.

The average travel time among all these destinations is 6h 15min. Again, Praha is the city with lower travel time to all the other cities, corresponding to 5h, while Lodz is the one with highest travel time, being over 9 hours.

Considering the commercial speed of the trains travelling among all the cited points we have the following table:

Railway commercial speed (in Km/h) among the 30 centroides

Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	0	104	85	65	61	85	111	93	59	88	61	71	102	81	93	90	70	90	73	83	87	83	92	84	77	78	93	69	85	74
2	104	0	93	79	73	91	117	86	80	92	49	77	101	85	90	86	88	92	78	79	83	85	94	87	90	85	91	64	83	76
3	85	93	0	73	69	86	102	90	64	90	79	84	97	80	91	89	73	91	84	81	86	111	94	100	84	79	92	66	82	88
4	65	79	73	0	68	77	91	82	61	81	62	74	90	77	85	78	74	79	77	79	82	87	110	90	80	70	82	68	82	75
5	61	73	69	68	0	72	67	52	56	76	61	72	71	74	79	84	78	79	85	66	76	92	90	84	85	71	87	67	72	78
6	85	91	86	77	72	0	98	89	67	94	77	85	95	77	90	88	88	94	104	74	86	115	96	103	99	80	91	63	81	101
7	111	117	102	91	67	98	0	67	92	97	65	83	85	91	80	77	98	97	95	64	69	98	97	91	98	80	86	68	76	87
8	93	86	90	82	52	89	67	0	104	90	59	94	75	86	94	85	110	91	108	65	81	108	92	99	106	84	93	67	74	92
9	59	80	64	61	56	67	92	104	0	80	64	100	91	83	107	127	127	92	112	81	104	110	127	106	107	83	103	78	83	86
10	88	92	90	81	76	94	97	90	80	0	82	86	95	132	91	89	105	94	106	77	87	121	96	107	101	81	91	83	105	107
11	61	49	79	62	61	77	65	59	64	82	0	82	61	61	65	64	73	84	88	69	56	101	81	92	87	69	72	53	69	90
12	71	77	84	74	72	85	83	94	100	86	82	0	84	112	103	108	138	83	192	77	102	133	157	117	121	92	102	80	98	97
13	102	101	97	90	71	95	85	75	91	95	61	84	0	81	73	79	96	95	94	51	50	96	92	90	96	81	81	63	73	87
14	81	85	80	77	74	77	91	86	83	132	61	112	81	0	87	86	109	113	126	64	82	134	146	127	116	83	88	78	99	117
15	93	90	91	85	79	90	80	94	107	91	65	103	73	87	0	78	113	94	110	63	98	109	111	107	107	82	92	66	71	92
16	90	86	89	78	84	88	77	85	127	89	64	108	79	86	78	0	127	99	118	70	89	114	126	111	114	84	90	71	76	93
17	70	88	73	74	78	88	98	110	127	105	73	138	96	109	113	127	0	108	102	86	109	105	148	128	98	75	108	82	87	79
18	90	92	91	79	79	94	97	91	92	94	84	83	95	113	94	99	108	0	111	79	90	131	109	114	102	89	96	84	103	109
19	73	78	84	77	85	104	95	108	112	106	88	192	94	126	110	118	102	111	0	86	107	107	166	142	86	83	106	85	100	74
20	83	79	81	79	66	74	64	65	81	77	69	77	51	64	63	70	86	79	86	0	50	93	78	87	88	74	72	71	90	82
21	87	83	86	82	76	86	69	81	104	87	56	102	50	82	98	89	109	90	107	50	0	107	105	105	106	87	94	58	63	92
22	83	85	111	87	92	115	98	108	110	121	101	133	96	134	109	114	105	131	107	93	107	0	144	160	97	90	107	101	116	82
23	92	94	94	110	90	96	97	92	127	96	81	157	92	146	111	126	148	109	166	78	105	144	0	136	139	113	117	93	110	118
24	84	87	100	90	84	103	91	99	106	107	92	117	90	127	107	111	128	114	142	87	105	160	136	0	119	98	105	94	111	106
25	77	90	84	80	85	99	98	106	107	101	87	121	96	116	107	114	98	102	86	88	106	97	139	119	0	83	105	84	90	69
26	78	85	79	70	71	80	80	84	83	81	69	92	81	83	82	84	75	89	83	74	87	90	113	98	83	0	87	73	78	77
27	93	91	92	82	87	91	86	93	103	91	72	102	81	88	92	90	108	96	106	72	94	107	117	105	105	87	0	72	76	93
28	69	64	66	68	67	63	68	67	78	83	53	80	63	78	66	71	82	84	85	71	58	101	93	94	84	73	72	0	85	92
29	85	83	82	82	72	81	76	74	83	105	69	98	73	99	71	76	87	103	100	90	63	116	110	111	90	78	76	85	0	104
30	74	76	88	75	78	101	87	92	86	107	90	97	87	117	92	93	79	109	74	82	92	82	118	106	69	77	93	92	104	0

Table 3.13. Railway commercial speed among all the centroides. Own elaboration from data of [G] and [H]

The average speed of railway trips among all these cities is 90 Km/h. The fastest connections are those that depart or arrive to Hannover, corresponding to 113 Km/h, while the slowest ones are those that depart or arrive to Wroclaw, corresponding to 72 Km/h in average. In addition, it should be said again that these commercial speeds are calculated without considering possible train interchanges; therefore, they would actually be significantly lower.

If one take a detailed look at the table, it is possible to see how the high speed corridors shown in the figure 2.8 have the highest commercial speed, such as Nürnberg – München (192 Km/h), Hannover –München (166 Km/h), Suttgart – Frankfurt (160 Km/h), Hannover – Nürnberg (157 Km/h), Hannover – Berlin (146 Km/h), Berlin – Leipzig (132 Km/h), Stuttgart – Erfurt (131 Km/h) and Wien

– Salzburg (127 Km/h). In the Czech Republic, the highest speeds are reached in the corridor Plzeň – Praha – Pardubice – Olomouc, corresponding to 111 Km/h in average.

In general, however, as the average commercial speed is 90 Km/h, we cannot talk about fast rail connections among the studied zone, especially in the Czech Republic part. All this makes us think about the incompetence of rail communications against other transportation modes, especially road transport modes, making even clearer the need of reformation and introduction to high speed railway in the Czech Republic.

3.2. Demand analysis

Once we have talked about Czech railway offer it is time to talk about its demand. Current demand of railway transport can be seen in the passengers and goods traffic (see fig. 2.5). This demand, as we mentioned at the beginning of this section, is influenced by the existing offer, and represents only the conventional railway demand. Nevertheless, there is a potential demand of high speed railway transport which cannot be seen on those graphics but can be estimated with sequential demand models. For our study, we have chosen the classic one, called Urban Transportation Planning (UTP) model. [E] This model is based in four main stages, which are: trip generation and attraction, trip distribution, modal split and route assignment. Subsequently, we are going to study each one of these phases, in a very simplified way, to estimate the high speed railway demand in the Czech Republic and Central Europe.

3.2.1. Trip generation and attraction

Trip generation and attraction stage is used to determine the frequency of origins or destinations of trips in each study zone. It includes all the different kind of trip purposes such as the business, leisure, tourism… It can be calculated as a function of land uses, household demographics and other socio-economic factors, which will be now explained.

3.2.1.1. Society and demography

Trip generation and attraction is influenced by several socio-demographic factors such as the country population distribution, the population density, the number of metropolitan cities, the percentage of active population…

The structure of the population in the Czech Republic is hierarchically organized. Praha dominates significantly, being approximately three times bigger than the second largest city in the country: Brno. With the exception of Ostrava and Ústí nad Labem, the vicinities of large cities, including Brno, as compared to western European regions, are sparsely populated. We can see it in the next representation of the population density in the Czech Republic:

Figure 3.14. Density of population of the Czech Republic in 1996 [O]

Moreover, basic characteristics are shown in the following table:

	City agglomeration	Population (thousands)			Category center
		Agglomeration	Core area	Main center	
1	Praha	1500	1250	1169	Metropolitan
2	Ostrava	710	520	400	
3	Brno	620	405	376	
4	Ústí nad Labem - Teplice	370	190	95 + 51	Transregional
5	Hradec Králové - Pardubice	350	105 + 120	97 + 91	
6	Plzeň	280	200	165	
7	Olomouc - Prostějov	300	120 + 60	103 + 48	
8	Liberec - Jablonec nad Nisou	215	155	98 + 45	
9	České Budějovice	180	120	97	
10	Zlín - Otrokovice	190	115	80 + 19	
11	Chomutov - Most	230	75 + 70	72 + 68	Regional
12	Karlovy Vary - Sokolov	170	60 + 30	52 + 25	
13	Kolín - Kutná Hora	150	60	30 + 22	
14	Český Těšín/Czieszyn - Třinec	140	70 + 45	60 + 39	
15	Mladá Boleslav	80	55	48	
16	Opava	115	65	61	
17	Přerov - Hranice	110	55 + 25	48 + 20	
18	Nový Jičín - Kopřivnice	95	30 + 25	27 + 24	
19	Jihlava	70	55	50	
20	Tábor	75	50	44	

Table 3.15. Major areas of population concentration in the Czech Republic in 2007 [7]

As it can be noticed in the table, regional centers are relatively weak, with the exception of Praha, Ostrava, Brno and Plzeň, having population under 100 thousand. Closest cities are considered as agglomerations, though their size may not be very great. Main part of the population of the Czech Republic are located in the corridor Plzeň – Praha – Pardubice – Olomouc – Ostrava, according to the current *Pendolino*'s line. Other important cities out of this corridor are Brno, Ústí nad Labem, Liberec, Karlovy Vary, Chomutov, Most and České Budějovice. Most of them are located on the northern part of the Czech Republic, but in general, the Czech population is quite well distributed around the whole country.

In the next figure it is shown the population settlement and its main corridors around the Czech Republic, showing the above mentioned distribution of population:

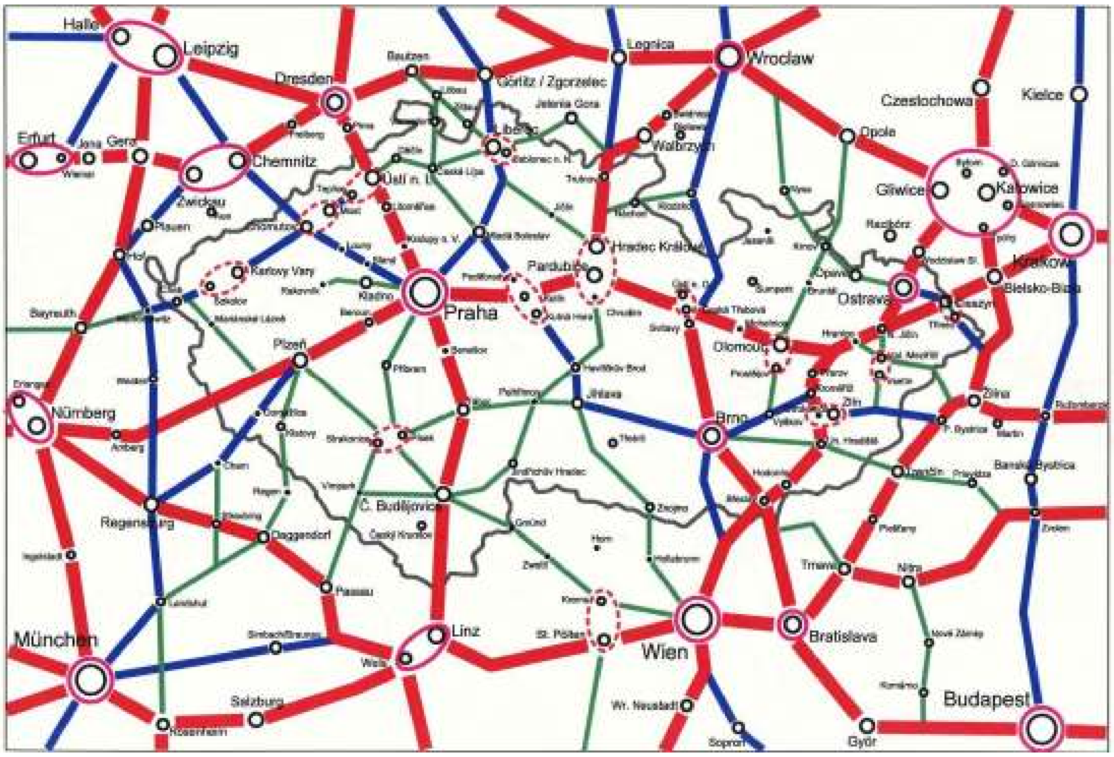


Figure 3.16. Settlement and main population corridors of the Czech Republic [7]

Regarding the Central European distribution of the population, it is to be said that there is a real core area which is characterized by the occurrence of major metropolitan areas, high economic performance and a large share of innovation. There are two best-known definitions of this area:

- Blue bananas: from the southeast of England through the Benelux and Rhineland to Lombardy.
- Western European Pentagon: territory among the cities of London, Paris, Milan, Munich and Hamburg.

The core area represents over 40% of the population, approximately 50% of Central European income and generates about 75% of expenditure on research and development in the EU 15. [7]

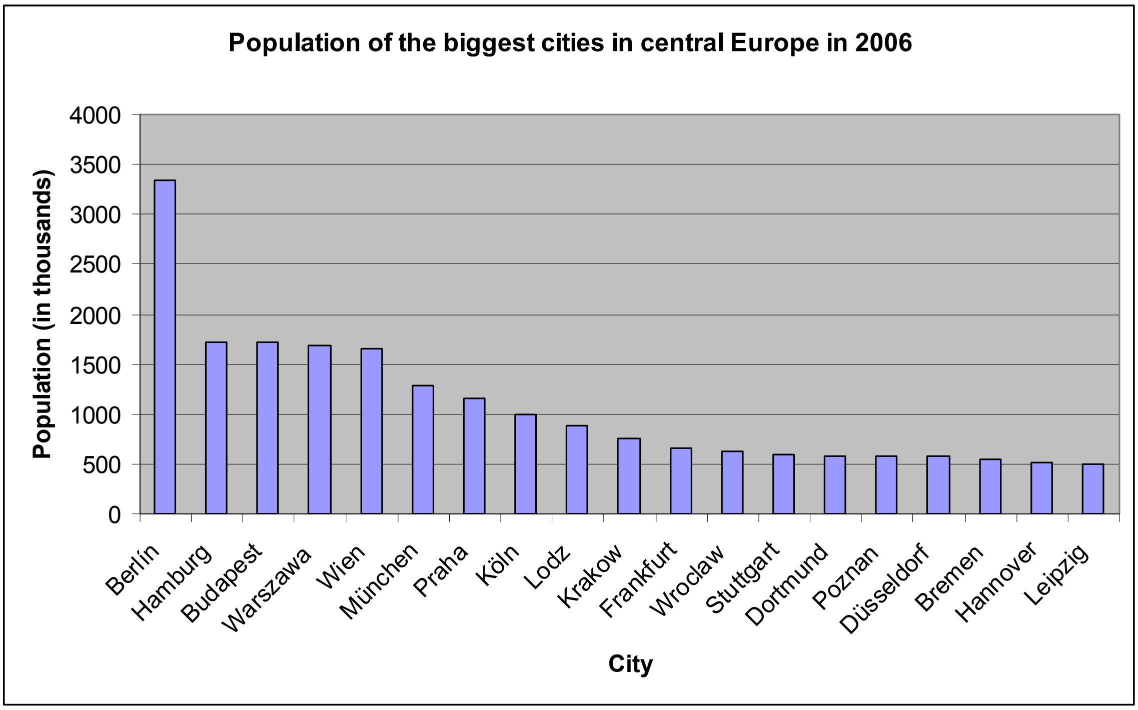
In the next table, basic demographic data of Central European countries are shown:

State	Provinces	Population (millions)	Surface area (thous. km²)	Density (inhab./ km²)	Capital
Czech Republic		10,2	78,9	129	Praha
Slovakia		5,4	49,0	110	Bratislava
Poland		38,5	312,7	123	Warszawa
of which	Dolnoslaskie	3,0	19,9	151	Wroclaw
	Lodzkie	2,6	18,2	143	Lodz
	Malopolskie	3,2	15,1	212	Krakow
	Mazowieckie	5,1	35,6	143	Warszawa
	Slaskie	4,8	12,3	390	Katowice
Hungary		10,1	93,0	109	Budapest
Austria		8,2	83,9	97	Wien
Switzerland		7,5	41,3	179	Bern
Germany		82,7	357,0	232	Berlin
of which	Niedersachsen	8,0	47,6	168	Hannover
	Nordrhein – Westfalen	18,1	34,1	531	Düsseldorf
	Hessen	6,0	21,1	284	Wiesbaden
	Baden – Württenberg	10,7	35,8	299	Stuttgart
	Bayern	12,4	70,5	176	München
	Thüringen	2,5	16,2	154	Erfurt
	Sachsen	4,3	18,4	234	Dresden

Table 3.17. Basic demographic data of Central European countries in 2007 [7]

The review shows a considerable diversity of population within national territories. In some countries the population is concentrated in the potential of significantly small number of regions or even in the capital. This is, particularly, the case of the less populated countries like Austria, Slovakia, Hungary and a large extent of the Czech Republic (Prague, Ostrava, Ústecký).

In the next graphics the size of the biggest cities and agglomerations in Central Europe are shown:



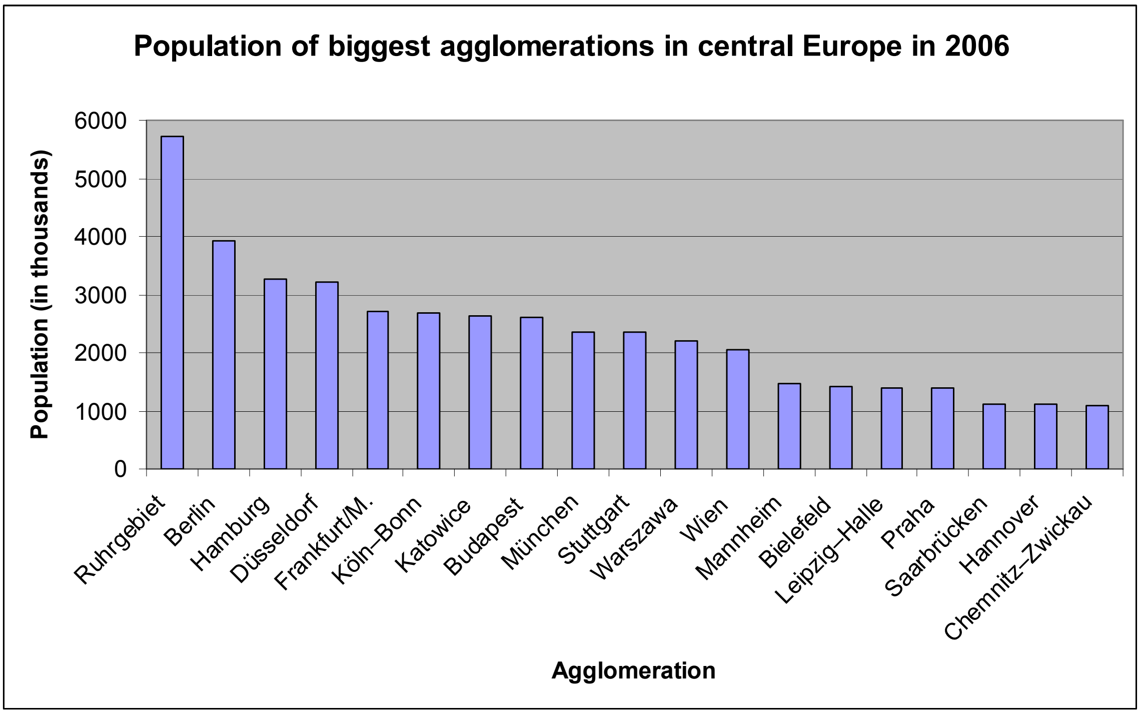


Figure 3.18.a. Population of the biggest agglomerations in Central Europe in 2006. b. Population of the biggest cities in Central Europe in 2006. Own elaboration from data of [7]

As it may be extracted from the graphics, a substantial part of intensive urbanized territory in Central Europe is in Germany in the "corridor" Hamburg - Hannover / Bremen - Bielefeld - Ruhrgebiet - Köln - Frankfurt / M. - Mannheim - Stuttgart - München, which is almost identical to the definition of so-called "Blue banana" including the most advanced part of Europe. Outside the corridor of the major metropolitan centers there is just Berlin, Warsaw, Katowice, Vienna, Budapest and Prague, being all of them the capitals of the respective countries but Katowice. There is also another significant corridor connecting Frankfurt / M. - Erfurt - Leipzig / Halle - Dresden - Wroclaw - Katowice - Krakow.

The population settlement and the main population corridors in Central Europe explained above can be seen in the next picture:

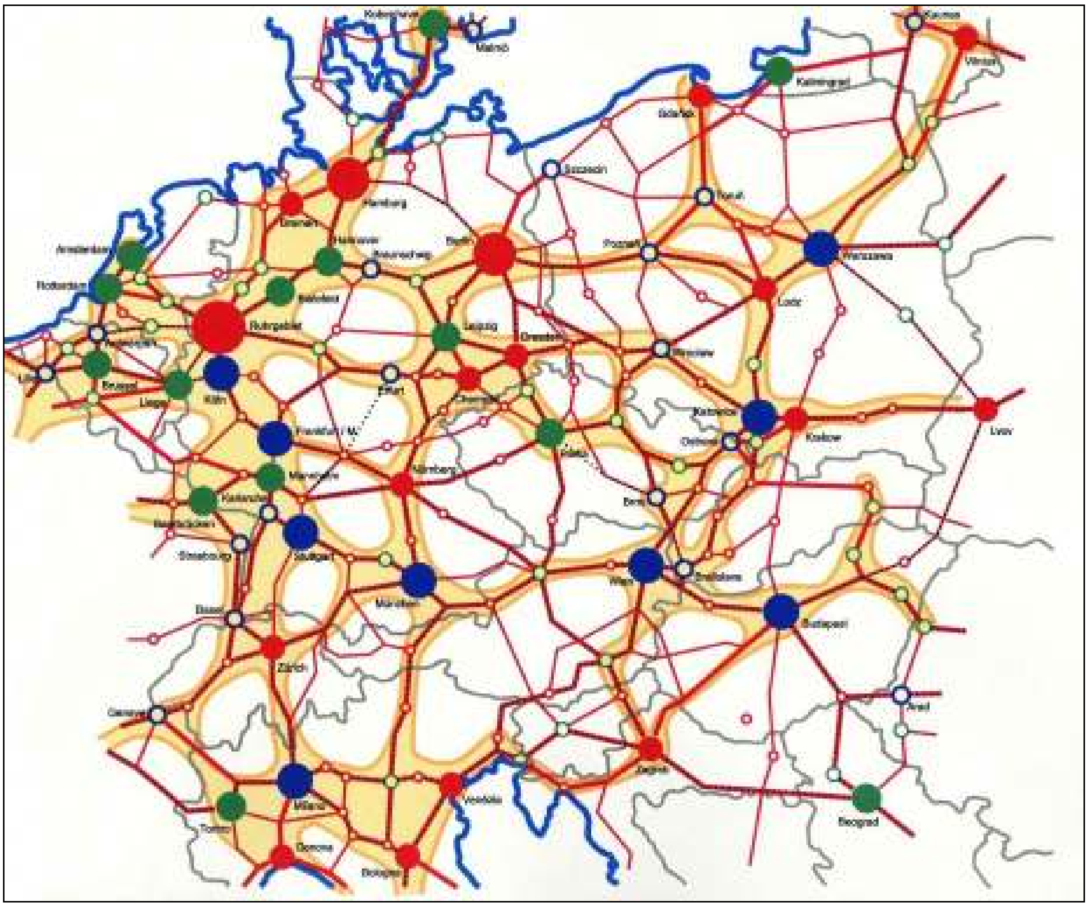


Figure 3.19. Settlement and main population corridors of Central Europe [7]

Until now we have been talking about the total population in the Czech Republic and Central Europe. However, sometimes it is useful to know not only the total population but the active one, this means, that part of the population who is in age and conditions of working, usually people between 16 and 65 years old. In average, we can consider that the active population in our study zone is about the 60% of the total population.

3.2.1.2. Economy

It is important to study the economy of the affected regions in our study zone due to the fact that trips by rail rise as economies grow, though at a slower rate than the national income, as it can be extracted from elasticity of passenger demand studies. [8] We will consider the main macro-economic indicators, such as the employment rates and the income level.

The employment rates in the studied zone are shown in the next graphic:

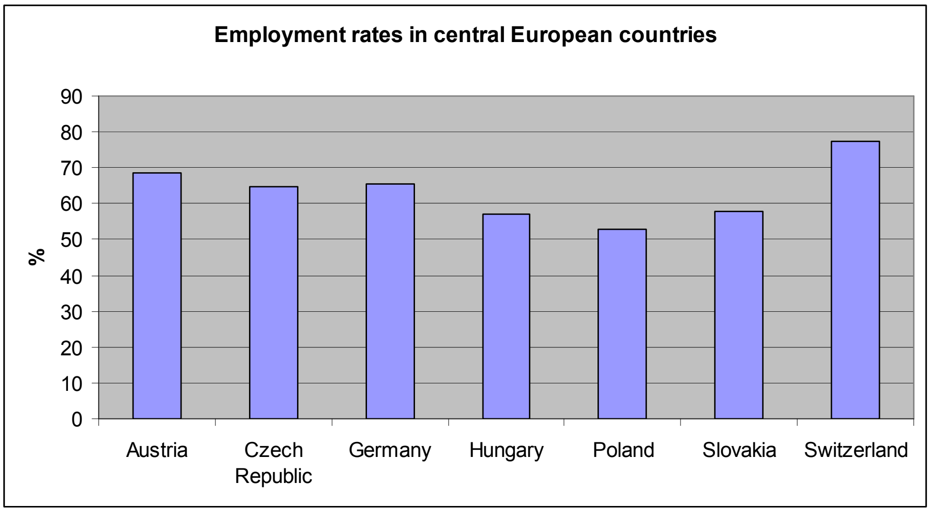


Figure 3.20. Employment rates in the Central European countries in 2005 [E]

From the graphic one can see that the Czech Republic has an employment rate of 65%, similar to Germany and to the Central European average. Poland has de lowest employment rate (53%) while Switzerland has the highest (78%).

To estimate the income level it is used the Gross Domestic Product (GDP) per capita, which is a national measure of the country income per head. In the next table we are going to show the GDP per capita in each region of the Czech Republic, in order to see the differences in the national territory. Besides this, we are showing the GDP per capita as a percentage of the EU 27 average:

Region	GDP per capita (in €)	% GDP per capita of EU 27 average
Praha	35.168	157
Central Bohemia	16.419	73
South Bohemia	16.368	73
Plzeň	16.991	76
Karlovy Vary	13.851	62
Ústí nad Labem	14.651	65
Liberec	15.378	69
Hradec Králové	15.783	70
Pardubice	14.832	66
Olomouc	15.308	68
Moravia-Silesia	16.505	74
South Moravia	13.484	60
Zlín	14.682	66
Vysočina	15.597	70
Average	**18.415**	**82**

Table 3.21. GDP per capita in the Czech Republic's regions in € in 2008. Own elaboration from data of [E] and [K]

From the table it can be seen that Praha is the richest region of the Czech Republic, highly above all the other regions level, having a 157% of the GDP per capita average in the EU 27 (corresponding to 22.400€) while the country's average is about 82%. The rest of the regions have similar GDP per capita, being all of them between 60% and 76% of EU 27 average. This means that national wealth is not very well distributed, being most of it located in the capital, according to the population distribution of the Czech Republic.

In the same way, we are going to show the cities in Central Europe over 100 thousand population with highest income level, according to GDP per capita, exceeding 50% of the EU 27 average:

Rank	City	GDP per capita (EU 27 = 100)	Population (in thousands)		Airport
			City	Agglomeration	
1	Frankfurt	334	652,0	2720 *(Rhein-Main)*	●
2	Düsseldorf	296	577,4	3225 *(Rhein-Ruhr Mitte)*	●
3	Regensburg	291	145,0	230	*München*
4	Wolfsburg	288	130,0	670	*Hannover*
5	Ludwigshafen	264	167,4	1464 *(Rhein-Neckar)*	*Frankfurt*
6	Ingolstadt	260	118,0	180	*München*
7	München	246	1288,0	2355	●
8	Koblenz	239	108,0	250	*Köln-Bonn*
9	Darmstadt	237	136,0	2720 *(Rhein-Main)*	*Frankfurt*
10	Mannheim	228	325,4	1464 *(Rhein-Neckar)*	*Frankfurt*
11	Karlsruhe	216	271,0	582	*Stuttgart*
12	Hamburg	209	1734,8	3270	●
13	Ulm	207	156,0	230	*Stuttgart*
14	Heilbronn	203	120,0	180	*Stuttgart*
15	Wiesbaden	202	273,6	2720 *(Rhein-Main)*	*Frankfurt*
16	Mainz	200	197,0	2720 *(Rhein-Main)*	*Frankfurt*
17	Leverkusen	197	162,0	3225 *(Rhein-Ruhr Süd)*	*Köln-Bonn*
18	Nürnberg	197	495,3	1017	●
19	Heidelberg	192	140,0	1464 *(Rhein-Neckar)*	*Frankfurt*
20	Köln	189	991,5	3080 *(Rhein-Ruhr Süd)*	●
21	Augsburg	189	258,0	470	*München*
22	Würzburg	188	128,0	220	*Frankfurt*
23	Wien	180	1550,0	2044	●
24	Münster	178	220,0	350	●
25	Bremen	175	545,9	1005	●
26	Bonn	168	314,0	3080 *(Rhein-Ruhr Süd)*	●
27	Osnabrück	167	164,0	290	●
28	Kaiserslautern	167	102,0	200	*Saarbrücken*
29	Kiel	166	230,9	300	*Hamburg*
30	Trier	165	99,0	130	*Hahn*
31	Praha	157	1164,0	1389	●
32	Pforzheim	156	110,0	582	*Stuttgart*
33	Essen	154	584,3	5710 *(Rhein-Ruhr Nord)*	*Düsseldorf*
34	Freiburg	154	214,7	320	*Basel*
35	Linz	150	185,0	380	●
36	Salzburg	150	147,0	230	●

Table 3.22. Cities over 100 thousand population in Central Europe exceeding 50% of the EU 27 GDP per capita average [7]

As it can be seen in the table, the first 22 places are occupied by German cities, making it very clear the high income level of Germany according to the GDP per capita. Wien occupies the 23rd place, while Praha the 31st. The richest cities are generally agglomerations, such as Frankfurt, Düsseldorf, Köln and Bonn, located in the Blue Bananas part of Germany, showing the strong correlation between the urban population and richness of the regions.

The situation in the new EU countries like the Czech Republic is different from Germany, Austria and Switzerland. It is likely that while there isn't any improvement of their economic parameters, the population is not going to grow. However, their population settlements are to be considered as a basic factor in their economic growth and generation of transport demand.
In the last table, we have taken into account the airports of the cities and agglomerations. This is because distribution and performance of airports substantially correspond to the intensity of population and economic performance of regions. Performance of airports fairly reflects the potential demand for high speed rail, though number of main terminals of high speed will undoubtedly be significantly higher than the number of airports.

It is very unlikely that the regions which induce low demand for air transport will be important high speed rail transport terminals. Because we want to know the trip generation and attraction of high speed railway, we will now analyze which are the more demanded airports. Thus, in the next graphic it is shown the Central European airports performance in 2006:

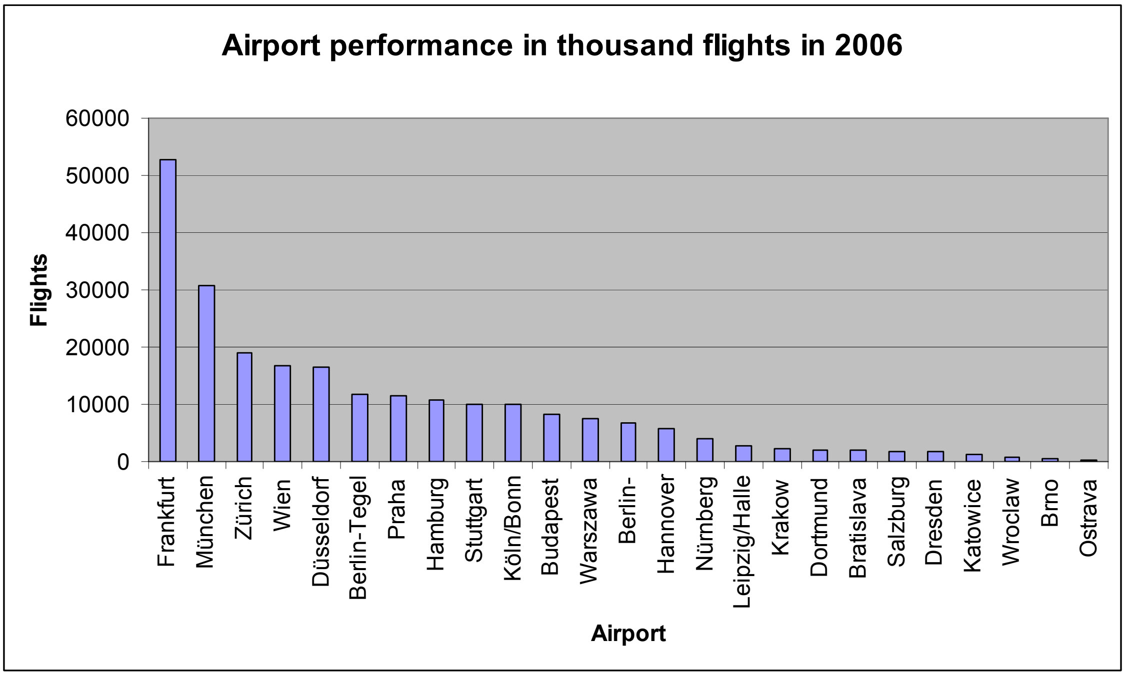


Figure 3.23. Central European airports sorted according to their performance in 2006. Own elaboration from data of [7]

Again Frankfurt is the top one, followed in this case by München. Praha had over 10 million flights a year in 2005, following Berlin, Düsseldorf, Wien and Zürich. Other German, Austrian and Swiss airports have less traffic than Praha, like main airports of Poland, Hungary and Slovakia. The second and the third most important airports of the Czech Republic (Brno and Ostrava) have relatively few performance, in comparison with the main Central European airports, though both were over 300 thousand flights a year in 2006.

The tendency in air transport during the last years has been the traffic concentration to the main airport terminals, since they allow free transfers to a larger number of destinations. Large airports are often used for relatively large regions and even across borders. While performance of airports in countries with advanced high speed railway rather stagnated, they registered an increase in the metropolis especially of new EU countries, such as Prague, Warsaw and Budapest, which don’t have high speed railway yet. Most western European metropolises have connections from the airport to rail transportation, which, in some cases, are a direct link to high speed rail.

Other important economic factors to take into account are the good transport flow between Czech regions and Central European countries, as they give a lot of information about the production and consumption of each region. Regarding the transport of goods in the Czech Republic, we are showing a table with the freight traffic inside regions and among regions:

Region code	Exporting \ Importing	CZ010	CZ020	CZ031	CZ032	CZ041	CZ042	CZ051	CZ052	CZ053	CZ061	CZ062	CZ071	CZ072	CZ080	TOTAL
CZ011	Praha	65,2	96,3	13,8	18,1	18,6	48,1	1,9	3,9	5,5	20,7	21,8	44,3	339,5	131,2	**828,8**
CZ021	Central Bohemia	160,1	627,8	36,0	95,4	171,5	1.495,9	57,8	40,1	93,1	76,2	69,9	121,6	13,8	228,1	**3.287,3**
CZ031	South Bohemia	27,3	43,7	131,0	65,6	24,0	195,9	1,7	28,3	12,1	226,6	69,7	116,9	25,7	259,8	**1.228,1**
CZ032	Plzeň	14,1	18,1	31,0	204,1	101,3	436,4	0,3	8,3	4,5	171,7	20,2	32,5	21,8	169,0	**1.233,2**
CZ041	Karlovy Vary	22,5	417,9	678,4	1.144,9	2.226,1	1.242,9	24,9	31,8	26,6	111,0	14,9	43,9	7,7	103,0	**6.096,5**
CZ042	Ústí nad Labem	91,0	1.666,9	380,8	330,3	78,8	5.545,1	76,2	762,0	5.194,0	148,0	124,1	413,8	599,8	271,7	**15.682,5**
CZ051	Liberec	1,3	15,6	6,3	3,9	2,7	82,4	28,2	12,3	0,6	31,9	58,8	45,3	0,8	44,3	**334,3**
CZ052	Hradec Králové	7,5	22,2	12,3	6,3	93,3	376,6	11,2	76,0	10,3	60,2	8,7	11,8	5,3	112,7	**814,2**
CZ053	Pardubice	8,4	53,9	24,5	15,9	16,9	157,5	4,4	30,8	66,2	12,6	95,5	29,6	22,0	89,5	**627,6**
CZ061	Olomouc	3,9	14,0	16,8	15,5	8,1	178,1	0,1	8,7	3,6	76,0	25,2	7,7	24,8	160,6	**543,0**
CZ062	Moravia-Silesia	41,1	404,6	20,1	8,5	10,8	39,4	3,4	10,8	31,0	30,0	980,4	150,4	62,5	278,2	**2.071,3**
CZ071	South Moravia	38,9	63,1	26,0	11,3	6,5	82,6	1,1	24,8	43,7	40,8	170,6	443,8	40,6	867,2	**1.861,1**
CZ072	Zlín	318,6	11,3	13,3	2,8	3,0	22,5	0,9	2,9	7,3	18,6	24,6	30,3	29,7	195,2	**681,1**
CZ081	Vysočina	212,1	775,9	53,6	71,9	110,8	234,6	18,6	142,4	384,2	129,8	388,6	699,8	527,8	7.919,9	**11.670,0**
TOTAL		**1.012,0**	**4.231,2**	**1.444,0**	**1.994,6**	**2.872,5**	**10.138,0**	**230,7**	**1.182,9**	**5.882,4**	**1.154,0**	**2.073,0**	**2.191,7**	**1.721,8**	**10.830,2**	**46.958,9**

Table 3.24. National good transport flow in 2007 in thousand tonnes [7]

From the table one can see that Ústí nad Labem region is the region that most exports to the rest of the country, while the Moravian-Silesian region is the one that most imports. Both of them are located on the Czech Republic borders, and still serve the whole country. Liberec region is the one that less imports and exports to the other regions in the nation. By the way, Prague’s region is not especially important for its good transportation flow, though it is one of the most populated, together with the Moravian-Silesian region.

It is also important to analyze the transportation of goods between the Czech Republic and Central Europe. If we consider all the transportation modes, Austria is the country with more influence in Czech goods flow, as in exportation from the Czech Republic as in importation, being both rates over 10 million tonnes. It is followed by Belgium, France, Germany and Hungary, though importation flow from France is quite low in comparison with its exportation flow. Neighbor countries such as Slovakia and Poland, though their proximity, have very few goods traffic flow with the Czech Republic. [6]

In general, both the exportation and importation rates among European countries are quite equilibrated, being the importation rate higher than the exportation only in Belgium, Germany and Slovakia. This means that the Czech Republic has a very big industry, and therefore, a high level in generation and attraction of good transportation travels.

We can see all these importation and exportation rates among the Czech Republic and Central Europe represented in the next graphic:

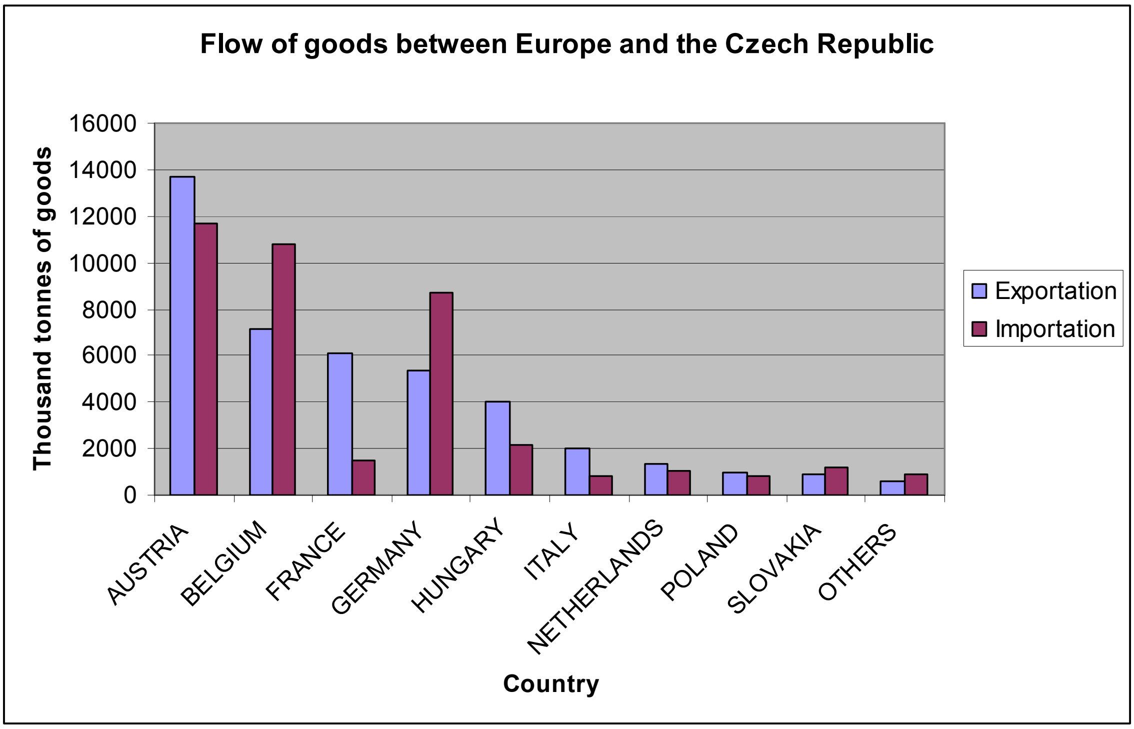


Figure 3.25. Goods transport flows exported and imported from/into the Czech Republic in 2007. Own elaboration from data of [6]

The tourism is another important economic factor when estimating the trip generation and attraction of a region. Regarding the international tourism with the neighbor countries we have:

International tourism (thousands)	
TOTAL Arrivals	**100.120**
of which (by border crossings):	
from Germany	51.489
from Austria	12.947
from Poland	15.701
from Slovakia	15.689
TOTAL Departures	**36.657**
of which (by border crossings):	
to Germany	10.990
to Austria	6.761
to Poland	6.379
to Slovakia	9.407

Table 3.26. International tourism of the Czech Republic in 2006 [6]

From the table we can deduce that the Czech Republic is a touristic attraction country, having almost three times more arrivals from people around neighbor countries than departures to those. Germany represents more than half of the tourists that the Czech Republic receives from its frontiers, probably due to German population size in comparison with the other neighbors. However, Germany is also the favorite country for Czech people, followed by Slovakia. The number of tourists coming from Austria, Poland and Slovakia are quite similar, though their population size is very different.

3.2.1.3. Trip generation and attraction estimation

To estimate the trip generation and attraction of every region in our studied zone we will use a very simplified version of the formulation provided by the Institute of Transportation Engineers [J].

The equation used will be:

$$G_i / A_i = K \cdot P_i \cdot GDP_i^{0,5}$$

where G_i is the trip generation of the zone *i*, A_i is the trip attraction for the zone *i*, *K* is a constant, P_i is the population of the zone *i* and GDP_i is the Gross Domestic Product of the zone *i*. We are considering trip generation and attraction equals for simplicity.

In the next table it is shown all the zones with their centroides, population, GDP and the trip generation and attraction estimation (as a function of *K*) using the previous equation:

Zone	Centroid	Country	Population of the zone	GDP (€)	Trip generation / attraction
1	Praha	Czech Republic	2.438.000	25.825	391.790.469·*K*
2	Pardubice	Czech Republic	1.068.000	15.324	132.207.875·*K*
3	Ústí nad Labem	Czech Republic	1.271.000	14.900	155.142.719·*K*
4	Plzeň	Czech Republic	874.000	15.882	110.144.808·*K*
5	České Budejovice	Czech Republic	635.000	16.368	81.240.303·*K*
6	Dresden	Germany	4.226.000	20.350	602.853.379·*K*
7	Olomouc	Czech Republic	1.233.000	15.008	151.048.791·*K*
8	Brno	Czech Republic	515.000	14.139	61.237.376·*K*
9	Linz	Austria	1.406.000	30.270	244.619.757·*K*
10	Leipzig	Germany	2.420.000	19.835	340.825.020·*K*
11	Wroclaw	Poland	7.270.000	12.691	818.997.041·*K*
12	Nürnberg	Germany	5.000.000	32.263	898.095.207·*K*
13	Ostrava	Czech Republic	1.250.000	16.505	160.587.301·*K*
14	Berlin	Germany	5.967.000	21.736	879.722.805·*K*
15	Bratislava	Slovakia	1.868.000	20.655	268.466.111·*K*
16	Wien	Austria	3.529.000	32.485	636.052.690·*K*
17	Salzburg	Austria	1.090.000	30.519	190.419.600·*K*
18	Erfurt	Germany	2.293.000	19.538	320.511.862·*K*
19	München	Germany	7.500.000	32.263	1.347.142.810·*K*
20	Katowice	Poland	8.982.000	11.902	979.902.857·*K*
21	Trenčín	Slovakia	1.952.000	10.921	203.991.005·*K*
22	Stuttgart	Germany	10.755.000	30.776	1.886.759.309·*K*
23	Hannover	Germany	8.000.000	23.500	1.226.376.777·*K*
24	Frankfurt	Germany	24.000.000	28.530	4.053.798.219·*K*
25	Innsbruck	Austria	1.063.000	32.430	191.428.563·*K*
26	Graz	Austria	1.204.000	26.783	197.040.771·*K*
27	Budapest	Hungary	10.031.000	14.717	1.216.897.154·*K*
28	Lodz	Poland	3.846.000	10.599	395.951.257·*K*
29	Warszawa	Poland	7.232.000	16.986	942.549.088·*K*
30	Zürich	Switzerland	2.156.000	39.413	428.024.376·*K*

Table 3.27. Trip generation and attraction estimation per year (as a function of K). Own elaboration from [E], [K] and all the previous data

Note that the trip generation and attraction estimation results obtained have not been multiplied yet by the constant *K*, as we have not compared these results with real ones to calibrate it, what we will do in the next stage. We also have not considered the percentage of active population and employment rate due to the fact that they are quite similar in all the studied zones and, therefore, it can be assumed that they have been included in the constant factor *K*. On the other hand, tourism and freight traffic will be considered when designing the network in the next chapter.

3.2.2. Trip distribution

The second step in the UTP process is the trip distribution. This stage is used to match origins with destinations, without considering the modal split yet. In our case, we are going to use a gravity model function[1]. [E] It is important to stress that in this stage we are not going to consider prices, travel times and many other features of the system, which will be taken into account in the next stage.

The equation of the gravity model we are going to use is:

$$T_{ij} = \lambda \cdot \frac{G_i \cdot A_j}{{d_{ij}}^2} \quad [3.28]$$

where T_{ij} is the estimated number of trips between the regions *i* and *j*, λ is a constant to determine, G_i is the trip generation of the zone *i*, A_j is the trip attraction of the zone *j* and d_{ij} is the distance between the centroides of the zones.

The distances among centroides that we will use to calculate the trip distribution are the ones shown in the figure 3.11. Those distances are actually the distances following the railway network, but we consider them valid as an approximation. The income level expressed as GDP represents the average in the all zone in 2007, and has been converted into Euros with the average currency change in the same year.

The obtained results are shown in the next table:

[1] The gravity model illustrates the macroscopic relationships between places and is very used in transportation demand estimations. It has long been posited that the interaction between two locations declines with increasing distance, but is positively associated with the amount of activity at each location. The distance decay factor has been updated to a more comprehensive function of generalized cost, assuming distances, times and prices, being not necessarily linear. While the gravity model is very successful in explaining the choice of a large number of individuals, the choice of any given individual varies greatly from the predicted value.

Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	0	5.451	6.157	3.779	1.268	7.292	1.078	420	126	1.592	3.016	3.178	565	2.929	763	174	479	788	310	2.083	400	1.814	1.660	5.228	0	297	1.284	490	846	33
2	5.451	0	529	349	164	1.035	107	404	232	30	2.070	641	381	599	474	1.063	104	172	68	1.177	221	461	401	1.274	56	11	614	242	393	87
3	6.157	529	0	402	190	14.393	210	83	270	1.460	1.135	746	133	2.298	188	432	121	553	0	578	106	552	989	2.150	66	82	376	189	307	102
4	3.779	349	402	0	551	807	143	6	450	24	481	1.938	91	479	13	392	159	167	1.589	375	73	736	325	226	97	95	312	97	176	131
5	1.268	164	190	551	0	428	124	102	1.448	138	283	584	76	284	17	593	28	84	759	306	90	418	205	1.007	89	130	355	62	139	80
6	7.292	1.035	14.393	807	428	0	53	210	711	17.084	7.652	4.245	367	19.937	533	1.229	35	4.016	2.815	3.164	313	2.711	5.767	11.538	24	250	1.178	99	1.531	372
7	1.078	107	210	143	124	53	0	1.053	22	188	926	422	2.457	399	795	1.764	102	121	486	3.894	409	374	311	992	57	161	854	353	783	73
8	420	404	83	6	102	210	1.053	0	15	75	366	168	264	159	94	200	61	48	245	720	288	178	0	398	31	107	54	95	213	35
9	126	232	270	450	1.448	711	22	15	0	261	553	2.367	151	56	1.041	4.906	329	270	4.784	65	0	1.935	0	3.625	514	0	1.766	143	328	35
10	1.592	30	1.460	24	138	17.084	188	75	261	0	2.110	2.587	141	12.535	0	485	0	9.083	1.672	1.138	128	2.221	6.774	11.242	139	105	513	375	679	260
11	3.016	2.070	1.135	481	283	7.652	926	366	553	2.110	0	1.969	1.756	6.581	871	2.004	300	117	2.022	25.303	887	1.901	3.082	0	194	323	1.818	5.812	6.117	328
12	3.178	641	746	1.938	584	4.245	422	168	2.367	2.587	1.969	0	325	3.177	780	2.451	1.635	5.242	37.356	1.515	41	10.287	5.675	76.328	1.477	609	2.137	50	91	1.702
13	565	381	133	91	76	367	2.457	264	151	141	1.756	325	0	386	511	922	77	10	389	17.215	1.066	321	276	831	47	113	699	653	1.414	63
14	2.929	599	2.298	479	284	19.937	399	159	56	12.535	6.581	3.177	386	0	463	1.074	308	4.036	2.573	3.328	307	3.459	18.737	13.971	24	238	1.180	1.524	2.915	461
15	763	474	188	13	17	533	795	94	1.041	0	871	780	511	463	0	31.945	373	145	1.371	1.909	4.120	926	398	1.816	168	726	576	31	697	182
16	174	1.063	432	392	593	1.229	1.764	200	4.906	485	2.004	2.451	922	1.074	31.945	0	1.372	396	4.415	3.397	3.655	2.702	928	5.245	529	3.235	14.324	606	1.377	523
17	479	104	121	159	28	35	102	61	329	0	300	1.635	77	308	373	1.372	0	196	12.472	355	165	2.634	400	2.630	1.091	47	826	85	196	452
18	788	172	553	167	84	4.016	121	48	270	9.083	117	5.242	10	4.036	145	396	196	0	2.516	740	91	3.296	7.453	22.390	185	106	433	252	47	336
19	310	68	0	1.589	759	2.815	486	245	4.784	1.672	2.022	37.356	389	2.573	1.371	4.415	12.472	2.516	0	1.863	695	49.808	4.291	3.441	9.921	1.466	3.619	56	1.102	6.614
20	2.083	1.177	578	375	306	3.164	3.894	720	65	1.138	25.303	1.515	17.215	3.328	1.909	3.397	355	740	1.863	0	3.053	1.622	2.142	4.989	227	494	3.212	8.276	17.231	324
21	400	221	106	73	90	313	409	288	4	128	887	41	1.066	307	4.120	3.655	165	91	695	3.053	0	527	258	1.045	9	271	1.988	36	809	105
22	1.814	461	552	736	418	2.711	374	178	1.935	2.221	1.901	10.287	321	3.459	926	2.702	2.634	3.296	49.808	1.622	527	0	8.998	217.634	2.410	876	284	577	1.183	18.156
23	1.660	401	989	325	205	5.767	311	0	0	6.774	3.082	5.675	276	18.737	398	928	400	7.453	4.291	2.142	258	8.998	0	48.662	384	252	1.134	942	1.933	1.018
24	5.228	1.274	2.150	226	1.007	11.538	992	398	3.625	11.242	1	76.328	831	13.971	1.816	5.245	2.630	22.390	3.441	4.989	1.045	217.634	48.662	0	2.478	1.393	5.660	1.777	3.542	10.933
25	0	56	66	97	89	24	57	31	514	139	194	1.477	47	24	168	529	1.091	185	9.921	227	9	2.410	384	2.478	0	175	459	60	139	1.401
26	297	11	82	95	130	250	161	107	0	105	323	609	113	238	726	3.235	47	106	1.466	494	271	876	252	1.393	175	0	1.301	110	253	169
27	1.284	614	376	312	355	1.178	854	54	1.766	513	1.818	2.137	699	1.180	576	14.324	826	433	3.619	3.212	1.988	284	1.134	5.660	459	1.301	0	707	162	572
28	490	242	189	97	62	99	353	95	143	375	5.812	50	653	1.524	31	606	85	252	56	8.276	36	577	942	1.777	60	110	707	0	2.634	105
29	846	393	307	176	139	1.531	783	213	328	679	6.117	91	1.414	2.915	697	1.377	196	47	1.102	17.231	809	1.183	1.933	3.542	139	253	162	2.634	0	215
30	33	87	102	131	80	372	73	35	35	260	328	1.702	63	461	182	523	452	336	6.614	324	105	18.156	1.018	10.933	1.401	169	572	105	215	0

Table 3.29. Trip distribution matrix in thousand trips per year. Own elaboration

Note that the quantities shown on the table represent the total trip distribution in one year, not only the rail trips, but the total[2], as we have not spoken yet about the modal split. We have not considered the trips with origin and destination in the same region because they are useless to study high speed railway demand, as high speed lines need to have a minimum distance between stations which make it impossible to have more than one station in each region of our study zone. We will talk about it in the next chapter.

To determine the constants K and λ we have summed all the trips with both origins and destinations in different zones of the Czech Republic and compared to the trips registered by the Ministry of Transport, shown in the next table:

Transport mode	Thousand trips
Rail	182.194
Aircraft	113
Bus	348.395
TOTAL	**530.702**

Table 3.30. Trips by public transport mode in the Czech Republic in 2007 [6]

The values shown in the table consider the trips carried out inside zones and among different zones. Assuming that only a 10% of the trips are interzonals, we have obtained an aggregate value of $K \cdot \lambda = 1{,}113818 \cdot 10^{-9}\ Km^2 \cdot €^{-1} \cdot person^{-1}$.

Summing up the values obtained in the table 3.29 for each region, we have:

Rank	Centroid	Total trip distribution (in thousands)
1	Frankfurt	462.446
2	Stuttgart	339.001
3	Nürnberg	169.724
4	München	158.721
5	Hannover	123.397
6	Katowice	110.695
7	Dresden	109.788
8	Berlin	104.418
9	Wien	92.336
10	Wroclaw	79.976
11	Leipzig	73.039
12	Erfurt	63.286
13	Praha	53.501
14	Bratislava	51.926
15	Budapest	48.398

Rank	Centroid	Total trip distribution (in thousands)
16	Warszawa	47.452
17	Zürich	44.870
18	Ústí nad Labem	34.797
19	Ostrava	31.698
20	Salzburg	27.032
21	Lodz	26.437
22	Linz	26.403
23	Innsbruck	22.448
24	Trenčín	21.158
25	Pardubice	18.811
26	Olomouc	18.707
27	Plzeň	14.462
28	Graz	13.392
29	České Budejovice	10.001
30	Brno	6.091

Table 3.31. Total departing / arriving trips for region sorted from most to least. Own elaboration

[2] It should be mentioned that when talking about total trips we are not considering private transport modes and navigable inland waterways.

The total of departing and arriving trips have already considered the distances as an influencing factor on the trip estimation and should not be confused with the trip generation and attraction of each zone.

Looking the table 3.31 one can see that Frankfurt is the region with higher demand, over 460.000 trips, followed by Stuttgart, München, Nürnberg and Hannover. Praha occupies the 13th place with 53.501 trips, almost 20.000 trips more than the second zone in the Czech Republic, Ústí nad Labem, while the other zones occupy the last places of the ranking, being Brno the last one with just 6.091 trips.

Taking a look at the table 3.29 it can be seen that the most demanded connection is Stuttgart – Frankfurt, with over 200 million trips, followed by the connections Frankfurt – Nürnberg (76 million trips), München – Stuttgart (50 million trips) and Hannover – Frankfurt (49 million trips), all of them among Germany zones. In the Czech Republic, the most demanded connection is Praha – Ústí nad Labem (6,1 million trips) followed by Praha – Pardubice (5,4 million trips), Praha – Plzeň (3,7 million) and Ostrava – Olomouc (2,4 million trips). The international connections Ostrava – Katowice, Ústí nad Labem – Dresden and Plzeň – Nürnberg are the most demanded.

3.2.3. Modal split

Once we have talked about the trip distribution, next step is the modal split. This stage computes the proportion of trips between each origin and destination that use a particular transportation mode. The factors that take part in the election of the transportation mode are the social-economic factors explained in section 3.2.1 and the generalized costs such as the price of the service and substitute services, its accessibility, travel time, frequency, and quality of the service, basically. Subsequently we are going to talk about these factors regarding the election of high speed railway in the Czech Republic.

3.2.3.1. Influence of the price of the service and substitute services

The price of the service is maybe the most important factor to make the decision of the transportation mode. For the analysis, we will consider only the public transport, this is, bus, aircraft, conventional railway and high speed railway, excluding private car.

To explain the influence of the price of the service in the demand it is necessary to talk about its elasticity. The price elasticity is negative; this means that the higher the fares are, the lower the demand is. This elasticity is different for each transportation mode: the same changes in fares do not have the same consequences for each mode. Conventional railways and bus transport have higher elasticity than air and high speed railway transport, as they are cheaper public transports that attract the part of the population which is more sensible to the demand. Consequently, prices for conventional railways and bus transport should be more accurate, as small changes in them may cause big changes in the demand.

We will consider next prices for each transportation mode:

- Conventional railway transport: average fare of 5€ per 100 Km
- Bus transport: average fare of 5€ per 100 Km
- High speed railway transport: average fare of 10€ per 100 Km
- Air transport: average price of 15€ per 100 Km of flight for those trips with distances over 500 Km

Although these prices are not accurate, it is to be said that they represent quite well the average fares of the Czech Republic, though they should be higher in the western countries like Germany, Austria and Switzerland and lower in the eastern countries like Slovakia, Poland and Hungary. However, we will not distinguish prices among different countries for simplicity, as a good approximation.

3.2.3.2. Influence of the accessibility of the service

Another factor to choose the transportation mode is the accessibility of the service, it means, the distance needed to access the system and the time required to reach it. The accessibility is highly related to the network length of the service: the higher the network length is, the higher the accessibility becomes. Thus, analyzing the network length of each transportation mode one can have an approximation of its accessibility. However, although accessibility is an important factor in choosing a transportation mode, network length shows a small impact on demand; the elasticity of it can be approximately considered of 0,35, implying that an increase of 1% in network length would raise passenger demand by only by 0,35%. [8]

The accessibility can be expressed in time, in distance or as a combination of both. However, we will consider only the time as the unique factor to determine it. The access time can be considered as the average time needed to go from any place of the whole region to the nearest station/airport with connections to the different places of our study zone. It also considers the waiting time in the station/airport provided the knowledge of the schedule times. Therefore, there is no need to consider the access distance, as long as access time already includes it some way.

We will consider next access times for each transportation mode:

- Conventional railway transport: average time of 0,5h
- Bus transport: average time of 0,5h
- High speed railway transport: average time of 1,5h
- Air transport: average time of 3,5h

Note that for conventional railway and bus transport we have considered 30 minutes of access time, as their network length is quite high and there are several connections with the different points of the region. Nevertheless, for high speed railway we have considered 1h 30min of access time, as there would be a station only in every centroid of the region. For air transport it is more difficult to estimate, as some zones may not have airport and others may have more than one. However, we will consider an access time of 3h 30min for all the zones as there should be a displacement to the airport of its region or a neighbor one and a waiting time over 2 hours before taking off.

3.2.3.3. Influence of travel time and frequency of the service

Demand is particularly sensitive to factors associated with elapsed time, like the travel time and the frequency. As we would expect, they both have a positive impact on demand. Because we are studying inter-regional trips which are planned with scheduled times rather than with fixed frequencies, we are not going to consider the waiting time in the stations for the bus/train to arrive. However, we are taking into account the daily frequency of every transportation mode as it affects to the decisions of the travelers: one will prefer taking a transportation mode that covers a trip three times a day rather than only once, as the election becomes freer.

The travel time has a negative demand elasticity coefficient of 0,013; meaning that for every added minute of travel time, the demand decays in a 1,3%. This value, reflecting a negative time trend in demand, is especially high in a model which includes competitive transport modes, like in our case, which are usually taken to cause a negative trend. [8]

To analyze the travel time of each transportation mode, we will consider their commercial speed. The frequency and commercial speed of each transportation mode in our study zone are:

- Conventional railway transport: average commercial speed of 90 Km/h and frequency of 8 trains per day
- Bus transport: average commercial speed of 60 Km/h and frequency of 4 buses per day
- High speed railway transport: average commercial speed of 200 Km/h and frequency of 2 trains per day
- Air transport: average commercial speed of 600 Km/h and frequency of 1 flight per day

The commercial speed of conventional railway transport is the average extracted from the table 3.13, and the frequency has been taken from [G] and [H] considering all the connections, not only the direct ones. The bus transport data has been also extracted from [G], while high speed railway and air transport are assumptions. It should be mentioned that bus connections between closer centroides may have higher frequencies, though the frequencies fast decay with the separation of the centroides, until the fact that there might not be any connection between the furthest destinations. However, as always, we are considering a representative average for simplicity.

3.2.3.4. Influence of the quality of the service

The quality of the service includes all the non quantifiable factors by time, distance and money, such as the comfort of the transportation mode, the technology, the service offered in the ticket sale and during the trip, the staff, the reliability of the service, the maintenance systems, the station emplacements, the security, etc.

The quality of the service shows a strong effect on demand with an estimated elasticity of 0,25; while the technology investments and maintenance services appear to have a lesser effect, with an elasticity of 0,10, and ticket sale service and staff even lower. Elasticity values of comfort, situation emplacements, reliability and security of the service are significantly higher. [8]

In the next table we are showing the ranking of each transportation mode according to all the previous cited factors regarding the quality of the service:

Rank / Quality indicator	1st	2nd	3rd	4th
Comfort	High speed train	Conventional train	Aircraft	Bus
Technology	Aircraft	High speed train	Conventional train	Bus
Service offered	Aircraft	High speed train	Conventional train	Bus
Staff	Aircraft	High speed train	Conventional train	Bus
Reliability of the service	Bus	High speed train	Conventional train	Aircraft
Maintenance systems	Aircraft	High speed train	Conventional train	Bus
Station emplacement	Bus	Conventional train	High speed train	Aircraft
Security	Aircraft	High speed train	Conventional train	Bus
AVERAGE	Aircraft	High speed train	Conventional train	Bus

Table 3.32. Ranking of quality indicators by transportation mode. Own elaboration

As shown in the table, the transportation mode that best quality of the service offers is air transport, followed by high speed railway, conventional railway and ending by bus transport. It is therefore clear that high speed train would compete hardly with the other transportation modes regarding the quality of offered the service. Because of the difficulty in quantifying these criteria, we are not including the quality of the service indicators in the modal split estimation done next.

3.2.3.5. Modal split estimation

To estimate the modal split we will consider the *logit* form, developed by Nobel Prize winner Daniel McFadden. [E] The *logit* form is a disaggregate mathematical model that calculates the probability of individuals of choosing a mode among available alternatives. Its formulation is [9]:

$$P_i = \frac{e^{U_i}}{\sum_j^n e^{U_j}} \quad [3.33]$$

where:

- P_i = Probability of an individual choosing alternative i
- U_i = Utility function of mode i
- n = Set of modal alternatives
- e = Base of natural logarithm

The utility function measures the degree of satisfaction that people derive from their choices, while a disutility function represents the generalized cost associated with each choice. Therefore, it is assumed that the probability of choosing a particular mode is the probability that the perceived utility from that mode is greater than the perceived utility from each of the other available modes. In our case, regarding the influencing factors on the modal election we have explained before, the utility function of a mode i will be expressed as:

$$U_i = a_1 \cdot d_i + a_2 \cdot t_i + a_3 \cdot f_i + a_4 \cdot c_i \quad [3.34]$$

where

- a_1, a_2, a_3 and a_4 are constants
- d_i is the access time for the mode i in hours
- t_i is the travel time for the mode i in hours
- f_i is the frequency for the mode i in times per day
- c_i is the out of pocket cost for the mode i in €

The constants take into account the elasticity of the mode demand and will be given as a_1 = -0,004; a_2 = -0,004; a_3 = +0,003 and a_4 = -0,005, considering times in hours and costs in €. [L]

We are just going to obtain the origin/destination matrix for high speed railway, this means that we will have to obtain the probability of choosing the high speed railway transport for every origin/destination pair of our study zone.

Developing the formula 3.33 we have:

$$P_{HS} = \frac{e^{U_{HS}}}{e^{U_{HS}} + e^{U_{CR}} + e^{U_B} + e^{U_A}} \quad [3.35]$$

where we will apply the formula 3.34 to obtain the corresponding utilities for each transportation mode for each origin/destination pair. We will skip the intermediate calculus to offer directly the probability matrix of high speed railway election for each origin/destination trip and, therefore, the estimated trip distribution matrix for high speed railway, obtained as a result of multiplying every probability value for the total trips shown in the table 3.29 for every origin/destination trip.

The two matrixes are shown next:

Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1		0,3322	0,3322	0,3324	0,3337	0,3342	0,3355	0,3356	0,3365	0,3369	0,3377	0,3379	0,3379	0,3381	0,3388	0,3390	0,3394	0,3395	0,3398	0,3402	0,3406	0,2619	0,2597	0,2600	0,2605	0,2591	0,2613	0,2603	0,2624	0,2634
2	0,3322		0,3346	0,3348	0,3360	0,3366	0,3331	0,3333	0,3389	0,3392	0,3354	0,3402	0,3356	0,3405	0,3365	0,3367	0,2588	0,2589	0,2591	0,3379	0,3383	0,2640	0,2618	0,2621	0,2626	0,2585	0,2592	0,3410	0,2603	0,2654
3	0,3322	0,3346		0,3348	0,3361	0,3318	0,3379	0,3380	0,3389	0,3344	0,3379	0,3403	0,3403	0,3357	0,2583	0,2585	0,2588	0,3371	0,2592	0,2592	0,2599	0,2638	0,3404	0,2598	0,2626	0,2613	0,2634	0,2604	0,2630	0,2655
4	0,3324	0,3348	0,3348		0,3329	0,3368	0,3381	0,3382	0,3358	0,3394	0,3403	0,3353	0,3405	0,3407	0,2585	0,3400	0,3386	0,3409	0,3372	0,2597	0,2601	0,2596	0,2620	0,3406	0,3411	0,2585	0,2622	0,2625	0,2646	0,2611
5	0,3337	0,3360	0,3361	0,3329		0,3380	0,3375	0,3352	0,3327	0,3406	0,2586	0,3384	0,3398	0,2590	0,3384	0,3370	0,3356	0,2602	0,3390	0,2591	0,3402	0,2612	0,2631	0,2605	0,3400	0,3383	0,2595	0,2636	0,2641	0,2624
6	0,3342	0,3366	0,3318	0,3368	0,3380		0,3398	0,3400	0,3408	0,3325	0,3360	0,3385	0,2592	0,3338	0,2600	0,2602	0,2605	0,3352	0,2597	0,3403	0,2616	0,2621	0,3385	0,3409	0,2632	0,2630	0,2651	0,2587	0,2613	0,2660
7	0,3355	0,3331	0,3379	0,3381	0,3375	0,3398		0,3321	0,3398	0,2594	0,3387	0,2604	0,3322	0,2606	0,3353	0,3355	0,2596	0,2618	0,2621	0,3346	0,3365	0,2668	0,2647	0,2650	0,2635	0,3402	0,3410	0,3398	0,3401	0,2683
8	0,3356	0,3333	0,3380	0,3382	0,3352	0,3400	0,3321		0,3375	0,2595	0,3388	0,2605	0,3345	0,2607	0,3330	0,3332	0,3404	0,2619	0,2606	0,3368	0,3349	0,2654	0,2648	0,2651	0,2615	0,3380	0,3388	0,2590	0,2594	0,2666
9	0,3365	0,3389	0,3389	0,3358	0,3327	0,3408	0,3398	0,3375		0,2603	0,2611	0,3372	0,2592	0,2615	0,3359	0,3342	0,3327	0,2598	0,3362	0,2612	0,3387	0,2587	0,2642	0,2594	0,3371	0,3355	0,3398	0,2658	0,2661	0,2599
10	0,3369	0,3392	0,3344	0,3394	0,3406	0,3325	0,2594	0,2595	0,2603		0,3386	0,3382	0,2616	0,3336	0,2624	0,2625	0,2625	0,3325	0,2594	0,2598	0,2640	0,2597	0,3359	0,3383	0,2629	0,2653	0,2674	0,2611	0,2629	0,2642
11	0,3377	0,3354	0,3379	0,3403	0,2586	0,3360	0,3387	0,3388	0,2611	0,3386		0,2613	0,3365	0,3378	0,2590	0,2591	0,2636	0,2584	0,2640	0,3342	0,3403	0,2675	0,2604	0,2635	0,2674	0,2633	0,2641	0,3356	0,3384	0,2702
12	0,3379	0,3402	0,3403	0,3353	0,3384	0,3385	0,2604	0,2605	0,3372	0,3382	0,2613		0,2625	0,2589	0,2601	0,2586	0,3377	0,3355	0,3342	0,2645	0,2626	0,3396	0,3405	0,3351	0,3381	0,2598	0,2635	0,2663	0,2688	0,2584
13	0,3379	0,3356	0,3403	0,3405	0,3398	0,2592	0,3322	0,3345	0,2592	0,2616	0,3365	0,2625		0,2612	0,3369	0,3379	0,2617	0,2639	0,2642	0,3321	0,3341	0,2689	0,2663	0,2671	0,2656	0,2596	0,2595	0,3374	0,3378	0,2704
14	0,3381	0,3405	0,3357	0,3407	0,2590	0,3338	0,2606	0,2607	0,2615	0,3336	0,3378	0,2589	0,2612		0,2635	0,2637	0,2640	0,3362	0,2627	0,2591	0,2646	0,2630	0,3357	0,2590	0,2662	0,2664	0,2685	0,2585	0,2596	0,2675
15	0,3388	0,3365	0,2583	0,2585	0,3384	0,2600	0,3353	0,3330	0,3359	0,2624	0,2590	0,2601	0,3369	0,2635		0,3316	0,3388	0,2647	0,2592	0,3388	0,3326	0,2640	0,2676	0,2648	0,2601	0,3364	0,3356	0,2608	0,2611	0,2652
16	0,3390	0,3367	0,2585	0,3400	0,3370	0,2602	0,3355	0,3332	0,3342	0,2625	0,2591	0,2586	0,3379	0,2637	0,3316		0,3370	0,2636	0,3405	0,3402	0,3344	0,2625	0,2678	0,2632	0,2585	0,3346	0,3355	0,2620	0,2623	0,2637
17	0,3394	0,2588	0,2588	0,3386	0,3356	0,2605	0,2596	0,3404	0,3327	0,2625	0,2636	0,3377	0,2617	0,2640	0,3388	0,3370		0,2602	0,3333	0,2637	0,2586	0,3388	0,2645	0,2598	0,3343	0,3367	0,2596	0,2683	0,2686	0,3401
18	0,3395	0,2589	0,3371	0,3409	0,2602	0,3352	0,2618	0,2619	0,2598	0,3325	0,2584	0,3355	0,2639	0,3362	0,2647	0,2636	0,2602		0,3398	0,2622	0,2663	0,3402	0,3354	0,3357	0,2605	0,2647	0,2685	0,2634	0,2653	0,2619
19	0,3398	0,2591	0,2592	0,3372	0,3390	0,2597	0,2621	0,2606	0,3362	0,2594	0,2640	0,3342	0,2642	0,2627	0,2592	0,3405	0,3333	0,3398		0,2662	0,2617	0,3353	0,2615	0,3395	0,3337	0,3401	0,2626	0,2690	0,2711	0,3370
20	0,3402	0,3379	0,2592	0,2597	0,2591	0,3403	0,3346	0,3368	0,2612	0,2598	0,3342	0,2645	0,3321	0,2591	0,3388	0,3402	0,2637	0,2622	0,2662		0,3360	0,2709	0,2642	0,2673	0,2676	0,2616	0,2613	0,3351	0,3355	0,2724
21	0,3406	0,3383	0,2599	0,2601	0,3402	0,2616	0,3365	0,3349	0,3387	0,2640	0,3403	0,2626	0,3341	0,2646	0,3326	0,3344	0,2586	0,2663	0,2617	0,3360		0,2665	0,2692	0,2672	0,2625	0,3391	0,3384	0,2583	0,2587	0,2676
22	0,2619	0,2640	0,2638	0,2596	0,2612	0,2621	0,2668	0,2654	0,2587	0,2597	0,2675	0,3396	0,2689	0,2630	0,2640	0,2625	0,3388	0,3402	0,3353	0,2709	0,2665		0,2591	0,3344	0,3392	0,2622	0,2674	0,2724	0,2742	0,3350
23	0,2597	0,2618	0,3404	0,2620	0,2631	0,3385	0,2647	0,2648	0,2642	0,3359	0,2604	0,3405	0,2663	0,3357	0,2676	0,2678	0,2645	0,3354	0,2615	0,2642	0,2692	0,2591		0,3376	0,2649	0,2691	0,2726	0,2636	0,2647	0,2636
24	0,2600	0,2621	0,2598	0,3406	0,2605	0,3409	0,2650	0,2651	0,2594	0,3383	0,2635	0,3351	0,2671	0,2590	0,2648	0,2632	0,2598	0,3357	0,3395	0,2673	0,2672	0,3344	0,3376		0,2602	0,2644	0,2681	0,2685	0,2703	0,3395
25	0,2605	0,2626	0,2626	0,3411	0,3400	0,2632	0,2635	0,2615	0,3371	0,2629	0,2674	0,3381	0,2656	0,2662	0,2601	0,2585	0,3343	0,2605	0,3337	0,2676	0,2625	0,3392	0,2649	0,2602		0,3410	0,2635	0,2721	0,2724	0,3357
26	0,2591	0,2585	0,2613	0,2585	0,3383	0,2630	0,3402	0,3380	0,3355	0,2653	0,2633	0,2598	0,2596	0,2664	0,3364	0,3346	0,3367	0,2647	0,3401	0,2616	0,3391	0,2622	0,2691	0,2644	0,3410		0,3402	0,2662	0,2665	0,2633
27	0,2613	0,2592	0,2634	0,2622	0,2595	0,2651	0,3410	0,3388	0,3398	0,2674	0,2641	0,2635	0,2595	0,2685	0,3356	0,3355	0,2596	0,2685	0,2626	0,2613	0,3384	0,2674	0,2726	0,2681	0,2635	0,3402		0,2659	0,2662	0,2686
28	0,2603	0,3410	0,2604	0,2625	0,2636	0,2587	0,3398	0,2590	0,2658	0,2611	0,3356	0,2663	0,3374	0,2585	0,2608	0,2620	0,2683	0,2634	0,2690	0,3351	0,2583	0,2724	0,2636	0,2685	0,2721	0,2662	0,2659		0,3327	0,2752
29	0,2624	0,2603	0,2630	0,2646	0,2641	0,2613	0,3401	0,2594	0,2661	0,2629	0,3384	0,2688	0,3378	0,2596	0,2611	0,2623	0,2686	0,2653	0,2711	0,3355	0,2587	0,2742	0,2647	0,2703	0,2724	0,2665	0,2662	0,3327		0,2772
30	0,2634	0,2654	0,2655	0,2611	0,2624	0,2660	0,2683	0,2666	0,2599	0,2642	0,2702	0,2584	0,2704	0,2675	0,2652	0,2637	0,3401	0,2619	0,3370	0,2724	0,2676	0,3350	0,2636	0,3395	0,3357	0,2633	0,2686	0,2752	0,2772	

Table 3.36. Probability matrix for high speed railway election among the studied zones. Own elaboration

Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	0	1.811	2.046	1.256	423	2.437	362	141	42	536	1.019	1.074	191	990	259	59	163	268	105	709	136	475	431	1.359	0	77	335	128	222	9
2	1.811	0	177	117	55	348	36	135	79	10	694	218	128	204	159	358	27	45	18	398	75	122	105	334	15	3	159	83	102	23
3	2.046	177	0	135	64	4.775	71	28	92	488	384	254	45	772	49	112	31	186	0	150	28	146	337	559	17	21	99	49	81	27
4	1.256	117	135	0	183	272	48	2	151	8	164	650	31	163	3	133	54	57	536	97	19	191	85	77	33	25	82	25	47	34
5	423	55	64	183	0	145	42	34	482	47	73	198	26	74	6	200	9	22	257	79	31	109	54	262	30	44	92	16	37	21
6	2.437	348	4.775	272	145	0	18	71	242	5.680	2.571	1.437	95	6.655	139	320	9	1.346	731	1.077	82	711	1.952	3.934	6	66	312	26	400	99
7	362	36	71	48	42	18	0	350	7	49	314	110	816	104	267	592	26	32	127	1.303	138	100	82	263	15	55	291	120	266	20
8	141	135	28	2	34	71	350	0	5	19	124	44	88	41	31	67	21	13	64	243	96	47	0	106	8	36	18	25	55	9
9	42	79	92	151	482	242	7	5	0	68	144	798	39	15	350	1.639	109	70	1.608	17	0	501	0	940	173	0	600	38	87	9
10	536	10	488	8	47	5.680	49	19	68	0	715	875	37	4.181	0	127	0	3.020	434	296	34	577	2.275	3.803	37	28	137	98	179	69
11	1.019	694	384	164	73	2.571	314	124	144	715	0	515	591	2.223	226	519	79	30	534	8.455	302	508	803	0	52	85	480	1.950	2.070	89
12	1.074	218	254	650	198	1.437	110	44	798	875	515	0	85	823	203	634	552	1.759	12.484	401	11	3.494	1.932	25.580	499	158	563	13	24	440
13	191	128	45	31	26	95	816	88	39	37	591	85	0	101	172	312	20	3	103	5.718	356	86	73	222	12	29	181	220	478	17
14	990	204	772	163	74	6.655	104	41	15	4.181	2.223	823	101	0	122	283	81	1.357	676	862	81	910	6.289	3.619	6	63	317	394	757	123
15	259	159	49	3	6	139	267	31	350	0	226	203	172	122	0	10.593	126	38	355	647	1.370	244	107	481	44	244	193	8	182	48
16	59	358	112	133	200	320	592	67	1.639	127	519	634	312	283	10.593	0	462	104	1.503	1.156	1.222	709	248	1.381	137	1.082	4.805	159	361	138
17	163	27	31	54	9	9	26	21	109	0	79	552	20	81	126	462	0	51	4.157	94	43	892	106	683	365	16	214	23	53	154
18	268	45	186	57	22	1.346	32	13	70	3.020	30	1.759	3	1.357	38	104	51	0	855	194	24	1.121	2.500	7.516	48	28	116	66	12	88
19	105	18	0	536	257	731	127	64	1.608	434	534	12.484	103	676	355	1.503	4.157	855	0	496	182	16.701	1.122	1.168	3.311	499	950	15	299	2.229
20	709	398	150	97	79	1.077	1.303	243	17	296	8.455	401	5.718	862	647	1.156	94	194	496	0	1.026	439	566	1.333	61	129	839	2.773	5.780	88
21	136	75	28	19	31	82	138	96	1	34	302	11	356	81	1.370	1.222	43	24	182	1.026	0	140	69	279	2	92	673	9	209	28
22	475	122	146	191	109	711	100	47	501	577	508	3.494	86	910	244	709	892	1.121	16.701	439	140	0	2.331	72.773	817	230	76	157	324	6.081
23	431	105	337	85	54	1.952	82	0	0	2.275	803	1.932	73	6.289	107	248	106	2.500	1.122	566	69	2.331	0	16.427	102	68	309	248	512	268
24	1.359	334	559	77	262	3.934	263	106	940	3.803	0	25.580	222	3.619	481	1.381	683	7.516	1.168	1.333	279	72.773	16.427	0	645	368	1.518	477	958	3.711
25	0	15	17	33	30	6	15	8	173	37	52	499	12	6	44	137	365	48	3.311	61	2	817	102	645	0	60	121	16	38	470
26	77	3	21	25	44	66	55	36	0	28	85	158	29	63	244	1.082	16	28	499	129	92	230	68	368	60	0	443	29	67	45
27	335	159	99	82	92	312	291	18	600	137	480	563	181	317	193	4.805	214	116	950	839	673	76	309	1.518	121	443	0	188	43	154
28	128	83	49	25	16	26	120	25	38	98	1.950	13	220	394	8	159	23	66	15	2.773	9	157	248	477	16	29	188	0	876	29
29	222	102	81	47	37	400	266	55	87	179	2.070	24	478	757	182	361	53	12	299	5.780	209	324	512	958	38	67	43	876	0	60
30	9	23	27	34	21	99	20	9	9	69	89	440	17	123	48	138	154	88	2.229	88	28	6.081	268	3.711	470	45	154	29	60	0

Table 3.37.Trip distribution matrix for high speed railway in thousand trips per year. Own elaboration

Note that these two matrixes are estimations considering that high speed railway is already present in the whole study region.

Looking at the probability matrix one can see that the probability of choosing high speed railway transport is higher in short and medium distances, but it decreases as long as the travel distances become longer, as a consequence of air transport dominance. The average of the probability of electing high speed railway for travelling around the studied zones is around 29,5%, being the share always below 35%. This means that still with the introduction of high speed railway in the Czech Republic, other transportation modes would be preferred for travelling among the studied zones of the Czech territory and Central Europe. However, the highest rates of high speed railway transport election are estimated in the Czech Republic, demonstrating that high speed railway in the Czech Republic and its surroundings is something clearly demanded.

Taking a look at the trip distribution matrix for high speed railway one can see that the most demanded trips are those connecting Frankfurt and Stuttgart, with over 70 million trips per year, followed by Frankfurt – Nürnberg, over 25 million trips per year demanded, München – Suttgart, with over 16,7 million trips and Wien – Bratislava, with over 10,5 million trips. Berlin, Dresden, Leipzig, Hannover, Erfurt, Praha and Katowice are also some of the zones with more high speed railway demand, all of them over 600.000 estimated trips as average with all the other destinations. The most demanded connection between Czech Republic's zones is Praha - Ústí nad Labem, with over 2 million trips, while the most demanded connection between the Czech Republic and abroad is Ústí nad Labem – Dresden, with 4,7 million trips. The rest of the Czech Republic zones are quite demanded, being the less one the connection Brno - České Budejovice with only 34.100 trips per year.

Based on the above one can responsibly say that the volume of traffic flows in the Czech Republic is currently such that the critical backbone directions fully justifies the construction of high speed lines. Furthermore, it should be also taken into account the fact that transport intensity is increasing and, in 20 years time, we will face much higher values of traffic flows. However, the estimated values for the use of high speed will be achieved gradually, as it will be a new infrastructure of transport that needs to be consolidated before working at the highest performance.

3.2.4. Route assignment

The last stage of a sequential model of demand estimation is the route assignment, which consists in allocating trips between an origin and a destination by a particular mode of transport to a particular route. [E] This stage is especially important in urban transportation planning, where the private car traffic has a big paper on its analysis. The reason of this is that every driver chooses the fastest way to connect his origin and destination, depending on the traffic of the zone, which also depends on the route assignment of every driver; this is, the demand depends on the traffic which already depends on the demand, making it very difficult to study.

Regarding high speed railway transport, there are not such these problems because of the fixed travel times independent of the rail traffic, making it much easier to determinate the route assignment. Moreover, in our study model, there are very few viable combinations to travel from an origin to a destination and we have always considered the shortest time in the entire above exposed trip distribution matrixes.

Because of all this, and because the travel times of the high speed railway services are public, letting travelers know the time it will take them for every possible origin/destination match, we are not going to make any change to the previous trip distribution matrix for high speed railway shown in the table 3.37, which we will consider as the final high speed railway demand matrix for our study model.

4. PROPOSED NETWORK AND SERVICES

Once the offer and demand analysis is done we can now know where the rail lines should go through. In this chapter we are going to propose a high speed railway network and its main services, such as the frequency, the commercial speed, the technology used, the general fares, etc. To do it, we will first talk about the origin of the studies about the introduction to high speed railway in the Czech Republic and then we will analyze its topography, geology, climatology and land uses to design an appropriate network, including the connections with the neighboring countries and considering a mix traffic share between passenger and freight transport in the new high speed lines. Finally, we will explain the most relevant constructive aspects and the main features of the service.

4.1. Origin of the studies of high speed railway in the Czech Republic

Due to economic and political stabilization of Central and Eastern Europe, high speed rail network has been included in the medium and long term development of this area for the continued construction of the European high speed network. Because of transport infrastructure is one of the basic assumptions of economic and cultural prosperity, gross national product growth and living standards of citizens, it has become a great priority for all the States.

The first studies about the management of high speed lines in Czechoslovakia had been processed at the beginning of the seventies of the last century. Today's alternative routes are the result of the study “High speed coordination and the modernization of existing lines”, which was established on the basis of international negotiations and evaluation of economic performance. [10]

In 1975, Czechoslovakia was still constructing rolling stock in Škoda Plzeň, having the experience with electric locomotives MS 200 and MS 6 up to 200 Km/h for the then Soviet railways. They delivered a total of 20 locomotives MS 200 and 40 locomotives MS 6 which are still operated in the route Moscow - St. Petersburg. It was then founded the “Association of High Speed Rail Services”, whose members were specialists from different companies, railways and universities, engaged in the professional building of lines, bridges, tunnels, overhead lines, power and security systems, including construction rolling stock. [14]

Later, in 1985, it took place the “European Agreement on Main International Railway Lines” (AGC) in Genova, considering that, in order to strengthen relations between the European countries, it was essential to lay down a coordinated plan for the development and construction of railway lines adjusted to the requirements of future international traffic. The European railways were classified according to their orientation and main technical parameters and it was started to study the introduction to high speed railway in the Czechoslovak Socialist Republic with the modernization of some of its lines, though it was not until some years later that the first real studies were done. [15]

In 1989, on the basis of government resolutions CSFR No 765/89, it was given by the Czechoslovak Ministry of Transport and Industry the plan to process the studies of high speed railway, including the establishment of an experimental section between Plzeň and Rozvadov, where high speed was tested later in 1996; and also the entire high speed operation and the end of the trials to the further extension to Praha and the gradually connection to Western Europe.

One year later, this was the high speed proposal for the Czechoslovak Republic:

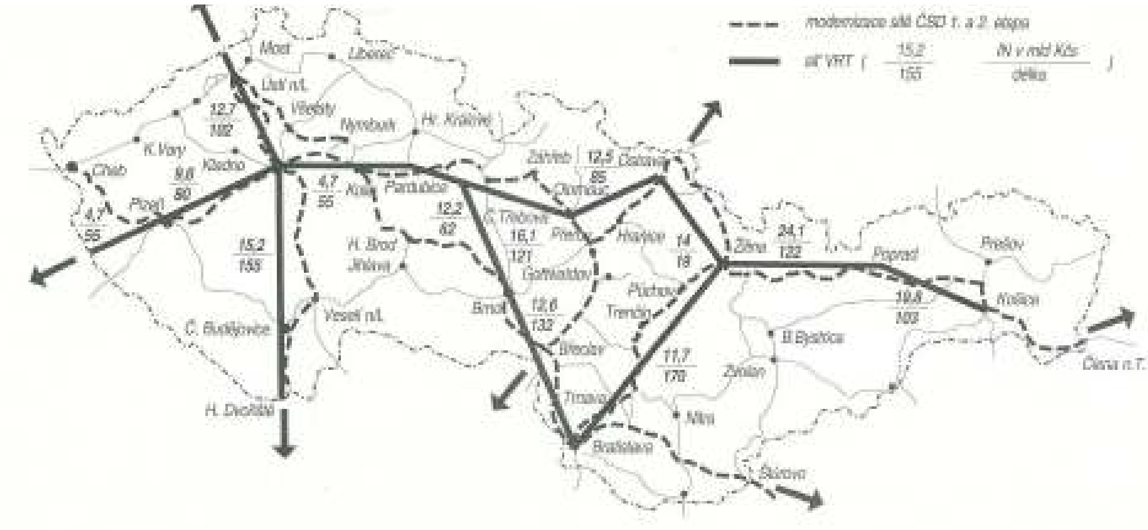


Figure 4.1. High speed network proposal for the Czechoslovak Republic in 1990 [14]

In this picture, we can see in continuous straight lines the proposed new high speed lines, while the discontinuous ones represent the expected lines to be modernized. There was planned one main route from West to East with several ramifications to the North and the South connecting with the neighboring countries. Despite this proposal was made in 1990, the whole scheme does not differ considerably from what is planned at this moment. It should be emphasized the timeliness of the long term application of the Czech Republic and the timeliness of investment in high speed railway infrastructure, as it was a main interest of the State to initiate the construction of new transport infrastructure at the corresponding European level.

From the 90th of the last century it was approved the building of the Trans-European Transport Networks (TENs). It was planned the routing of ten multimodal transport corridors in Central and Eastern European countries, most of them looking towards Moscow. Two of the corridors passed through the Czech Republic's territory: corridors No IV and No VI, as it can be seen in the next picture:

Figure 4.2. Trans-European Transport Network [10]

The corridor No IV leaded from Berlin via Dresden, Praha, Brno and Wien / Bratislava, Budapest to Konstanz / Istanbul, with a branch Nürnberg – Praha, where there would be an important concentration of traffic towards Paris. With this corridor, the capacity of the existing conventional lines would be released for the growing urban and suburban rail transport and, in addition, these locations would be upgrading to increase line speed, though not very much due to improper configuration of the terrain and dense settlements. The other corridor was No VI, which was the trace between the cities of Gdansk / Warsaw / Katowice - Ostrava – Břeclav, with the branch Katowice - Žilina. [10]

The Ministry of Transport finally decided to promote the government's consent to the four modernizations transit railway corridors up to the speed of 160 Km/h on the basis of the conference in Crete in 1994 and based on the AGC agreements, which corresponded to the multimodal TEN corridors. The upgrading, but, is being carried out today with the need of significant financial resources, being all the activities related to high speed railway almost stopped. [14]

In 1995, the SUDOP PRAHA A.S. enterprise studied the technical documentation about the high speed railway corridors in the Czech Republic, as the Czech State authorities ordered. The study was based on the assumption of high speed rail connections in the Czech Republic to the Western high speed railway lines, while the high speed lines should be conducted as quickly as possible through the territory of Praha, Brno and Ostrava, already on the design speed of 300 Km/h.

The high speed network in the Czech Republic had been planned with the following routes: [10]

- Praha – Plzeň – Nürnberg / München
- Praha – Dresden
- Praha – Brno – Bratislava / Wien
- Brno – Ostrava

The places where there should be high speed railway stations in the Czech Republic were divided in three levels of importance: [10]

- Praha: the most objective and biggest source of passengers on both international and national perspective. High speed station should be in the outskirts of the city linked to the rail network, and all the passenger trains would stop there. National freight and passenger trains passing through the city could either continue on the high speed network or in the classic one.

- Brno, Ostrava and Plzeň: the most important places in the Czech Republic from the transport point of view. High speed trains should pass through these cities, besides classic rail network. There may be some high speed trains that will not stop in these cities, like some night trains.

- Ústí nad Labem, Olomouc / Přerov, Havlickuv Brod / Jihlava and Hradec Králové / Pardubice: in these areas it is expected a construction of a simple station of high speed trains outside the city for the transfer with classic rail network or other modes of transport. Some trains would pass them without stopping.

For the most important agglomerations like Praha, Brno and Ostrava, there would be two options: drive the high speed railway to the city center after the reconstruction of existing lines or bypass the city and construct a new terminal with links to public transport. The first option, although loosing a few minutes of the running time of high speed trains, would be more attractive for passengers with origin or destination in the city center, while the second option would offer lower travel times, especially for those who would be just crossing the Czech territory. [12]

Taking a look on the list of cities in the Czech Republic with over 90.000 inhabitants, there are cities which had not been considered in the station emplacement of high speed railway network, like Liberec and České Budějovice. Liberec was not considered because its situation in the North of the Czech Republic, lying only in the route E65 without having important connections, while České Budějovice was not considered because of its emplacement on the IV national railway corridor and in the expected extension of the corridor X of the TEN railway network from Salzburg to Praha. [10]

Regarding the construction stages, there was a preferred link between Berlin and Vienna, which is likely to be started with the first building section Kolín – Brno. There is also another preferred connection with Germany to the West, linking Praha and Nürnberg, which should be started with the stretch Praha – Beroun. The rest of the network should be started afterwards.

SUDOP PRAHA A.S. appointed a study considering that high speed railway in the Czech Republic would be designed for mixed traffic, despite the current global trend towards the exclusively passenger transport. The main reason was that freight traffic requires smaller investment costs, as there are less demanding conditions regarding the trace, besides the view that rail freight transport capacity in the existing rail network would be properly streamlined. [12] Mixed transport also plays an important role in the design speed and the merits of particular speed over 300 Km/h should be assessed in relation to the achievement of a "systematic" driving time between stops. [10]

In 2003, the IKP Consulting Engineers enterprise developed the “Coordinated study of high speed railway”, which is one of the latest studies done about high speed railway in the Czech Republic and provides its construction after 2010. It also guarantees the territorial protection of land in local plans for individual regions. Two years later, in 2005, a document was drawn with a serious transport policy for the period 2005 – 2013 by a new entity called Management of Railway Traffic Routes, which will take care of the building of new infrastructures that the construction of high speed railway in the Czech Republic requires. [14]

In 2007, the Department of Transport prepared the first part of the study “Updating the concept of high speed rail services in the Czech Republic”, being its main aim to solve several problematic areas, as well as to ensure the protection of territorial management of individual routes, which are still in the discussion of authorities. Designers have begun to handle a more detailed study about where high speed lines in the Czech Republic should go. It is quite clear that the connection between Prague and Brno will not go through the Highlands but through the North and Pardubice. [10]

There should also be interconnection lines between high speed lines and the conventional network to ensure maximum utilization, besides allowing the construction of network in different stages. When assessing individual routes, it should also be very carefully considered the benefits of high speed rail transport in comparison with the upgraded transport corridors. Substantial part of the study would evaluate the economic efficiency of the implementation of high speed lines and would also consider specific problematic areas such as the confluence of various routes, hubs and urban conurbations passages.

It is clear that the preparatory work of the construction of high speed railway routes for the regional offices and buying land in accordance with the relevant laws will require a lot of time, as well as the creation of new legislative documents. It might be useful to create an independent organization in the Czech Republic, for example type consortia comprising of Czech representatives, even from foreign companies and railways, which, in collaboration with the responsible State organizations, monitories all the preparatory work. In individual companies, rail industry should be prepared in advance of projects, which is the condition that the Government requests to build high speed rail in the Czech Republic. [14]

4.2. Network design and frontier connections

In this section we are going to design an appropriate network of high speed railway, considering both the new parts and the renewal ones, including the connections to the neighboring countries, the stations emplacement and the expected constructive stages. We will take into account all the information about the offer and demand analysis regarding passenger and freight traffic and other useful data such as the topography, geology, climatology and land uses of the Czech Republic, which are essential for the high speed railway emplacement, which will be analyzed next.

4.2.1. Previous analysis

The Czech Republic is located between the latitudes 48°33' and 51°03' North and the longitudes 12°05' and 18° 51' East. The distance from the Western to the most Eastern part is 278 km, likewise the maximum North - South distance is 493 km.

Regarding the topography, the Czech Republic is situated on the boundary of two different mountain systems. The State borders are formed by the Šumava, the Bohemian Forest, the Ore Mountains, the Giant Mountains, the Orlické Hory, and the Jeseníky. In the centre there are the Czech Highlands and the Bohemian and Moravian Uplands. In the eastern part of Czech Republic there are the West Carpathians and the White Carpathians. The outlines of both mentioned mountain systems are filled by valleys, the most fertile of them being the valleys of the Morava River in Moravia and the valley around the middle course of the Elbe River in Bohemia. The highest place in the country is Snežka, located in Krkonoše (Giant Mountains) at 1,602 m above sea level, being the lowest place (only 115 m above sea level) the point where the river Elbe leaves the Czech Republic to Germany. A third of the Czech territory is above 500 m. [16]

A simple topographic map of the Czech Republic is shown next:

Figure 4.3. Topographic map of the Czech Republic [O]

The whole area of the Czech Republic is covered by highlands, structured by several big rivers. Those highlands are the remains of old mountain ridges, where rocks are folded and alterated by a long orogenetic history. The sedimentary rocks are not in their original state of horizontal layering, but torn into pieces, folded and slanted.

All the country is dotted with caves, all of them located in small, not to say tiny, karst areas. All the limestone karst areas of the Czech Republic are small and have a complex structure. Some tiny karst areas have only small caves, which are not open to the public, while others have only one shown cave. There are only two areas which are bigger and contain numerous caves with some of them open to the public.

The country is divided into three principal karst territories, a division which covers the whole surface of the Czech Republic. This means the territories are not limited to the karst areas, but cover the basic geological structure of the country. Also they are not the same size. The borders run more or less straight from Znojmo, at the southern border to Austria, to the North-East. The Western division covers most of the country, the Western and Central part, which makes about 75% of the area.
There are numerous caves, many shown caves, but typically they are located in small isolated karst areas. The only bigger karst area in this division is the Český Kras (Czech Karst) near Praha. The border to the next division runs from Znojmo, North of Brno towards Sumperk and the Polish border. The second border runs also from Znojmo, North-East, south of Brno towards Ostrava also at the Polish border. The triangle in between includes the Moravský Kras (Moravian Karst), which is the most famous karst area of the country. The third area is the smallest one and only has one shown cave. It is part of the Carpathian Mountain Range. [P]

In the next picture, a thematic map of the Czech Republic according to the geology and history of the soil is shown:

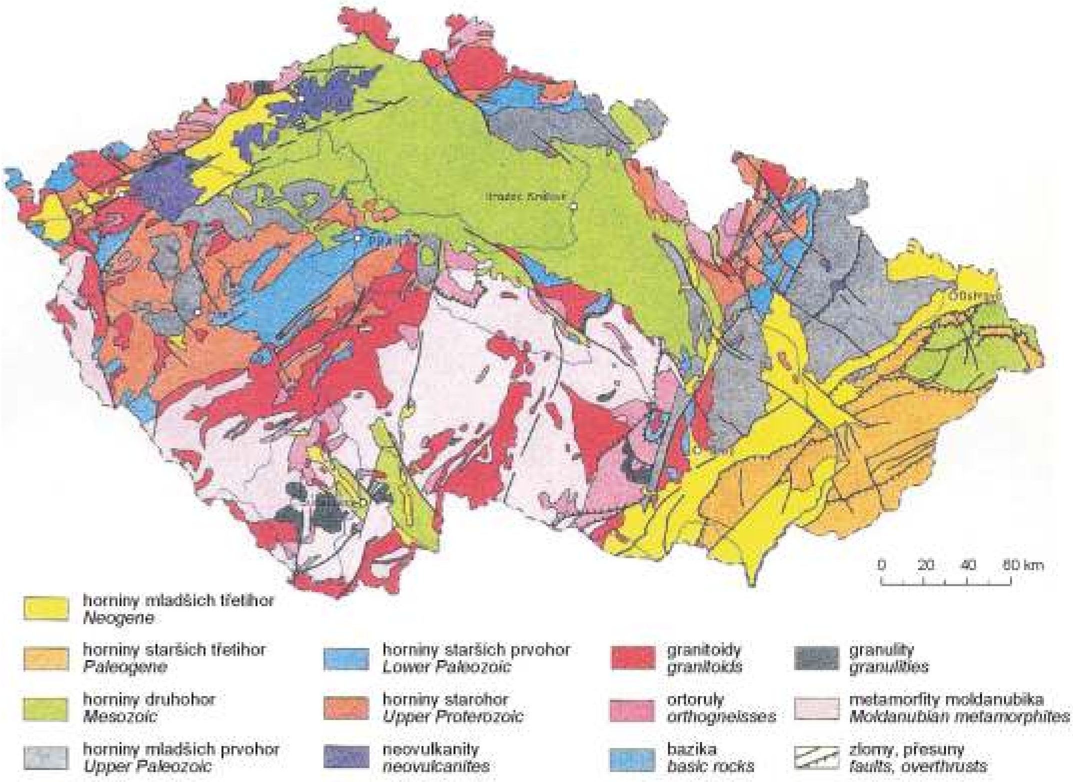


Figure 4.4. Geologic map of the Czech Republic [O]

As it can be appreciated in the figure, there is a big diversity of soil types along the whole national territory, existing three big differenced zones: the North Bohemian zone, with predominance of Mesozoic soil; the South Bohemian zone with predominance of Moldanubian metamorphites and the Moravian zone, with predominance of Granulity, Neogene and Paleogene soil.

According to soil genetic and agronomical classification, they can be divided into five groups. Cambisols represent the prevailing type (40% of total agricultural land), followed by stagno-gleyic luvisols and cambisols (20%), luvisols (19%), chernozems (11%) and fluvisols (10%). According to the soil maps of the Czech Republic, there are 60% of middle heavy soils, 20% light, 15% heavy and 5% of stony soils. The most fertile soils can be found in lowlands along the big rivers (the lower part of the Elbe River in Bohemia and the Morava River in Moravia). On the other hand, the worst (shallow and stony) soils are in higher elevations.

The climate of the Czech Republic is formed by mutual penetration and blending of oceanic and continental effects. The westerly flow is characteristic of the described region as well as intensive cyclonic activity, which causes frequent exchange of air masses with a great deal of precipitation. The maritime influence is more obvious in Bohemia, while in Moravia the continental climate is more marked. The climate is strongly affected by the altitude and by relief: the higher the altitude, the lowest temperatures and the higher precipitation rates. The average annual air temperature varies between 6 and 9°C, while the average annual precipitation of the Czech Republic is represented in the next figure:

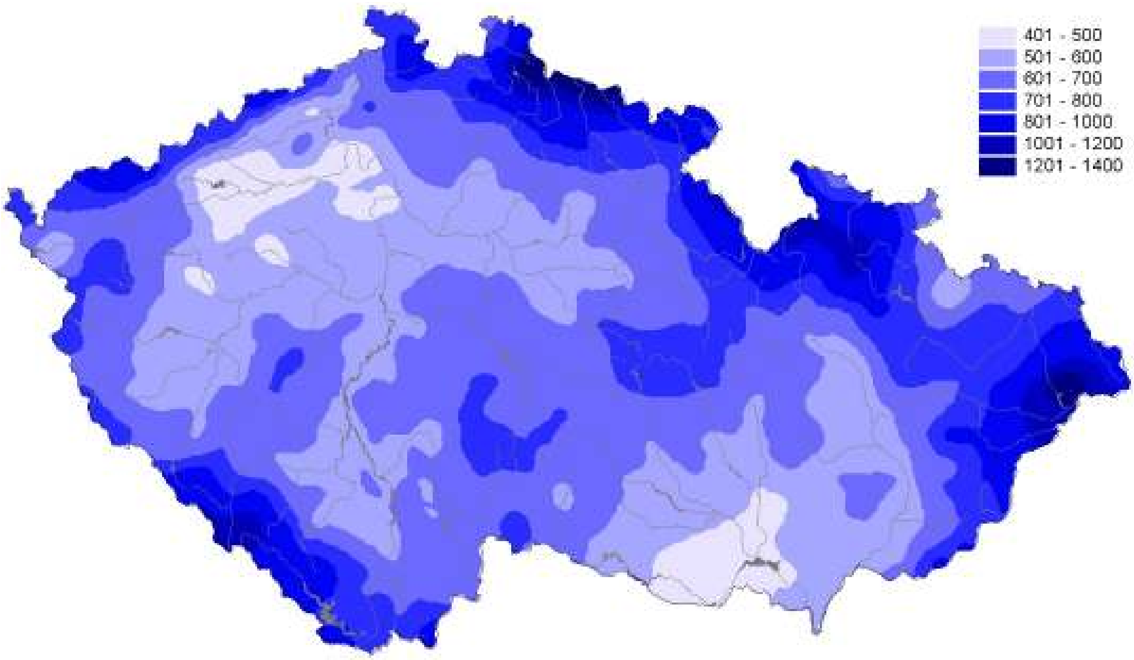


Figure 4.5. Annual precipitation rates of the Czech Republic in mm [Q]

One can clearly see that the precipitation rates are strongly related to the altitude, as it was said before, having the main part of the territory between 400 and 700 mm per year. However, the commented annual values of air temperature and precipitation have big fluctuations every year, making it very difficult to predict.

We are also going to talk about the land uses of the Czech Republic, especially about forests and agricultural lands, as they are the most important regarding a new infrastructure that will cross them through the whole national territory. Forests in the Czech Republic have undergone significant change over the past two centuries. The majority of natural forest ecosystems have been replaced by unstable spruce and pine monocultures, which do not fulfill the crucial environmental and social roles that natural or semi-natural forest ecosystems play within a healthy countryside and society. This change has been accompanied by a dramatic decline in biodiversity. According to scientists, the simplification of forest stands in the Czech Republic was also one of the reasons for the dramatic flood situations in 1999 and 2002. Forestry management in the majority of Czech forests remains poor and does not reflect the urgent need to move away from the focus on timber production and towards integrating environmental and social needs into forest management. [17]

The Ministry of Agriculture is the main authority for forest-management matters, with two exception forests within national parks that are managed by the Czech Ministry of the Environment and forests in military areas that are under control of the Ministry of Defense. State-level administration of forests is fully within the domain of the Ministry of Agriculture. The National State-Supervision and the

Czech Environmental Inspection Agency play only an inspection role. Both of these institutions are subordinate to the Czech Ministry of the Environment.

The Czech Forest Act distinguishes three categories of forests: [17]

- Commercial forests, occupying 76,7% of the overall forest territory.
- Protective forests, those maintained in areas with extremely harsh abiotic conditions and in areas bordering the timberline, in order to prevent erosion and landslides, occupying 3,5% of the overall forest territory.
- Special-purpose forests, occupying 19,8% of the overall forest territory, being those of National Parks or National Nature Reserves as well as where they are dedicated to preserving biodiversity.

The percentage of forests overall the national territory can be seen in the next picture:

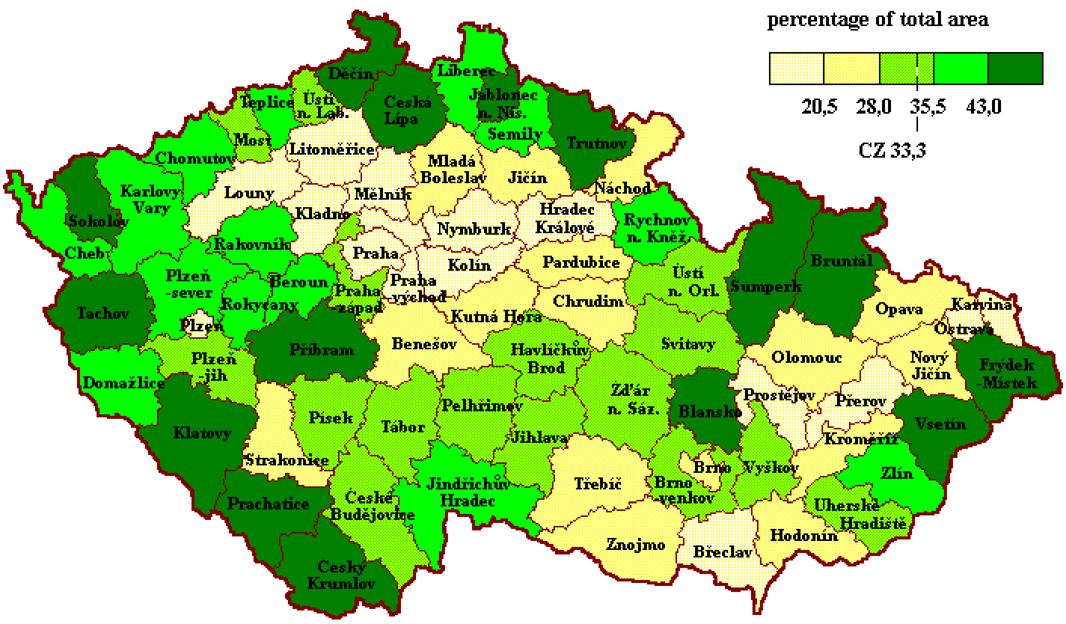


Figure 4.6. Forests in the Czech Republic [O]

As one can see, forests are fairly evenly distributed throughout the country, occupying a third part of the overall Czech territory. The areas with more forest percentage are those located on the borders of the Czech Republic, while the densest urban areas are, obviously, the ones with lowest percentage of forests.

At the end of 2000, 63,1% of forests were state-owned, 13,6% were municipality-owned, 0,9% were owned by forest co-operatives, 0,3% were owned by universities and 22,1% were in private hands. The ownership patterns have not yet stabilized since the overthrow of the Communist regime, and a slight drop in the share of state ownership can still be expected.

Regarding agricultural lands, it should be said that agricultural production and food production related to this is one of the traditional industries of the Czech economy. Czech agriculture has under its belt centuries of tradition that not only guaranteed the coveted self-sufficiency of the nation in basic foods, but also made this Central European corner of the world famous abroad. Commodities such as milk, livestock, grain, sugar and malt have long asserted themselves as agricultural exports.

While the area of arable land has continued to decline in recent decades, the area of permanent grass land has been rising. Half of the agricultural land fund is located in areas which are less favorable for farming and these are the areas which support the creation and maintenance of meadows and pastures.

Bohemian and Moravian agriculture can be characterized by the serious fragmentation of land ownership and the large percentage of leased land (90%). At the end of 2004, about 600 thousand hectares of land were owned by the State and rented out by the Land Fund of the Czech Republic. Most agricultural land is now owned by natural persons and legal entities. [18]

The percentage of agricultural land can be seen in the next picture:

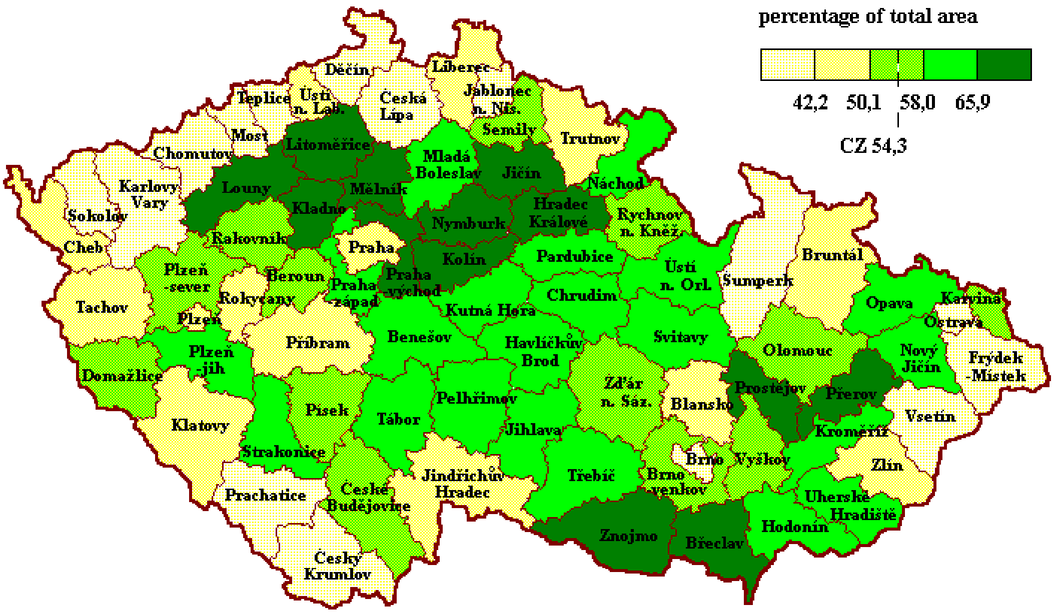


Figure 4.7. Agricultural land in the Czech Republic [O]

As it can be seen, more than a half of the national territory is agricultural land, corresponding to 4.264 thousand hectares. It means that there are 0,42 hectares of agricultural land per inhabitant, 0,30 hectares of them being arable land, roughly the European average. The forest proportion is only about 0,25 hectares per inhabitant. [18]

4.2.2. Designed national route

Once all the previous information has been analyzed, we are now ready to design a high speed railway route in the Czech Republic.

According to the passenger demand analysis, we have extracted a sub-matrix of the matrix shown in the fig. 3.37, where we have the trip distribution for high speed railway only among the Czech Republic zones:

	Praha	Pardubice	Ústí nad Labem	Plzeň	České Budejovice	Olomouc	Brno	Ostrava
Praha	0	1.811	2.046	1.256	423	362	141	191
Pardubice	1.811	0	177	117	55	36	135	128
Ústí nad Labem	2.046	177	0	135	64	71	28	45
Plzeň	1.256	117	135	0	183	48	2	31
České Budejovice	423	55	64	183	0	42	34	26
Olomouc	362	36	71	48	42	0	350	816
Brno	141	135	28	2	34	350	0	88
Ostrava	191	128	45	31	26	816	88	0

Table 4.8. High speed trip distribution in the Czech Republic in thousand trips. Own elaboration

As one can see, the most demanded connections are those joining Praha with Pardubice, Ústí nad Labem and Plzeň, followed by Olomouc – Ostrava, Praha – České Budejovice, Praha – Olomouc and Brno – Olomouc. This demand clearly reflects the need of a high speed railway corridor from West to East, connecting Plzeň – Praha – Pardubice – Olomouc – Ostrava, as well as the link Olomouc – Brno and a corridor from North to South connecting Ústí nad Labem – Praha – České Budejovice. This is consistent with the previous studies such as the first high speed study done in the Czechoslovak Republic in 1990 (see fig. 4.1) and later studies done by the SUDOP PRAHA A.S. enterprise in 1995.

As long as the main connections needed for the high speed railway in the Czech Republic are known, it should be now discussed the best solution for the emplacement of the high speed lines regarding the topography, geology, climatology, land uses, existing rail lines and other factors. If one considers the topography (see fig. 4.3), it can be noticed that the best would be to avoid the Moravian highlands and the bordering mountains, not only because it would be more expensive due to the need of tunnels, but also because of the climatology of mountainous zones (see fig. 4.5), where snow might be a problem in the winter season. This way, regarding the geology (see fig 4.4), granitoids and Moldanuvian metamorphites, which are hard to drill when constructing a tunnel, would be also avoided. So the main West-East line should be emplaced somewhere between the Moravian and Bohemian uplands and the North bordering mountains, following the valley of the Rivers Berounka, Elbe and Morava. The North-South corridor would be better emplaced in the valley of the Rivers Elbe, crossing Praha and going between the mountains of Šumava and the Bohemian uplands along the valley of the River Vltava. Regarding the land uses (see figures 4.6 and 4.7), it can be seen that this emplacement for the high speed railway would not affect much the forests, as it would mostly go through urban and rural areas. However, the affectation to the agricultural areas would be considerably higher and many expropriations should be carried out, reason why it is taking such a long time to start the high speed works in the Czech Republic.

Considering all the information explained above, the high speed railway lines for the Czech Republic should be the ones shown in the next figure:

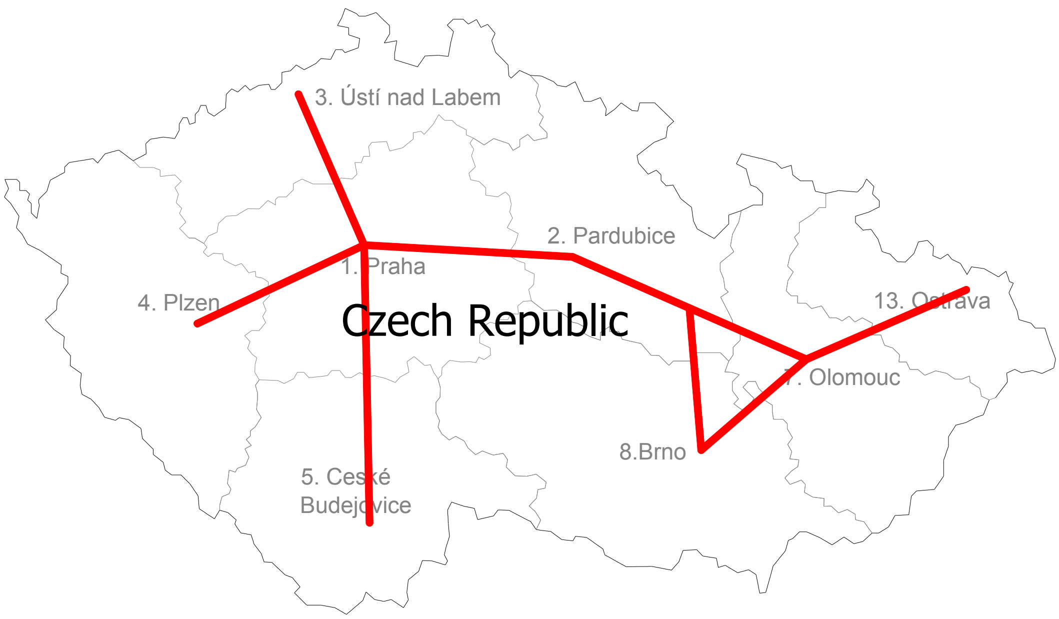


Figure 4.9. High speed railway proposal for the inner Czech Republic. Own elaboration

The proposed idea for the high speed railway emplacement highly reflects the current Czech rail map (see fig. 3.2), this means that one should consider the possibility of analyzing the existing railway corridors in order to upgrade some parts of them into high speed railway lines. Regarding the experience of Western Europe, it does not seem necessary to build only new segregated high speed lines, as part of the high speed network can work well with existing lines upgraded to the parameters for the speed of 200-230 Km/h. The result of this concept would be a high speed network made as a combination of new constructed lines with upgraded ones.

While the construction of new high speed lines requires a large investment in new materials, buying lands and demolition and constructive works, upgrading a railway line requires only changing the superstructure rail type, making it several times cheaper than a completely new construction. The size of the operating costs for the maintenance of the track is also based on the superstructure of the high speed railway. For classic high speed superstructures, costs are higher than for structure since high speed is subject to greater demands for tolerance. When driving the train is to be borne in mind that, although improving the aerodynamic shape of high-speed trains throughout the set, the air resistance is still growing with the second (at high speeds to the third) power of speed and thus increasing the traction power consumption at low time benefits. Besides, high speed modern trains need more frequent inspections and repair of vehicles, both in terms of electronic equipment, wheel-set, bogie and braking system.

All previous terms based on high speed railway new constructions are quite negative in comparison with the modernization of existing rail lines. The reason for the construction of high speed railways is, basically, the scope of much higher speeds as well as to travel with the near-absolute reliability of the latest security equipment.

Existing railways should be upgraded where possible, especially in the parts where the geometrical parameters and basic conditions are good enough for high speed. According to these conditions, the stretches Brno – Olomouc and Praha – České Budejovice could be totally upgraded to high speed tracks.

4.2.3. Frontier connections

The Czech Republic can not be designed without high speed network links to neighbor countries, since domestic demand will undoubtedly be limited. This concept is primarily necessary to properly understand the links to population and economic potential of Europe in a broader context and consider the "standard" system with regard to its major domestic use.

According to the demand analysis done in the previous chapter regarding the whole studied zone in Central Europe, if we take a look on the table 3.37, we can see that the most demanded connections between the Czech Republic and the neighboring countries are, sorted from most to least, Ústí nad Labem – Dresden, Plzeň – Nürnberg, České Budejovice – Linz, Brno – Bratislava / Wien and Ostrava – Katowice.

Moreover, as the “Union Internationale de Chemins de Fer” (UIC) studies proposed, high speed railway lines should be extended to all Europe by 2020 as shown in the next picture:

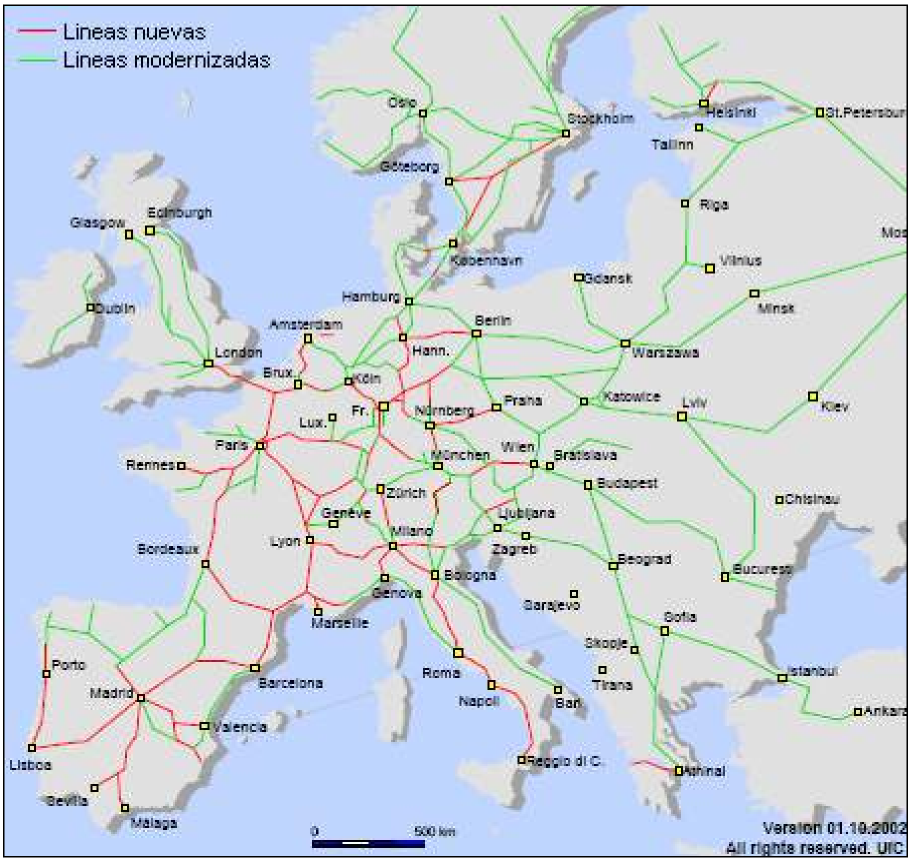


Figure 4.10. High speed proposal in 2020 [14]

As it can be seen, the main high speed lines concerning the Czech Republic are those connecting Praha – Berlin / Lepizig (via Dresden), Praha – Nürnberg / München (via Plzeň), Praha – Wien / Bratislava (via Brno) and Praha – Warszawa (via Katowice), as it was said in the Trans-European Transport Network (see fig. 4.2) and later by the SUDOP A.S. company. All these studies clearly reflect our demand analysis results of high speed railway in the Czech Republic and Central Europe. Other lines that should be taken into account are Praha – Linz (via České Budejovice) and Wien / Bratislava – Warszawa (via Brno and Katowice) which would satisfy the existing demand besides improving the connections between the Czech Republic, Austria and Poland.

Until 2007, the Czech and German governments planned to keep high speed lines intersecting in Rozvadov, in the line Praha – Nürnberg, and Petrovice in the line Praha – Berlin / Leipzig via Dresden. However, it has been recently agreed that the railway lines between Germany and the Czech Republic will be connected in the frontier town of Furth im Wald (Germany) and Domažlice (Czech Republic) in the line Praha – Nürnberg / München, keeping Petrovice as the connecting point of the line Praha – Berlin / Leipzig (via Dresden), being Rundteil the German side point.

The connection points of the other lines would be Český Heršlák (Czech Republic) and Deutsch-Hörschlag (Austria) for the line Praha – Linz (via České Budejovice), Břeclav (Czech Republic) and Kutý (Slovakia) for the line Praha –

Brno – Wien / Bratislava and Bohumín (Czech Republic) and Chalupki (Poland) for the line Praha – Katowice – Warszawa.

Taking a look again at the figure 4.10, one can see that, according to the UIC, most of the high speed lines should be from new construction in Western Europe and modernized railway lines in Eastern Europe. However, it will not be like this in the Czech Republic, where due to topographic, strategic and geometrical aspects, approximately half of the high speed lines will be from new construction. Regarding the frontier lines, only some of them could be upgraded from existing railways, such as the stretch Brno – Wien / Bratislava, Plzeň – Nürnberg / München and České Budejovice – Linz. These lines, together with the inner Czech Republic upgraded parts explained before and the new construction stretches, configure the next high speed rail map in the Czech Republic and the connections with the neighboring countries:

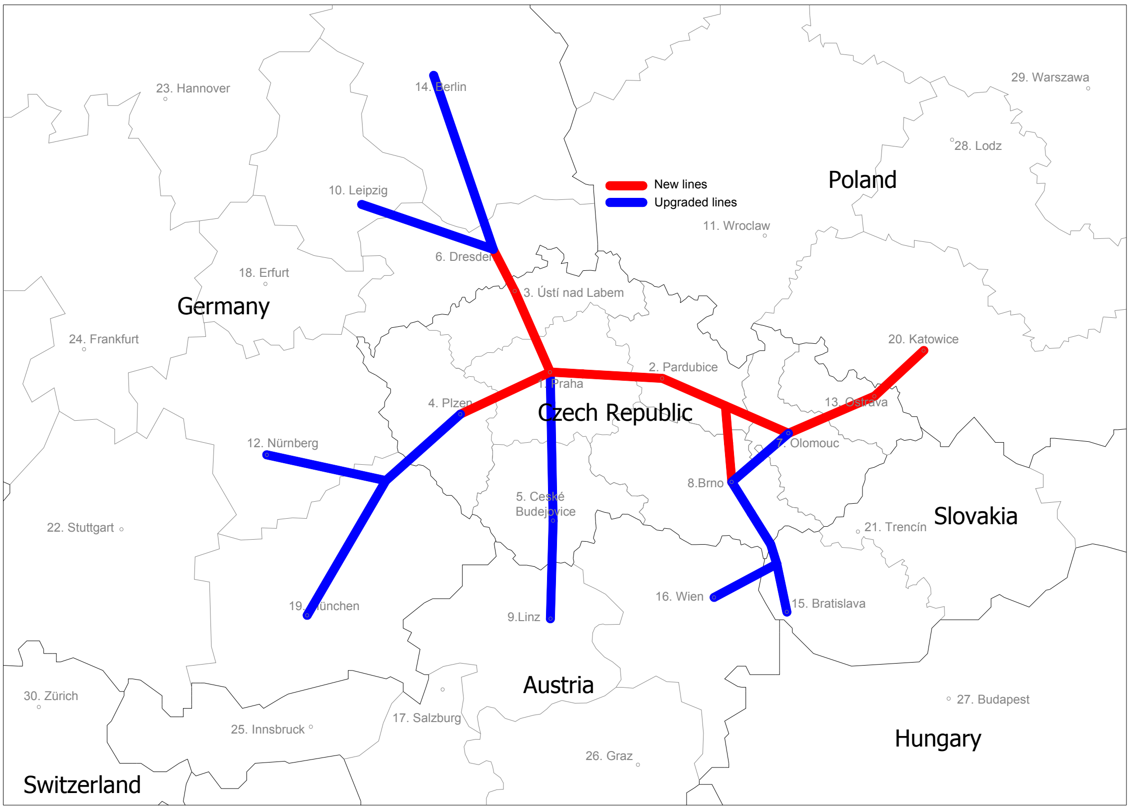


Figure 4.11. High speed railway proposal for the Czech Republic and its connections with the neighboring countries. Own elaboration

Note that approximately half of the high speed tracks will be upgraded, being the speed reached about 200 – 230 Km/h, while new constructed tracks should offer travel speeds about 300 – 350 Km/h.

4.2.4. Stations

Until the moment we have only talked about the emplacement of the high speed railway network and, although the tracks are going through specific cities, we

have not talked yet about which cities should have high speed rail stations and which may not.
Undisputed high speed railway stations are cities with more than 300.000 inhabitants. In general, the distance between high speed rail stations should be greater than 100 Km. Nevertheless, this criterion can be applied with certain exceptions, as big urban areas with populations over 500.000 inhabitants in close proximity induce substantial demand that need, in some cases, several stations. Stations are also needed in the major railway junctions, even those cities with less than 100.000 inhabitants.

In terms of size structure of city agglomerations, there are four basic categories of centers:

1. Centers over 1000 thousand population: compulsory station or several stations with compulsory stops. They usually are a junction of different lines.
2. Centers of 500 - 1000 thousand population: compulsory station with mostly compulsory stop. Sometimes they can be a junction of different lines.
3. Centers of 300 - 500 thousand population: compulsory station with optional stop.
4. Centers of 100 - 300 thousand population: optional stations, only needed if they are located in strategic places or in railway junctions.

For the election of high speed railway stations it will be considered not only the population of the main cities and its metropolitan areas but also the population of their regions and their situation. In the Czech Republic, as it had been analyzed in previous studies of the SUDOP A.S., the station emplacements are classified in three levels of importance:

- Praha: All passenger trains should stop there. It corresponds to the first category of the previous classification.
- Brno, Ostrava and Plzeň: all passenger trains should be led to their city center, with some trains only passing through the station without stopping. They correspond to the second category of the previous classification.
- Ústí nad Labem, Olomouc and Hradec Králové / Pardubice: these cities should have high speed railway station though some trains may not stop there. They correspond to the third category of the previous classification.

České Budejovice is not included on the list above due to the fact that its station is not compulsory because of its small dimension (agglomeration of 180.000 population), though its separation with Praha (169 Km) and its strategic location at half way between Praha and Linz makes it very interesting to have a high speed station. It would correspond to the fourth category of the previous classification and most of the trains would not stop there.

Other potential stops are centers of relevant importance such as:

- Major trade fair and congress centers
- Starting center of major tourist areas
- Extraordinary cultural attractiveness places (festivals, museums, monuments of European significance)
- The administrative center of large territorial units (federal states, provinces).
- Railway junctions, which will be considered next.

In the high speed proposal shown before, there are four main railway junctions in the Czech territory: Praha, Brno, Olomouc and Česká Třebová.

On the right hand, Praha is one most important transportation hubs in the Czech Republic. It is the crossroad of three conventional railway corridors and would be the junction of the two main high speed tracks in the future, the North - South line and the West – East line. This means that most of the high speed combinations should go to Praha, which would be the point with higher rail traffic regarding high speed transport in the Czech Republic.

On the other hand, Brno is currently one of the most important railway junctions of the conventional railway in the Czech Republic and would be another important junction regarding high speed railway. Located at the intersection of the line connecting Praha to Wien / Bratislava and the line connecting Wien / Bratislava to Ostrava and Katowice, Brno is a very important hub for the Eastern Czech part of the high speed railway.

Olomouc would be another high speed railway junction of the Czech Republic. Located in the Center of Moravia, it would be the intersection of the line going from Praha to Katowice and the line joining Wien / Bratislava to Katowice.

Finally, there would be the junction of Česká Třebová, configuring the triangle of the high speed railway communications in the Eastern Czech Republic, though there would not be any station due to its small dimensions.

Taking into account all the previous information, the high speed railway stations that will be considered in the Czech Republic are:

1. Praha
2. Brno
3. Ostrava
4. Plzeň
5. Ústí nad Labem
6. Pardubice
7. Olomouc
8. České Budejovice

Praha would be the main high speed station in the Czech Republic. The station should be located in the outskirts of the city, due to the difficulty to lead it to the city center, though it should be connected to the existing railway and other transports. All the passenger trains should stop in Praha.

Brno, Ostrava and Plzeň would be the next most important stations, which would better be located in their city centers, well connected to the other railways and means of transport. Most of the passenger trains should stop there, except some night trains.

Ústí nad Labem, Pardubice, Olomouc and České Budejovice would be the last high speed stations in the Czech Republic. Their stations should be located outside the city in order to not affect the commercial speed of the trains that would not stop there, which would be a considerable quantity. These stations should have transfers with classic rail network and other modes of transport.

Thus, the most intensive used corridors would ride as long-distance connections, with stops only in the main centers of metropolitan regions, as well as connections with more frequent stops or with stops in all the cited stations.

Regarding abroad, for later analysis we will consider high speed stations in all the centroides of our study zone (see figure 4.10), as all of them are cities with enough population to have a stop when high speed railway will go through them.

4.2.5. Construction stages

Once the high speed railway map of the Czech Republic and the stations have been defined, we should talk about the construction process of this infrastructure, as it needs to be built gradually for decades. We will talk about the stages of this network, explaining which should be the first stretches to be built and the main reasons.

It is clear that the first high speed track in the Czech Republic should connect to the existing high speed network in Western Europe. Therefore, the first lines to be built should be the connections Praha – Berlin / Leipzig via Dresden and Praha – Nürnberg / München via Plzeň.

Regarding the line Praha – Berlin / Leipzig, the first section of this line would be from new construction, joining Praha and Dresden. It is also being studied the possibility of a connection to the airport of Praha Ruzyně, where there could be a high speed station between Praha's center and Ústí nad Labem. The connection between Praha – Ústí nad Labem and Petrovice (German frontier) should be done in a first stage. The connection from Petrovice to Dresden and Berlin should be then upgraded, in a second stage, to a speed of 200 Km/h, as well as to Leipzig, though in this last case it is already upgraded in most of the route.

The line Praha – Nürnberg / München would go through Plzeň, Domažlice (Czech Republic), Cham (Germany) and Regensburg (Germany), where there should be a rail junction allowing trains to go either to Nürnberg or to München. The construction of this line is currently on project by SUDOP A.S., and it will begin with the stretch Praha – Beroun, on the left bank of the Vltava River, where there will be a tunnel of 24 Km allowing trains run up to 250 Km/h towards Plzeň. Compared to the original ideas, the section Praha – Beroun will not be a pure new high speed track, which runs around 300 Km/h, but it will have some modernized parts, which will go up to 200 Km/h. In the next picture it is shown a virtual reproduction of the tunnel, done by SUDOP A.S.:

Figure 4.12. Virtual reproduction of the high speed stretch Praha – Beroun [1]

There will be another tunnel that will connect Ejpovice and Plzeň at a design speed of 200 Km/h. Finally, in a first stage, the line should be upgraded from Plzeň to Domažlice (German frontier). The stretch connecting Domažlice, Cham, Regensburg and Nürnberg / München is not going to be built as a new construction, but it is planned to be upgraded in a second stage, after the stretch Praha – Plzeň – Domažlice is finished, in 2016.

New sections of high speed lines should be constructed in a first stage at the exit of the major hubs, like Praha and Brno, as they offer a greater capacity which would allow the much needed segregation of slow and fast trains. Moreover, building some urban sections in the most concurred cities should not be a question of the distant future, but the lack of capacity of existing lines is to warrant the construction of new lines in the present. In the case of Brno, as it will run through upgraded lines, it would be convenient to modernize the tracks linking it to Olomouc to the North-East and to the Slovakian frontier in Břeclav, to the South, from where it would connect to Bratislava and Wien.

Besides upgrading the railway lines of Germany in connection with the Czech high speed railway lines, the main focus on a second stage should be on constructing national sections, especially those linking zones with very high value of traffic load, in particular, the corridor Praha – Brno. The construction of these sections would improve the supply of railway transport expected to significantly contribute to the transfer of traffic flows, in particular from road transport. These new stretches of high speed lines would be in a transitional period, initially to work as part of the conventional railway network, running at about 200 Km/h. This would contribute to a significant reduction of journey times on conventional long distance trains transferred to these new sections. Only when the high speed service will be totally implemented, those sections would run over 300 Km/h, unlikely before 2020.

In addition, in this second stage the line Praha – České Budejovice - Linz should be also upgraded to high speed, about 200 – 230 Km/h, making it possible to travel from the Czech Republic to Austria by two different railway corridors before 2020.

The section linking Olomouc to Ostrava, however, would be constructed in a third stage, after 2020, when high speed railway should be operative in all the Western part of the Czech Republic. Although it would be built from new construction, it is being studied the possibility of upgrading the existing line in order to avoid a possible overcapacity that would take place in the presence of two parallel lines. Finally, the connection between Ostrava and Poland would be done in a third stage, with the cooperation of the Polish government.

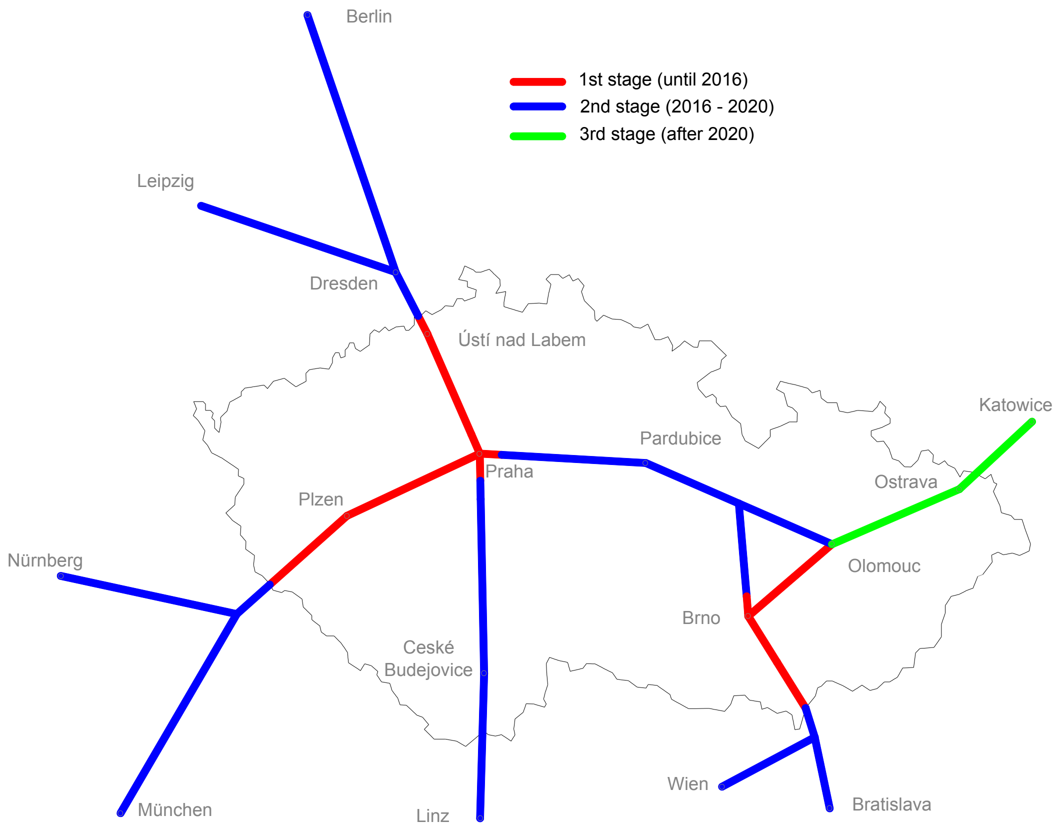


Figure 4.13. Construction stages of the high speed railway proposal for the Czech Republic and frontier connections. Own elaboration

It should be noticed that most part of the high speed railway construction in the Czech Republic will be done in the second stage, it is within 2016 and 2020. However, these dates may change as the real construction begins.

4.2.6. Consideration of freight transport

Until now we have regarded only the passenger high speed railway transport, with only a few comments about freight transport. However, as we have been saying since the very beginning of this minor thesis, high speed railway in the Czech Republic should consider both the passenger and the freight transport to be more competitive, and that is what concerns us now.

Since the first studies, SUDOP PRAHA A.S. considered that high speed railway in the Czech Republic would be designed for mixed traffic, despite the current global trend towards the exclusively passenger transport. The main reason was that freight traffic requires smaller investment costs, as there are less demanding conditions regarding the trace, besides the view that rail freight transport capacity in the existing rail network would be properly streamlined. [10]

As it has been analyzed in the previous chapter, taking a look at the Figure 3.24 one can see that national freight transport in the Czech Republic runs mainly from / to Ústí nad Labem region and from / to the Moravian / Silesian region (Ostrava in our study model), having also a big importance the regions of Pardubice and Praha. Regarding the international freight traffic shown in the figure 3.25, one can see that Austria is the country which most imports / exports to the Czech Republic, followed by Germany. This means that freight traffic actually affects the entire railway network of the Czech Republic, and it is necessary to design the tracks for this use.

It is true that freeing conventional railways from passenger traffic with the construction of new high speed tracks would allow more freight traffic in those conventional lines. Nevertheless, considering the expansion of national and especially international freight transport that the introduction to high speed railway in the Czech Republic would lead to, new lines should be prepared to receive freight transport in order to absorb the induced demand. Moreover, as approximately half of the tracks will be upgraded from existing ones, there will be no other choice but to lead both the passenger and freight traffic through the same tracks, forcing the upgraded high speed tracks to receive freight transport. Therefore, we will consider the whole high speed network as a mixed traffic network.

In the next picture it is shown the final proposal for the high speed railway network in the Czech Republic with its stations and its connections to the neighboring countries, distinguishing between the new constructed lines and the upgraded lines:

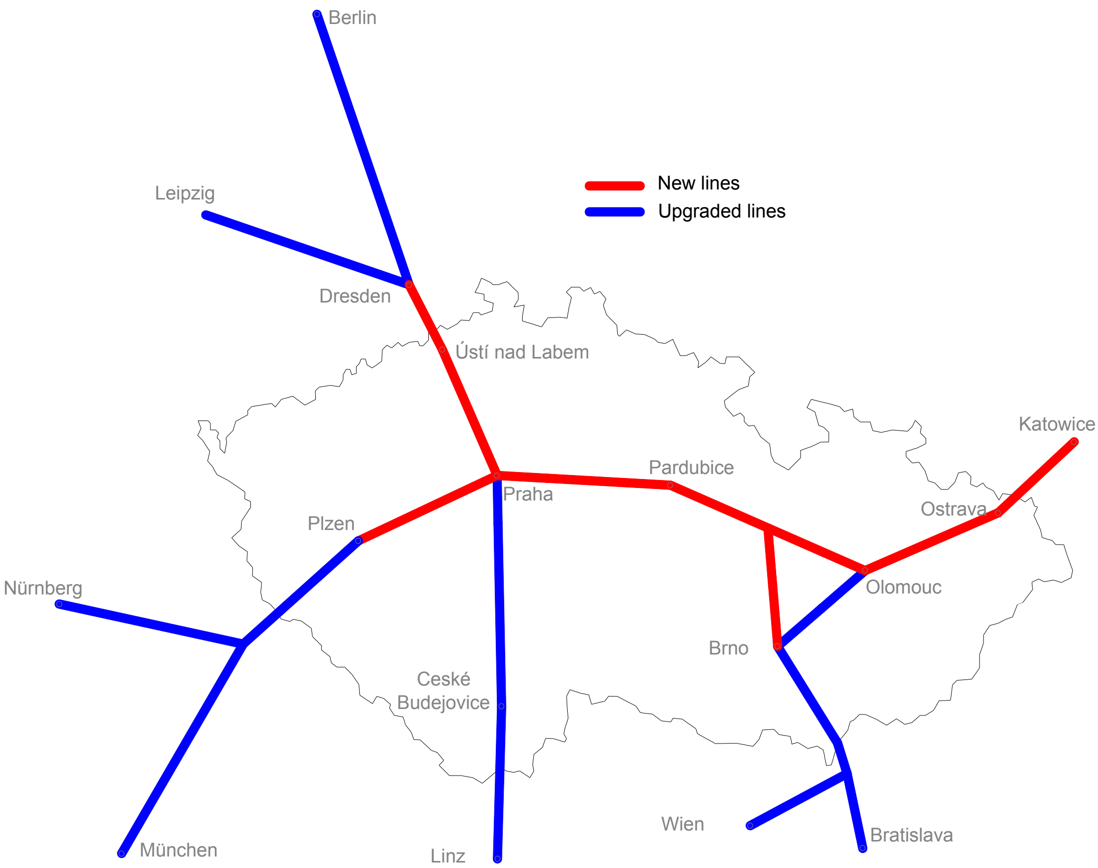


Figure 4.14. High speed railway network proposal for the Czech Republic with its stations. Own elaboration

As one can see, all the stations are well distributed in the whole national and international territory, existing more than 100 Km of separation between them (except between Ústí nad Labem and Dresden where there are 86 Km). It is important to mind which lines are from new construction and which ones are upgraded, as we will do some analysis of the network and their geometrical parameters and commercial speed is considerably different.

4.3. Construction and technology

In this chapter we will do a very brief description of the construction aspects of the high speed railway besides commenting the technology used for the railways and the high speed trains, as well as talk about the main adaptations needed for conventional trains to run through high speed tracks. We will distinguish between the new lines and the upgraded ones, as their big differences make it better to study them separately.

4.3.1. New constructed lines

For the construction of new high speed rail lines, there are some technical parameters which must be considered: [12]

- The design speed of the line must be at least of 250 Km/h, though freight trains can only travel at 160 Km/h.
- The minimal radius for the track curves must be of 7000 m and, exceptionally of 5100 m. The maximum cant cannot be higher than 150 mm.
- High speed lines must be at least double track lines, for basic reasons of interoperability.
- For high speed lines intended for mixed traffic, there should be an extra stretch of line every fixed distance, which will be used to overtaking slower passenger trains, freight trains, thereby increasing the capacity of lines.
- The maximum longitudinal slope of high speed lines depends on the performance of all the traction motors located in the trains and their highest weight. For only passenger traffic, longitudinal slopes can reach 40 ‰ as it has been proved to work. In contrast, it is assumed that for mixed traffic the maximum longitudinal slope should be only of 12,5‰ and exceptionally of 18,5 ‰.
- In rail links, the longitudinal slope should not be higher than 2.5 ‰. In tunnels up to 1000 m long, longitudinal slope should be at least of 2 ‰ while in tunnels over 1000 m long it should be at least of 4 ‰ in order to drain and evacuate possible smoke properly.
- High speed lines must not have any level crossings along the routes and, therefore, necessary device must be used to prevent the entry of persons and animals on the track, such as fences, etc.
- High speed traction is designed with an electric overhead contact line on one of the three units of the train, emplaced in a height of 7,0 m over the track, trying to maximize the uniformity in all Europe.
- High speed railway may have some areas managed centrally from the headquarters of the European Train Control System (ETCS) with the European railway interlocking with signal transmission applications GSM-R. As the existing railway lines, they must be subjected to the international agreements and regulations AGC, AGTC, UIC and EU.

The railway superstructure consists in the rails, fasteners, base plates and a flexible anchorage of pre-stressed concrete sleepers. Regarding its spatial layout, there are not any strict fixed rules though there are some thresholds that should not be achieved. We are going to consider a separation between the track axes of 4,7 m, with a total width of the bottom rail plains of 13,7 m. Therefore, distance between the rail axes and the edge of the embankment will be of 3,9 m. Railway grid will be lying on a 550 mm thick grave bed. Its slope will be designed according to applicable standards, normally 50%.

In the next picture the spatial layout of the high railway superstructure is shown:

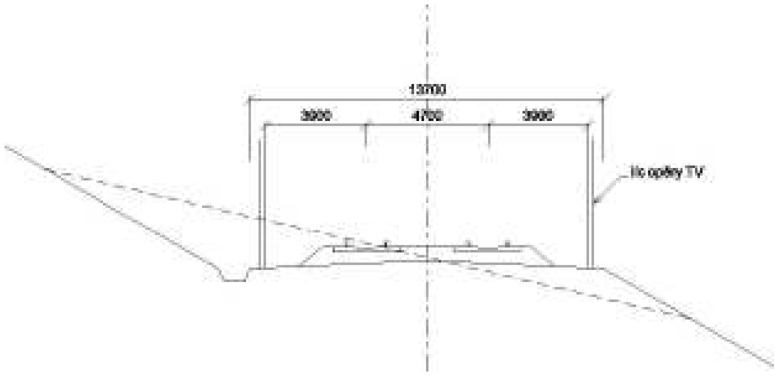


Figure 4.15. Spatial layout of the high speed railway superstructure [1]

The track connections shall be done using switches 1:26,5 (maximum speed of 130 Km/h and outstanding lateral acceleration of 0,52 m^2/s), with a maximum slope of 6 ‰. If they are placed in a curve, the radius must be at least 1,5 times the minimal radius in order to avoid interferences. These switches should be used for changing high speed lines and in the connections between high speed lines and conventional railway ones at railway stations. In the next figure an example of the disposition of the switches next to a high speed railway station is shown:

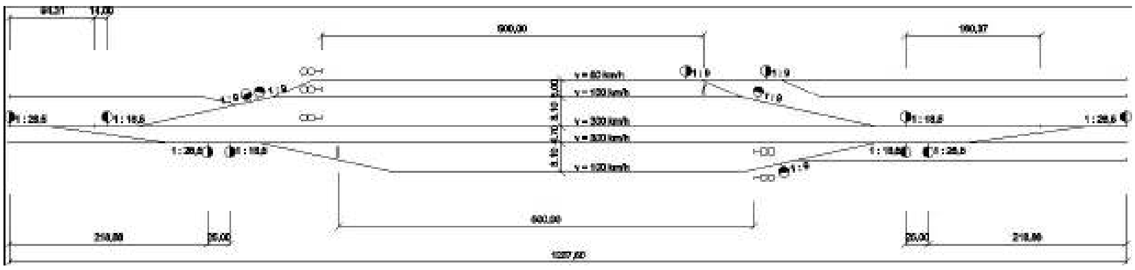


Figure 4.16. Disposition of the switches next to a high speed railway station [1]

Because of the generous design of the high speed lines to offer commercial speeds over 250 Km/h, there will be the need to construct curves with big radius, terrain cuts, embankments and, very probably, tunnels and bridges.

There are several structural types of bridges for high speed railway, all of them equipped with dilatation facilities in the rail bed:

- Concrete bridges: they are one of the most common types. Their main advantages are low maintenance costs, high rigidity of the structure to ensure a high driving comfort and very little thermal deformation due to thermal inertia of the massive structure.
- Chamber structure: they are also very common in the construction of high speed railway. Their application is primarily for long valley viaducts. For the implementation of technology it can be used telescopic curb and flying concrete. The maximum range for simple beams is 55 m and for continuous beams 65 m, while arc beams are used for the ranges greater than 60 m. Their bases consist in chamber construction combined with a diagonal brace frame or arch.

- Floor bridges: used for small and medium-range structures, they are cheaper than the concrete bridges and facilitate the adaptability of solutions to unusual conditions, offering a rapid and easy assembly without using space under the bridge. The upper bridge deck is made with beams spreading 60 m or with chamber design with two lattice beams.
- Steel bridges: it is assumed that steel bridges will not be used, mainly due to its price and lower stiffness compared to concrete bridges.

The basic layout of a high speed bridge is shown in the next figure:

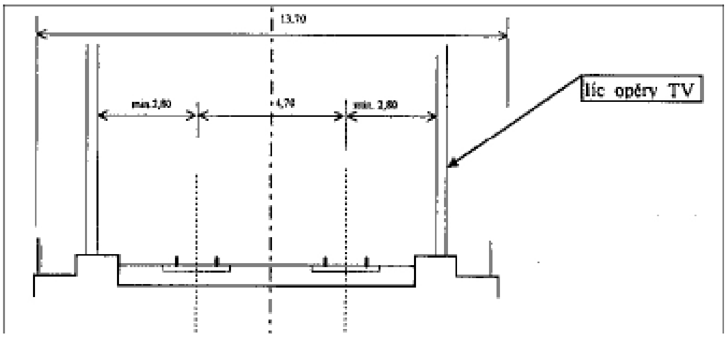


Figure 4.17. Layout of a high speed bridge [1]

Regarding the tunnels, it should be said that they are technically and economically the most difficult constructions. However, in the case of high speed railway it is necessary to build them in order to reduce distances when crossing mountainous terrains. Tunnels must be built with a design speed higher than 160 Km/h. The volume of work associated with embossing or dredging a tunnel significantly affects the level of investment costs. Because of this, there is a big effort to minimize the cross-cutting area of the tunnel. Double track tunnels are designed with a cross-section area of 82 to 95 m^2, while for simple track tunnels the area must be at least of 50 m^2. They are considered to use embedded grave bed or slab tracks. [1]

In the next picture it is shown the cross section of the Belgian high speed railway tunnel in the municipality of Soumagne, as an example of a double track high speed tunnel, in which one can see the dimensions of each of its parts:

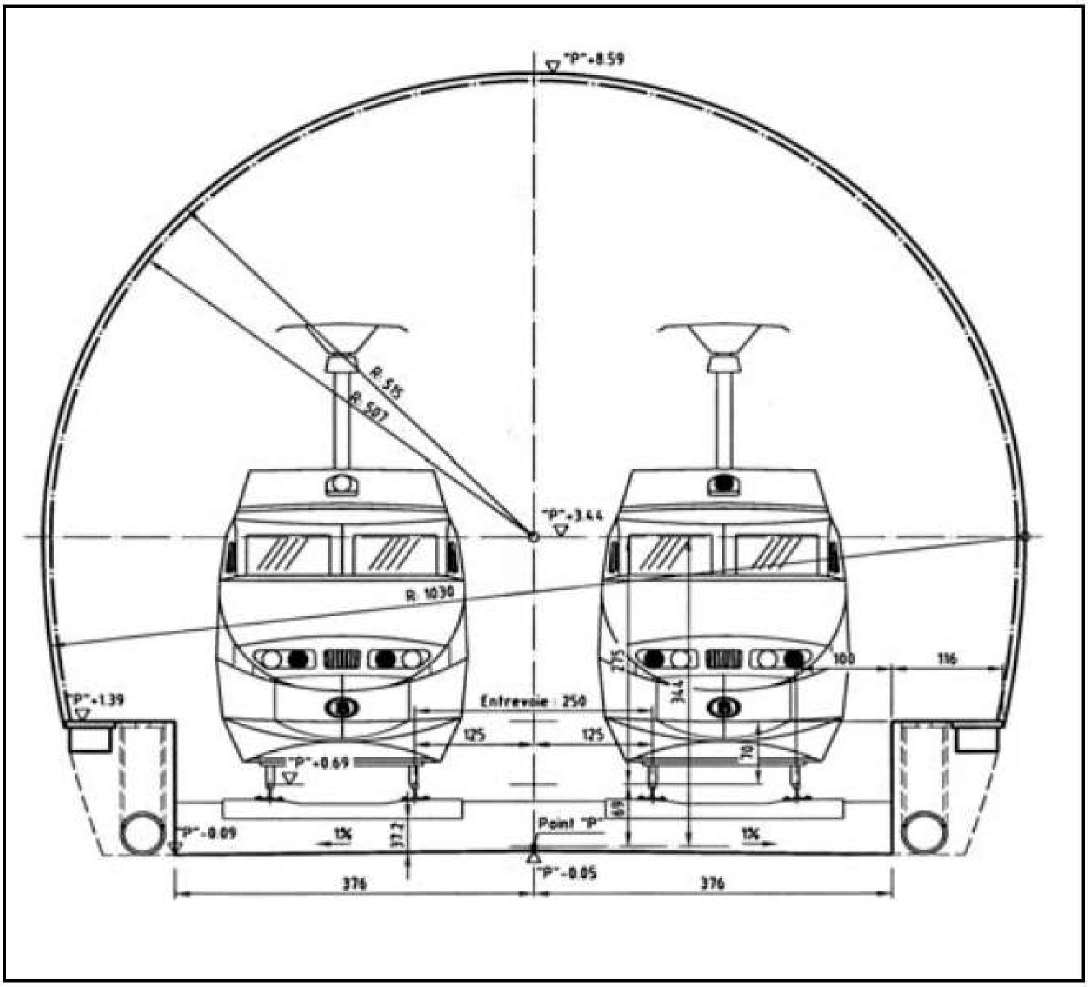


Figure 4.18. Cross section of the Soumagne high speed railway tunnel [19]

The tunnels can be constructed by dredging, stamping or as a combination of both methods. The most important criterion is usually the power and stability of the rock massif the tunnel is going through. As there is a big reduction of aerodynamic phenomena when train sets enter the tunnel, especially trains running speeds up to 300 Km/h, it is required to construct tunnel portals in order to avoid an instant pressure variation which is very uncomfortable for passengers. Construction site satisfying these requirements is to extract the tunnel tube lining in the field with a bevel angle of 30°, adjusting the funnel tube tunnel in the portal. This way, the entrance to an enclosure extending tunnel creates the conditions for a better dispersion of pressure effects.

Regarding the vehicles, there have been a big number of changes and a gradual development in order to reach an optimization of technical solutions for high speed. In basic terms, the existing types of train units are as follows: [14]

- High speed unit traction vehicles, both electrical and Diesel. Electric traction power system is dominated by 25 kV, 50 Hz. Their advantage is their easy maintenance because traction is concentrated only on the first vehicle. The problem is to achieve an axle low pressure and high performance with good adhesion properties.

- High speed units with traction equipment located along the entire length of the train. Their advantage is a low axle pressure and high performance with good adhesion. The problem is the hard maintenance, as the electrical equipment is located throughout the train, mostly under the car floor, partly on the roof and sometimes even inside cars.
- High speed units with tilting boxes and traction equipment throughout the length of the train. These units are used to increase speed on conventional upgraded or modified routes with frequent small radii, as we will explain in the next section.
- High speed trains with a main traction vehicle and connected cars working as tilting wagon boxes and a control car at the other end of the unit.

Modern vehicle designs are dealt with boxes of aluminum profiles which brings a great advantage in low weight. There are special materials used for heat and noise isolation and special materials for interior approaching air implementation, including air conditioning, lighting, etc. In electric traction equipment three-phase traction motors are used for auxiliary drives, as well as microprocessor control systems including automatic systems and diagnostics for electrodynamic brake resistance and recuperation. The electrical equipment requires a minimum maintenance besides special measuring devices, PC's and especially educated and well-trained staff, which is a huge difference with the earlier technologies.

Along the entire high speed railway it is proposed to place a cable with optical fiber in order to allow remote communication, enabling transmission at a wavelength of 1300 nm. In addition to that, to increase the operational management of train services it is proposed the construction of radio communication of GSM-R along the high speed railway. To ensure a good level of high signal in the vehicles, there will be placed radio fixed objects along the whole line. For tunnels up to 300 m long there will not be special measures though, for tunnels between 300 and 1000 m long, radio repeaters will be located near the portals while for larger tunnels cables will be placed directly over the whole length of the tunnel.

4.3.2. Upgraded lines

As we have said, approximately half of the proposed high speed network in the Czech Republic would be from upgraded lines. Upgrading lines means changing several factors of the existing conventional railway which we will regard in this section such as the geometry and the trace of the lines, the platform and the infrastructure, the electrical, telecommunication and signaling installations, the stations and the vehicles. Moreover, there are several difficulties in the upgrading process that should be considered such as the changes suffered in the conventional railway platform due to the traffic load and the need to keep the line operative during the upgrading works.

Improving the trace and the infrastructure and superstructure components of conventional lines it is possible to obtain a better quality track allowing higher running speeds of 200 – 230 Km/h and a reduction of the maintenance costs. However, it is clear that conventional railway cannot be totally transformed into high speed railway, as there requirements are substantially different, though it is possible to obtain a big improvement in the line trace and its security.

Regarding the geometry and the trace of lines it should be said that the first thing to do is to check whether the existing line is valid for running at 200 – 230 Km/h. Otherwise, the trace should be modified, being the main actuations the ones shown next:

- Increase of the horizontal curve radius
- Construction of local variants
- Duplication of the track
- Increase of the width between tracks
- Selective lateral displacements of the tracks
- More stringent criteria in gauges
- Construction of new upper and lower passes
- Extension of walkways and bridges
- Removal of level crossings
- Total enclosure

In the next table some of the geometric parameters to be taken into account for upgrading a railway are shown:

Width between tracks	4.000 mm
Gauge of the overpasses	7,00 m
Maximal cant	160 mm
Maximal uncompensated acceleration	0,65 m/s^2
Minimal horizontal curve radius	4.000 m
Maximal cant diagram slope	0,5 mm/m
Transition curve length	Increase length and radius
Minimal vertical radius	25.000 m
Maximal slope	Current ground level

Table 4.19. Geometric parameters for upgraded lines. Own elaboration from data of [13]

It is important to emphasize that in the upgrading process it is important to keep as long as it is possible the current ground level. Thus, the circulation of freight trains will not be complicated and the adaptation works in the existing overpasses will be minimized.

Regarding the platform and the infrastructure, it should be checked whether they will be able to support new loads derived from the increase in speed and traffic. A complete geotechnical study should be carried out, considering survey works to know the soil conditions below the platform and its surroundings, in order to determine the thickness and status of the different materials. With this, the horizontal alignment of every line should be done considering all the different cross sections, trying them to be as few as possible, and recalculating the new dimensions with the new expected loads.

There are some regulations such as UIC-722 that can be used as a reference for the upgrade of lines to high speed. The main actuations for conditioning the platform to high speed are:

- Cleaning previous field
- Extension of the soil layer with enough thickness
- Increase thickness of the sub-ballast and ballast layers
- Careful selection of the material
- Introduction of a geotextile layer or build the new platform phased respect the old one in case of not removing it.

The treatment of the platform supposes one of the biggest conditions at the moment of executing the upgrading works, not only for its difficulty, but due to the need of keeping operative the line during the work and not affecting the ground level.

Concerning the superstructure, there are also some changes that must be applied, such as:

- Substitution of the sleepers for polyvalent mono-block sleepers (usually PR-90, PR-01 or similar)
- Substitution of the rails for UIC-60 in bars of 288 m welded in a workshop
- Substitution of the track apparatus for polyvalent ones. The track connections shall be taken using switches 1:32,5 (maximum speed of 160 Km/h).

In the next picture it is shown an upgrading a railway line work:

Figure 4.20. Upgrading works of a railway line [R]

As it can be seen, the works are done by night in order to interfere as few as possible in the rail traffic.

Regarding the electrical, telecommunication and signaling installations, the main actuations to be done are:

- Adaptation of the electrification system, changing the catenaries either into AC 25.000 V or into CR-220 model working at DC 3000 V
- Increase the gauge (distances to the electrification poles)
- Increase the height of the aerial contact line
- Modernization of the telecommunications and the signaling systems
- Modification of the electronic latch
- Installation of the ERTMS system

The stations should be also adapted to high speed railway. The works that should be done in conventional stations so that they could work as high speed stations are the following:

- Build-up of platforms
- Modification of the lines situation
- Relocation of stations
- Adapt access of passengers to the trains

Finally, trains running through high speed upgraded railways should have the following:

- Velocity over 200 Km/h
- Suspension systems similar to the high speed trains
- Braking systems similar to the high speed trains
- A new image that attracts passengers relating these trains with high speed

It could be advantageous to have tilting trains in the upgraded lines in order to optimize the exploitation of them, as we mentioned before. A tilting train has a mechanism that enables increased speed on regular railway tracks. As a train (or other vehicle) rounds a curve at speed, objects inside the train experience centrifugal force. This can cause packages to slide about or seated passengers to feel squashed by the outboard armrest due to its centripetal force, and standing passengers to lose their balance. Tilting trains are designed to counteract this discomfort.

The train may be constructed such that inertial forces cause the tilting (passive tilt), or it may have a computer-controlled power mechanism (active tilt). In a curve to the left the train tilts to the left to compensate for the g-force push to the right, and vice versa. These systems work with hydraulic, electromechanical or mechanical systems, allowing a 30% better performance while passing through curves.

In the next picture, a tilting train is shown:

Figure 4.21. Tilting train near Hokuto (Japan) [E]

As one can see, as the curve is to the left, the train tilts also to the left to compensate the centripetal force to the right.

4.4. General features of the service

In this section we will talk about the proposed high speed service offer, explaining its main features such as the commercial speed, the operating lines, their frequency and fares. These features will be considered in the next chapter when analyzing the affectation of the high speed railway to the territory and the current network, comparing new travel times and costs.

4.4.1. Commercial speed

The commercial speed is probably the most important factor of the high speed railway service, as its name indicates, being the feature that provides most of its competitiveness and benefits.

Nevertheless, since we are considering high speed railway with mix traffic (passenger and freight) in the whole proposed network for the Czech Republic, we have to take into account the substantial differences in their commercial speed. Moreover, as there would be new constructed lines and upgraded ones, their commercial speed will be also different, making it necessary to define the design speed for every line for every type of vehicle.

As we have been saying, upgraded lines are modified in order to reach speeds of 200 – 230 Km/h. For passenger vehicles we will consider an average speed for all the upgraded lines of 200 Km/h, as we have to take into account the time when the trains are stopped in the stations, as well as the time needed to accelerate and brake.

In the same way, although new constructed high speed lines are designed for running speeds over 300 Km/h, we will consider the average commercial speed of passenger trains running through them of 250 Km/h.

Freight vehicles maximum speed is 160 Km/h, either running through upgraded tracks or new constructed ones. This means that there will be a big difference between passenger and freight trains velocity, especially in new constructed lines. In any case where freight trains interfere with passenger trains, the priority will be given to passenger trains, so that the commercial speed of them is affected as few as possible. Therefore, the average speed of freight trains may be reduced in order to consider the time necessary to allow the overtaking. With this purpose, we are going to consider the commercial speed of freight trains of 140 Km/h.

Commercial speed (Km/h)		Type of track	
		New	Upgraded
Type of vehicle	Passenger trains	250	200
	Freight trains	140	140

Table 4.22. Considered commercial speeds for the high speed network. Own elaboration

4.4.2. Operating high speed lines and their frequency

Another very important feature of the high speed railway offer is to know which are the operating high speed lines and their frequency, as travelers not only need a high commercial speed offer but also a high availability of the service according to their needs.

The operating lines that we will consider for the proposed network of high speed railway are:

1. Leipzig / Berlin – Dresden – Ústí nad Labem – Praha – Pardubice – Brno – Wien / Bratislava.
2. Leipzig / Berlin – Dresden – Ústí nad Labem – Praha – České Budejovice – Linz.
3. München / Nürnberg – Plzeň – Praha – Pardubice – Olomouc – Ostrava – Katowice.
4. Wien / Bratislava – Brno – Olomouc – Ostrava – Katowice.

These operating lines are thought to satisfy the demand of the travelers both in national and international trips. As one can see, all the lines begin abroad and go through the Czech Republic for ending also abroad. Two of them go mainly from North to South while the other two go from West to East. All them are according to the railway corridors in the Czech Republic (see figure 2.6) and the Trans-European Transport Network (see figure 4.2).

In the next picture it is shown the high speed railway network with its four operating lines:

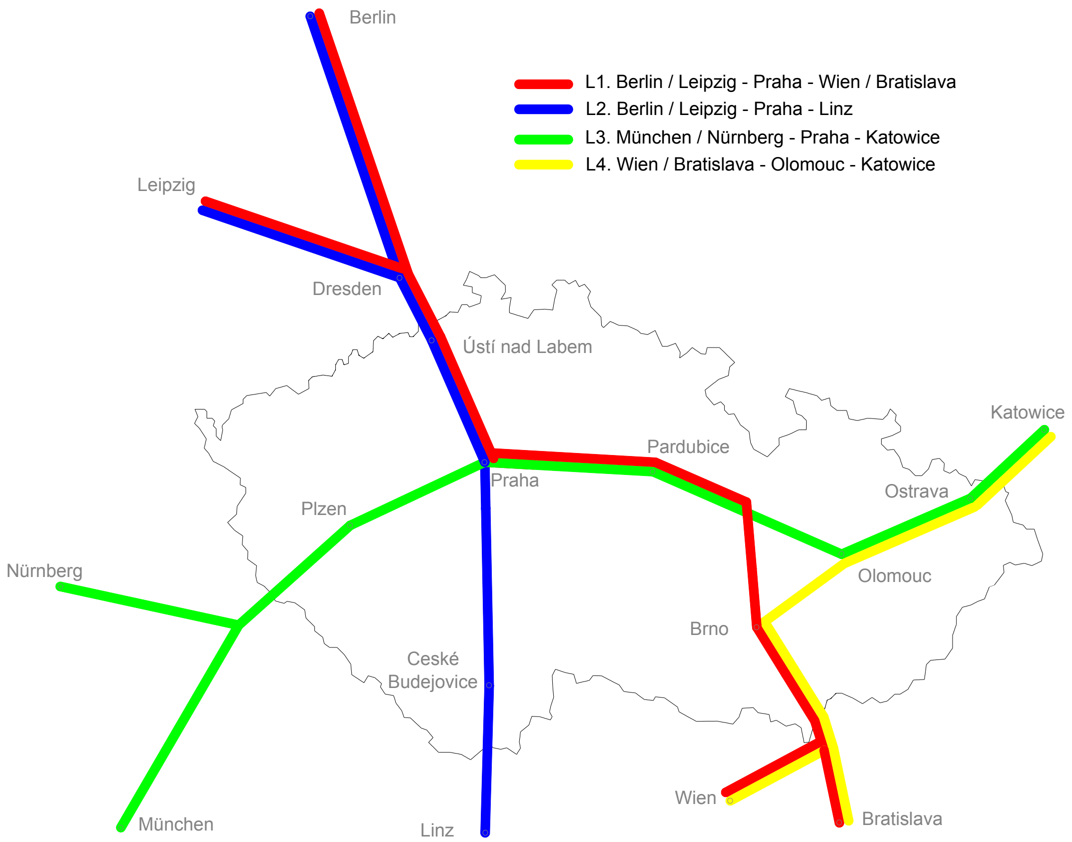


Figure 4.23. Proposed high speed operating lines. Own elaboration

As there may be some stretches busier than others, these lines may have trains running through the whole line and others running only through the busiest parts. To know this and the needed frequency of the service, we have to consider the demand analysis.

Taking a look at the table 3.37, one can see that most demanded connections regarding the proposed network are, sorted by number: Dresden – Berlin (6,6 million trips per year), Dresden – Leipzig (5,6 million trips), Ústí nad Labem – Dresden (4,78 million trips), Praha – Dresden (2,44 million trips), Praha – Ústí nad Labem (2,05 million trips), Praha – Pardubice (1,81 million trips), Praha – Nürnberg (1,07 million trips), Praha – Plzeň (1,96 million trips) and Praha – Berlin (1 million trips), all of them corresponding to the operating lines connecting with Germany. Other connections such as those going to Wien, Bratislava and Katowice are substantially less demanded, especially the connections among the Czech territory.

According to all the previous data and taking into account that these lines will be used also for passengers going to other further destinations not mentioned here, we have considered the following:

- Stretch Praha – Berlin / Leipzig: aggregated demand of 10 million trips per year
- Stretch Praha – Nürnberg / München: aggregated demand of 5 million trips per year
- Stretch Brno – Bratislava / Wien: 4 million trips per year
- Stretch Praha – Česká Třebová (railway junction between Pardubice and Brno): aggregated demand of 3 million trips per year
- Stretch Olomouc – Katowice: 2,5 million trips per year
- Stretch Praha – Linz: aggregated demand of 1 million trips per year
- Triangle of the railway junctions: aggregated demand in each side of 2 million trips per year

Considering a capacity of 400 passengers per high speed train and, converting the trips per year in daily trips, we have elaborated the next table of frequencies for each operating line:

Operating line	Frequency
1	Every 30 min between Berlin / Leipzig and Praha Every hour between Praha and Wien / Bratislava
2	Every 30 min between Berlin / Leipzig and Praha, 15 minutes behind Line 1 Every two hours between Praha and Linz
3	Every 30 minutes between München / Nürnberg and Praha Every hour between Praha and Katowice, 30 minutes behind Line 1
4	Every hour for the whole line, 30 minutes behind Line 3

Table 4.24. Proposed frequencies for every high speed operating line. Own elaboration

These frequencies are valid for weekdays except holidays. Timetable of trains must be fixed considering the frequencies of each operating line and having a maximal interval of two hours in daytime hours (from 05:00h to 22:00h) even in weekends and holidays. Between 22:00h and 05:00h there will not be any departure from any line origin regarding passenger trains.

At this point, it ought to be said that we have not considered the tourism as a vital factor to choose the high speed routes due to its small dimensions in comparison with daily passenger transport and freight traffic. However, we should take it into account when configuring the schedules of the touristic destination lines. Thus, from the table 3.26 we can see that the Czech Republic is a touristic attraction country, being Germany the country from where the Czech Republic receives most tourists. The number of tourists coming from Austria, Poland and Slovakia are quite similar and much less than the ones coming from Germany.

We can assume that the most touristic places of the Czech Republic are Praha, Karlovy Vary (near Plzeň) and Český Krumlov (near České Budejovice) [20]. Therefore the lines going to these destinations should be enhanced in weekends and holidays, especially those connected to Germany.

The frequency of freight transport has not been considered due to its difficulty to be estimated. However, their frequency should be such to avoid its interference with passenger traffic as much as possible. In any case, freight transport could be carried out mostly during the night, as far as the maintenance works and noise levels make it viable, what we will consider when studying the environmental impact of the high speed railway infrastructure.

4.4.3. Fares

Finally, we will refer to the fares of the proposed high speed railway service. As we said in the modal split section of the demand analysis, the average fare can be approximated by 10€ per 100 Km. These fares are according to the average of the high speed services of the West European countries such as TGV in France, AVE in Spain, TAV in Italy and ICE in Germany. According to these fares and, approximating the high speed travel distances to the existing distances of the conventional network, we have the next table of prices for each connection in our proposed high speed network:

Prices in €		1	2	3	4	5	6	7	8	9	10	12	13	14	15	16	19	20
Praha	1	0	10,4	10,6	11,4	16,9	19,2	25	25,5	29,4	30,9	35,5	35,6	36,6	39,6	40,4	44	45,8
Pardubice	2	10,4	0	21	21,8	27,3	29,6	14,6	15,1	39,8	41,3	45,9	25,2	47	29,2	30	54,4	35,4
Ústí nad Labem	3	10,6	21	0	22	27,5	8,6	35,6	36,1	40	20,3	46,1	46,2	26	50,2	51	54,6	54,7
Plzeň	4	11,4	21,8	22	0	13,6	30,6	36,4	36,9	26,1	42,3	24,1	47	48	51	45,1	32,6	57,2
České Budejovice	5	16,9	27,3	27,5	13,6	0	36,1	33,6	23,6	12,5	47,8	37,7	44,2	53,5	37,7	31,5	40,5	54,4
Dresden	6	19,2	29,6	8,6	30,6	36,1	0	44,2	44,7	48,6	11,7	38,1	54,8	17,4	58,8	59,6	57,3	46,1
Olomouc	7	25	14,6	35,6	36,4	33,6	44,2	0	10	43,9	55,9	60,5	10,6	61,6	24,1	24,9	69	20,8
Brno	8	25,5	15,1	36,1	36,9	23,6	44,7	10	0	33,9	56,4	61	20,6	62,1	14,1	14,9	61,9	30,8
Linz	9	29,4	39,8	40	26,1	12,5	48,6	43,9	33,9	0	60,3	32,5	54,5	66	26,8	19	28	64,7
Leipzig	10	30,9	41,3	20,3	42,3	47,8	11,7	55,9	56,4	60,3	0	36,7	66,5	16,5	70,5	71,3	55,9	57,8
Nürnberg	12	35,5	45,9	46,1	24,1	37,7	38,1	60,5	61	32,5	36,7	0	71,1	53,2	59,3	51,5	19,2	81,3
Ostrava	13	35,6	25,2	46,2	47	44,2	54,8	10,6	20,6	54,5	66,5	71,1	0	64,5	31	35,5	79,6	10,2
Berlin	14	36,6	47	26	48	53,5	17,4	61,6	62,1	66	16,5	53,2	64,5	0	76,2	77	72,4	54,3
Bratislava	15	39,6	29,2	50,2	51	37,7	58,8	24,1	14,1	26,8	70,5	59,3	31	76,2	0	7,8	54,8	39,6
Wien	16	40,4	30	51	45,1	31,5	59,6	24,9	14,9	19	71,3	51,5	35,5	77	7,8	0	47	45,7
München	19	44	54,4	54,6	32,6	40,5	57,3	69	61,9	28	55,9	19,2	79,6	72,4	54,8	47	0	89,8
Katowice	20	45,8	35,4	54,7	57,2	54,4	46,1	20,8	30,8	64,7	57,8	81,3	10,2	54,3	39,6	45,7	89,8	0

Table 4.25. Prices (in €) of the proposed high speed service. Own elaboration

As one can see, the prices are reasonable and very competitive against other modes of transport. However, as far as the distances are higher, high speed railway is not as competitive as air transport, not because of its price but for its travel time. In the next chapter, changes in the modal split due to the introduction of high speed railway service will be analyzed considering all these factors.

5. AFFECTATION TO THE TERRITORY AND THE CURRENT NETWORK

In this chapter we are going to analyze the affectation to the territory and current railway network of the Czech Republic and Central Europe due to the introduction to high speed railway. To do it, we will compare the accessibility of the railway network before and after the introduction to high speed, as well as the travel time and the commercial speed of the service, commenting where the affectation would be higher. We will also mention the expected changes in the transport modal distribution in the Czech Republic and the whole study region and, finally, we will talk about the affectation to the freight transport.

5.1. Affectation to the accessibility of the network

The current railway network in our study zone of Central Europe (defined in the figure 3.10) has the next rail map, where different design speeds for every line are shown:

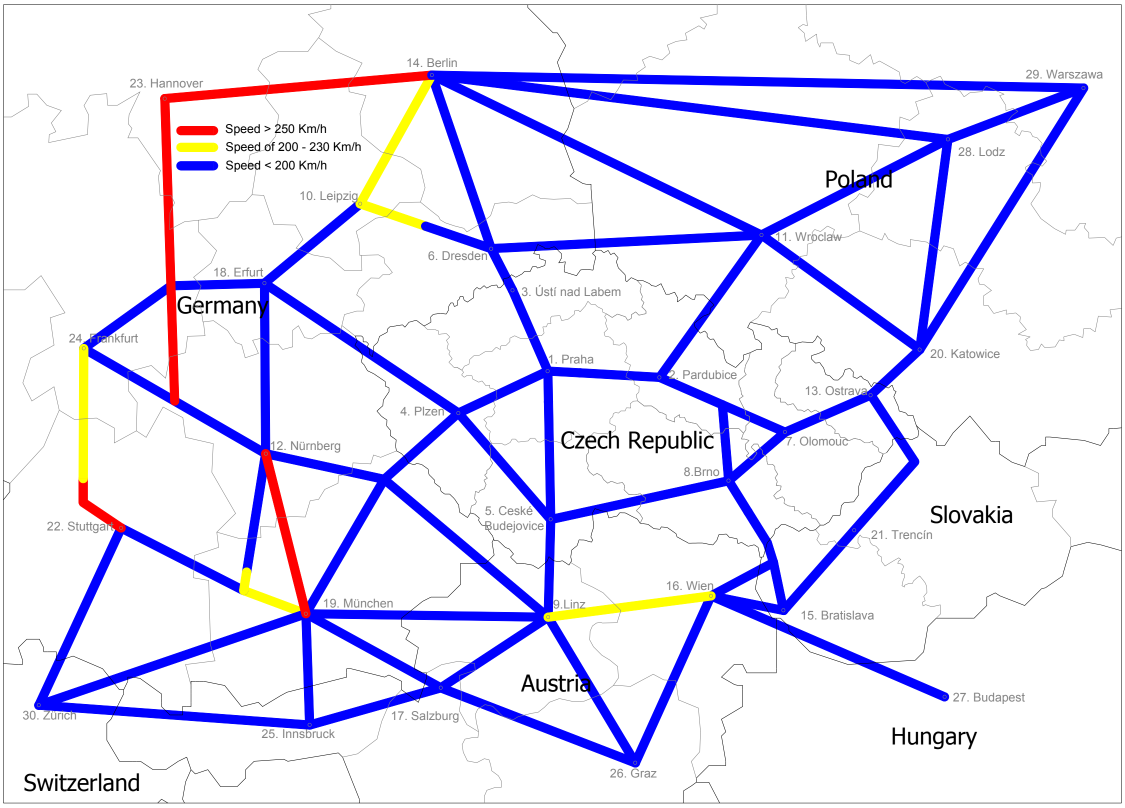


Figure 5.1. Rail map of the study zone before the introduction to high speed railway. Own elaboration from data of [3]

After the introduction of the proposed high speed railway network in the Czech Republic and its connections to the neighbor countries, the rail map of our study zone would be like the one shown in the next picture:

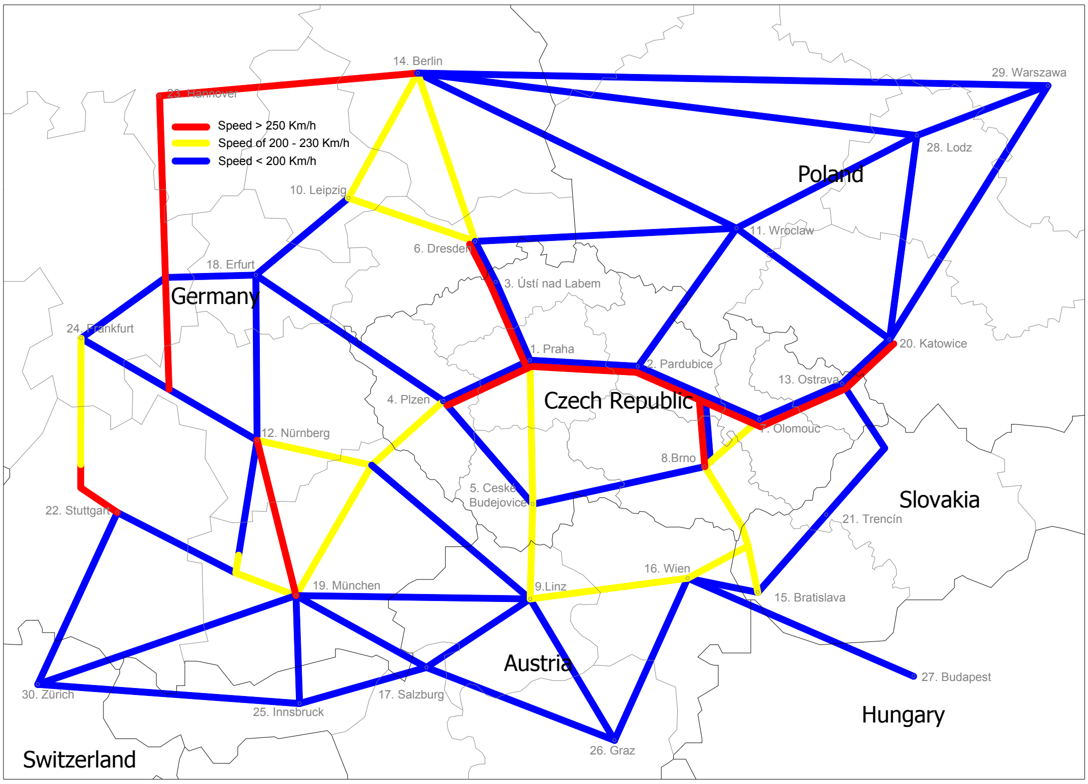


Figure 5.2. Rail map of the study zone after the introduction to high speed railway. Own elaboration from data of [3]

As one can see, the accessibility of the railway network before and after the introduction to high speed in the Czech Republic is quite the same, as approximately half of the new high speed lines would be upgraded from previous ones. In addition, new constructed lines would run parallel to the conventional ones, reason why the accessibility of the rail transport would rather remain similar.

In the same way, although distances in the new constructed tracks should be shorter due to a more generous track design, we have considered them equal to the existing in the conventional railways, as new tracks would run parallel to the old ones and differences in distance may not be great. However, many other features of the service would improve considerably, as we will explain in the next section.

5.2. Affectation to the travel time

The main benefit of the introduction to high speed railway respect the conventional one is the reduction of travel times. Therefore, when comparing the travel times before and after the introduction to high speed, one should notice a substantial difference, especially in the trips running on new constructed tracks.

The travel times of our study zone before the introduction to high speed railway have been exposed in the table 3.12. Taking the base point in Praha, we can trace isochrones for every hour of travel time by train, obtaining the following graph:

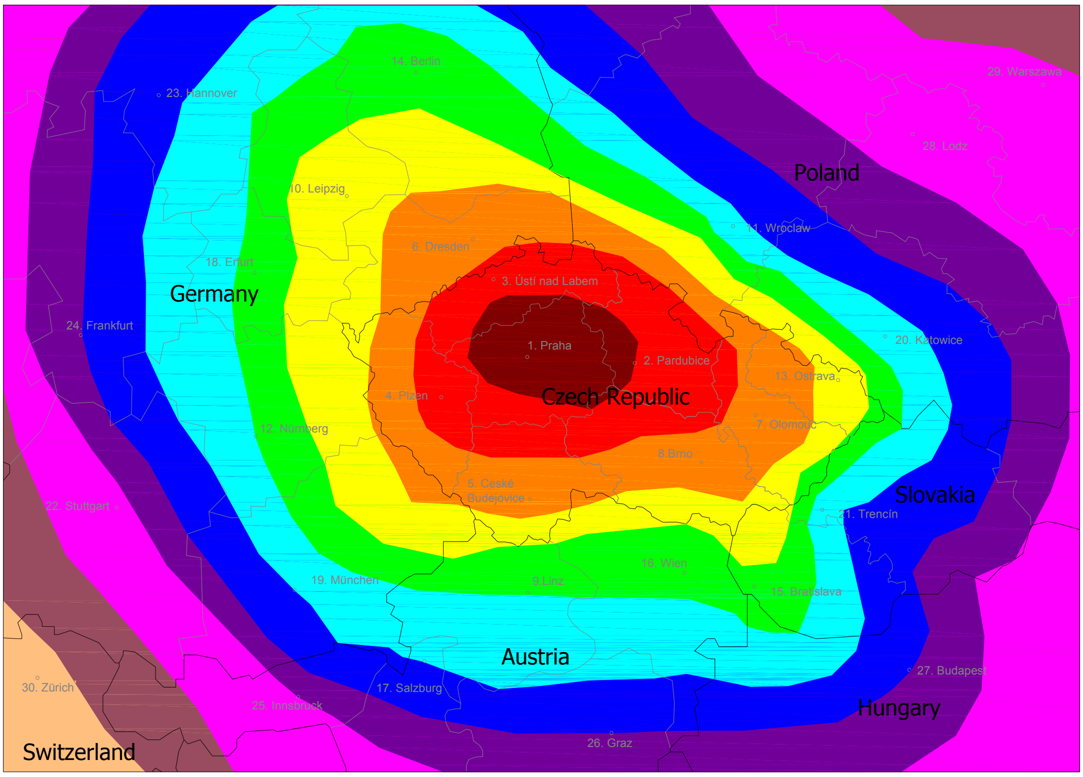


Figure 5.3. Isochrones for every hour of travel time from Praha before the introduction to high speed. Own elaboration

Looking at the isochrones one can see that their shape is mainly stretched from Norh-West to South-East, being more elongated where there are railway corridors, as the one joining Praha – Dresden – Berlin / Leipzig and the one joining Brno – Wien / Bratislava. The whole Czech Republic is reachable with less than 4 hours by conventional railway from Praha. The worst travel times in comparison with the aerial distance are obtained when travelling to Poland, while the best travel times are obtained travelling to the North-East of Germany. The highest travel time is from Praha to Zürich, being the only one over 10 hours.

What concerns to us now is to obtain the travel times once the whole high speed service is implemented in the Czech Republic and its neighboring connections. Considering the railway distances shown in the table 3.11 and the commercial speeds for every railway line shown in the figure 5.2 (250 Km/h for new constructed lines and 200 Km/h for upgraded lines), we obtain the following travel times for our study zone:

Travel time (in hours) among the 30 centroides																														
Zone	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
1	0,00	0,42	0,42	0,46	0,85	0,76	1,00	1,02	1,48	1,35	4,26	1,67	1,42	1,63	1,73	1,77	2,48	2,60	2,09	1,83	2,98	4,34	3,38	3,67	4,09	4,27	4,48	5,08	4,58	6,34
2	0,42	0,00	0,84	0,88	1,27	1,18	0,58	0,60	1,90	1,77	4,16	2,09	1,00	2,05	1,31	1,35	2,90	3,02	2,51	1,41	2,56	4,76	3,80	4,09	4,51	3,85	4,06	4,66	4,16	6,76
3	0,42	0,84	0,00	0,88	1,27	0,34	1,42	1,44	1,90	0,93	3,84	2,09	1,84	1,21	2,15	2,19	2,90	2,18	2,51	2,25	3,40	4,76	2,96	4,09	4,51	4,69	4,90	5,50	5,00	6,76
4	0,46	0,88	0,88	0,00	1,31	1,22	1,46	1,48	1,94	1,81	4,72	1,21	1,88	2,09	2,19	2,23	2,94	3,06	1,63	2,29	3,44	3,88	3,84	3,21	3,63	4,73	4,94	5,54	5,04	5,88
5	0,85	1,27	1,27	1,31	0,00	1,61	1,85	1,87	0,63	2,20	5,11	2,52	2,27	2,48	2,58	2,13	1,63	3,45	2,94	2,68	3,83	5,19	4,23	4,52	3,63	3,63	4,88	5,93	5,43	7,19
6	0,76	1,18	0,34	1,22	1,61	0,00	1,76	1,78	2,24	0,59	3,50	2,43	2,18	0,87	2,49	2,53	3,24	1,84	2,85	2,59	3,74	5,10	2,62	4,09	4,85	5,03	5,24	5,84	5,34	7,10
7	1,00	0,58	1,42	1,46	1,85	1,76	0,00	0,50	2,48	2,35	3,58	2,67	0,42	2,63	1,21	1,25	3,48	3,60	3,09	0,83	2,46	5,34	4,38	4,67	5,09	3,75	3,96	4,08	3,58	7,34
8	1,02	0,60	1,44	1,48	1,87	1,78	0,50	0,00	2,25	2,37	4,08	2,69	0,92	2,65	0,71	0,75	3,25	3,62	3,11	1,33	1,96	5,36	4,40	4,69	5,11	3,25	3,46	4,58	4,08	7,36
9	1,48	1,90	1,90	1,94	0,63	2,24	2,48	2,25	0,00	2,83	5,74	3,15	2,90	3,11	2,50	1,50	1,00	4,08	2,50	3,31	3,75	4,75	4,86	5,15	3,00	3,00	4,25	6,56	6,06	6,75
10	1,35	1,77	0,93	1,81	2,20	0,59	2,35	2,37	2,83	0,00	4,09	3,02	2,77	1,25	3,08	3,12	3,83	1,25	3,44	3,18	4,33	4,75	2,75	3,50	5,44	5,62	5,83	6,43	5,93	7,50
11	4,26	4,16	3,84	4,72	5,11	3,50	3,58	4,08	5,74	4,09	0,00	5,93	3,16	4,37	4,79	4,83	6,74	5,34	6,35	2,75	6,04	8,60	6,12	7,59	8,35	7,33	7,54	4,75	5,50	10,60
12	1,67	2,09	2,09	1,21	2,52	2,43	2,67	2,69	3,15	3,02	5,93	0,00	3,09	3,30	3,40	3,44	2,50	3,00	1,00	3,50	4,65	3,25	3,00	2,00	3,00	5,94	6,15	6,75	6,25	5,25
13	1,42	1,00	1,84	1,88	2,27	2,18	0,42	0,92	2,90	2,77	3,16	3,09	0,00	3,05	1,63	1,67	3,90	4,02	3,51	0,41	2,88	5,76	4,80	5,09	5,51	4,17	4,38	3,66	3,16	7,76
14	1,63	2,05	1,21	2,09	2,48	0,87	2,63	2,65	3,11	1,25	4,37	3,30	3,05	0,00	3,36	3,40	4,11	2,50	3,72	3,46	4,61	5,50	1,75	4,25	5,72	5,90	6,11	6,50	5,75	7,97
15	1,73	1,31	2,15	2,19	2,58	2,49	1,21	0,71	2,50	3,08	4,79	3,40	1,63	3,36	0,00	1,00	3,50	4,33	3,82	2,04	1,25	6,07	5,11	5,40	5,50	3,50	2,75	5,29	4,79	8,07
16	1,77	1,35	2,19	2,23	2,13	2,53	1,25	0,75	1,50	3,12	4,83	3,44	1,67	3,40	1,00	0,00	2,50	4,37	3,86	2,08	2,25	6,11	5,15	5,44	4,50	2,50	2,75	5,33	4,83	8,11
17	2,48	2,90	2,90	2,94	1,63	3,24	3,48	3,25	1,00	3,83	6,74	2,50	3,90	4,11	3,50	2,50	0,00	5,08	1,50	4,31	4,75	3,75	5,50	4,50	2,00	4,00	5,25	7,56	7,06	5,75
18	2,60	3,02	2,18	3,06	3,45	1,84	3,60	3,62	4,08	1,25	5,34	3,00	4,02	2,50	4,33	4,37	5,08	0,00	4,00	4,43	5,58	3,50	2,25	2,25	6,00	6,87	7,08	7,68	7,18	6,25
19	2,09	2,51	2,51	1,63	2,94	2,85	3,09	3,11	2,50	3,44	6,35	1,00	3,51	3,72	3,82	3,86	1,50	4,00	0,00	3,92	5,07	2,25	4,00	3,00	2,00	5,50	6,57	7,17	6,67	4,25
20	1,83	1,41	2,25	2,29	2,68	2,59	0,83	1,33	3,31	3,18	2,75	3,50	0,41	3,46	2,04	2,08	4,31	4,43	3,92	0,00	3,29	6,17	5,21	5,50	5,92	4,58	4,79	3,25	2,75	8,17
21	2,98	2,56	3,40	3,44	3,83	3,74	2,46	1,96	3,75	4,33	6,04	4,65	2,88	4,61	1,25	2,25	4,75	5,58	5,07	3,29	0,00	7,32	6,36	6,65	6,75	4,75	4,00	6,54	6,04	9,32
22	4,34	4,76	4,76	3,88	5,19	5,10	5,34	5,36	4,75	4,75	8,60	3,25	5,76	5,50	6,07	6,11	3,75	3,50	2,25	6,17	7,32	0,00	3,75	1,25	4,25	7,75	8,82	9,42	8,92	2,75
23	3,38	3,80	2,96	3,84	4,23	2,62	4,38	4,40	4,86	2,75	6,12	3,00	4,80	1,75	5,11	5,15	5,50	2,25	4,00	5,21	6,36	3,75	0,00	2,50	6,00	7,65	7,86	8,25	7,50	6,50
24	3,67	4,09	4,09	3,21	4,52	4,09	4,67	4,69	5,15	3,50	7,59	2,00	5,09	4,25	5,40	5,44	4,50	2,25	3,00	5,50	6,65	1,25	2,50	0,00	5,00	7,94	8,15	8,75	8,25	4,00
25	4,09	4,51	4,51	3,63	3,63	4,85	5,09	5,11	3,00	5,44	8,35	3,00	5,51	5,72	5,50	4,50	2,00	6,00	2,00	5,92	6,75	4,25	6,00	5,00	0,00	6,00	7,25	9,17	8,67	3,75
26	4,27	3,85	4,69	4,73	3,63	5,03	3,75	3,25	3,00	5,62	7,33	5,94	4,17	5,90	3,50	2,50	4,00	6,87	5,50	4,58	4,75	7,75	7,65	7,94	6,00	0,00	5,25	7,83	7,33	9,75
27	4,48	4,06	4,90	4,94	4,88	5,24	3,96	3,46	4,25	5,83	7,54	6,15	4,38	6,11	2,75	2,75	5,25	7,08	6,57	4,79	4,00	8,82	7,86	8,15	7,25	5,25	0,00	8,04	7,54	10,82
28	5,08	4,66	5,50	5,54	5,93	5,84	4,08	4,58	6,56	6,43	4,75	6,75	3,66	6,50	5,29	5,33	7,56	7,68	7,17	3,25	6,54	9,42	8,25	8,75	9,17	7,83	8,04	0,00	1,50	11,42
29	4,58	4,16	5,00	5,04	5,43	5,34	3,58	4,08	6,06	5,93	5,50	6,25	3,16	5,75	4,79	4,83	7,06	7,18	6,67	2,75	6,04	8,92	7,50	8,25	8,67	7,33	7,54	1,50	0,00	10,92
30	6,34	6,76	6,76	5,88	7,19	7,10	7,34	7,36	6,75	7,50	10,60	5,25	7,76	7,97	8,07	8,11	5,75	6,25	4,25	8,17	9,32	2,75	6,50	4,00	3,75	9,75	10,82	11,42	10,92	0,00

Table 5.4. Travel time for every connection in the study zone. Own elaboration

Looking at the table one can see that the travel times are considerably lower than before the introduction to high speed (check table 3.12). The average travel time between two random zones decreases from 6h 20min to 4 hours and the maximum travel time decreases from 14h 45min to 11h 30min. Thus, the reduction in travel time is about 37% in average. Moreover, while the average travel time from the Czech Republic to a random destination was about 5h 30min, now it is about 2h 45 min, this means, a reduction of 50%.

Again, as we did before, taking the base point in Praha, we can trace isochrones for every hour of travel time by train after the introduction to high speed railway, obtaining the following graph:

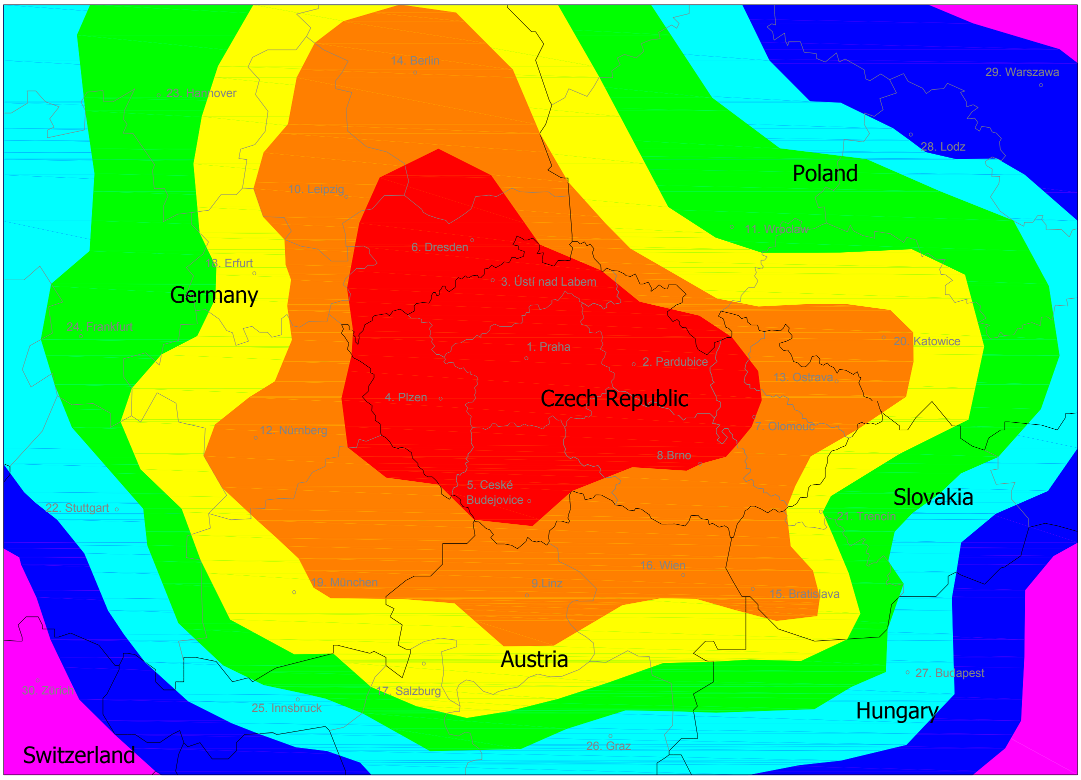


Figure 5.5. Isochrones for every hour of travel time from Praha after the introduction to high speed. Own elaboration

Looking at the isochrones one can see that again their shape is mainly stretched from North-West to South-East but with several differences. The zones near the high speed railway corridors reduce their travel time much considerably, as it can be seen in the corridors Praha – Berlin / Leipzig, Praha – Nürnberg / München, Praha – Katowice, Praha – Linz and Praha – Wien / Bratislava. The introduction to high speed railway in the Czech Republic causes a distortion in the travel times in the whole Central Europe, though the effects are more noticeable as one focuses on the Czech Republic. This way, the scope of the railway service in less than 2 hours travel time from Praha is much bigger than before, including the whole Czech territory as well as the main foreigner cities close to its frontiers.

As long as one moves away from the zone where the introduction to high speed railway has been made, the travel times increase much more rapidly. Thus, as one goes deep to Austria, Germany, Slovakia or Poland the travel times quickly increase from 2 hours to 4, 5 and 6 hours. Poland is still the worst communicated country regarding the relation between travel time and aerial distance from Praha. However, the travel times have reduced substantially, not only to Poland but to the rest of the study region, being all of them below 6h 30 min from Praha.

To appreciate better the differences of the railway connections before and after the introduction to high speed railway in the Czech Republic, we have elaborated an isochrones map of the differences in travel time from Praha, which it is shown next:

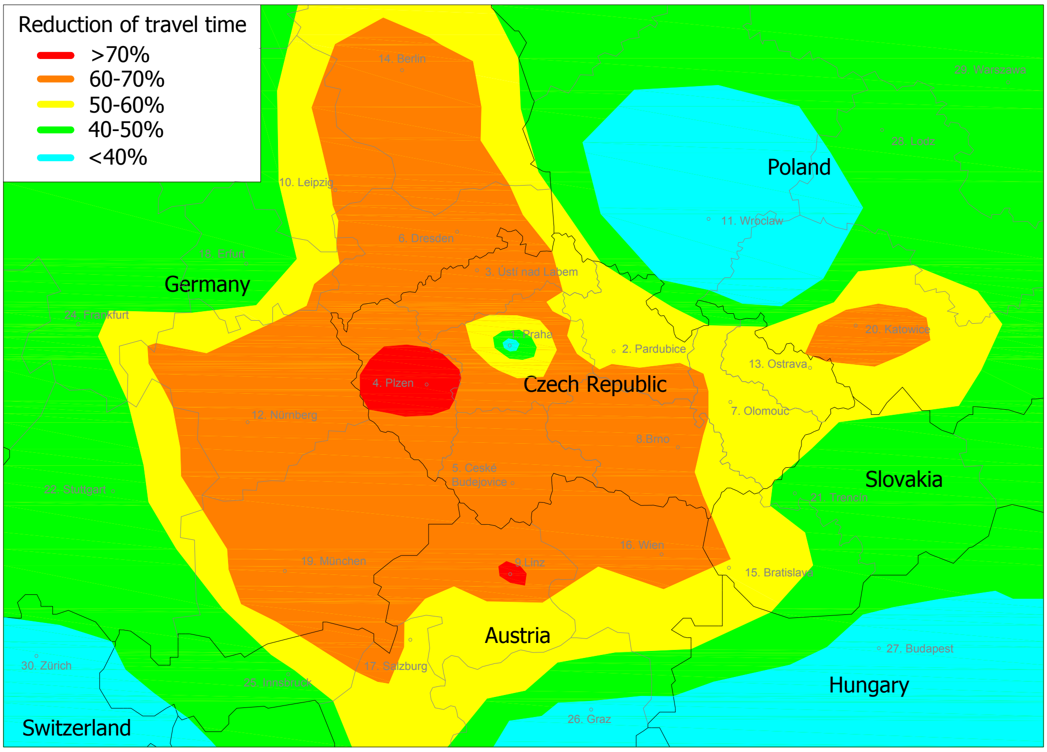


Figure 5.6. Isochrones of the differences in travel time from Praha before and after the introduction to high speed. Own elaboration

In this map one can clearly see that affectation of the introduction of high speed railway is most considerable in the Southern-Western part of the Czech Republic, North of Austria and East of Germany, where the reduction of travel times with Praha is between 60 and 70%, besides the region of Katowice in Poland, where its fast connection to Praha has its consequences in the travel time reduction. Moreover, Plzeň and Linz, due to the high speed railway corridors Praha – Nürnberg / München and Praha – Linz, respectively, are the most benefited zones, with reductions over the 70%.

In general, the rest of the study zone has a reduction of travel time between 40 and 60%, with the exception of Switzerland, Hungary and the South-West of Poland, where the reductions are lightly lower due to the fact that their distances to the nearest high speed railway are becoming larger. Nevertheless, even these more disconnected points have reductions of almost 40% in travel time, clearly showing that the introduction to high speed railway in the Czech Republic has big consequences in the reduction of travel times in all Central Europe.

5.3. Affectation to the commercial speed

Like it has been done with the comparison of travel times of our study region, we are going to show the differences in the commercial speed of the railway service before and after the introduction to high speed railway in the Czech Republic.

The commercial speed of the railway lines in the study zone before the introduction to high speed in the Czech Republic are shown in the table 3.13. The average speed of railway trips among all the centroides is about 90 Km/h, while the fastest connections are those that depart or arrive to Hannover (113 Km/h), being the slowest ones those that depart or arrive to Wroclaw (72 Km/h). The highest commercial speeds are achieved in the connections Nürnberg – München (192 Km/h), Hannover –München (166 Km/h), Suttgart – Frankfurt (160 Km/h), Hannover – Nürnberg (157 Km/h), Hannover – Berlin (146 Km/h), Berlin – Leipzig (132 Km/h), Stuttgart – Erfurt (131 Km/h) and Wien – Salzburg (127 Km/h). In the Czech Republic, the highest speeds are reached in the corridor Plzeň – Praha – Pardubice – Olomouc, corresponding to 111 Km/h in average.

The commercial speed of the railway lines once the introduction to high speed in the Czech Republic has been done would be those shown in the next table:

Railway commercial speed (in Km/h) among the 30 centroides

Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	0	248	252	248	199	253	250	250	199	229	82	213	251	225	229	228	170	164	211	250	160	157	170	160	150	127	145	118	154	119
2	248	0	250	248	215	251	252	252	209	233	59	220	252	229	223	222	181	175	217	251	146	165	178	169	159	132	134	106	144	127
3	252	250	0	250	217	253	251	251	211	218	93	221	251	215	233	233	182	147	218	243	171	163	158	141	159	139	154	111	147	127
4	248	248	250	0	104	251	249	249	135	234	98	199	250	230	233	202	132	160	200	250	172	146	179	148	137	108	141	129	163	109
5	199	215	217	104	0	224	182	126	198	217	101	150	195	216	146	148	155	172	138	203	120	124	176	135	123	103	115	130	146	98
6	253	251	253	251	224	0	251	251	217	198	77	157	251	200	236	236	189	127	201	178	179	135	146	120	154	146	161	90	122	125
7	250	252	251	249	182	251	0	200	177	238	109	227	252	234	199	199	163	188	223	251	119	174	188	179	150	122	125	108	127	137
8	250	252	251	249	126	251	200	0	151	238	97	227	224	234	199	199	143	188	199	232	113	160	188	180	129	110	114	118	136	125
9	199	209	211	135	198	217	177	151	0	213	112	103	188	212	107	127	127	141	112	195	104	110	164	108	107	83	103	134	148	86
10	229	233	218	234	217	198	238	238	213	0	95	122	240	132	229	229	186	94	163	182	182	121	96	107	134	152	164	100	124	107
11	82	59	93	98	101	77	109	97	112	95	0	110	92	81	112	113	114	95	124	69	77	112	100	100	115	103	105	53	69	104
12	213	220	221	199	150	157	227	227	103	122	110	0	230	161	174	150	138	83	192	232	154	133	157	117	121	97	124	134	165	97
13	251	252	251	250	195	251	252	224	188	240	92	230	0	211	190	213	172	195	227	249	65	180	188	185	157	135	129	91	110	143
14	225	229	215	230	216	200	234	234	212	132	81	161	211	0	227	226	191	113	195	157	177	134	146	127	157	154	166	78	99	121
15	229	223	233	233	146	236	199	199	107	229	112	174	190	227	0	78	113	190	143	194	98	130	190	153	107	82	92	119	134	105
16	228	222	233	202	148	236	199	199	127	229	113	150	213	226	78	0	127	175	122	220	89	116	190	138	114	84	90	129	146	95
17	170	181	182	132	155	189	163	143	127	186	114	138	172	191	113	127	0	117	102	180	109	105	148	128	98	75	108	133	145	79
18	164	175	147	160	172	127	188	188	141	94	95	83	195	113	190	175	117	0	111	157	162	131	109	114	102	120	143	99	119	109
19	211	217	218	200	138	201	223	199	112	163	124	192	227	195	143	122	102	111	0	229	132	107	166	142	86	83	109	145	172	74
20	250	251	243	250	203	178	251	232	195	182	69	232	249	157	194	220	180	157	229	0	83	185	153	173	164	146	136	71	90	148
21	160	146	171	172	120	179	119	113	104	182	77	154	65	177	98	89	109	162	132	83	0	125	165	143	106	87	94	77	86	104
22	157	165	163	146	124	135	174	160	110	121	112	133	180	134	130	116	105	131	107	185	125	0	144	160	97	90	109	129	147	82
23	170	178	158	179	176	146	188	188	164	96	100	157	188	146	190	190	148	109	166	153	165	144	0	136	139	137	156	93	110	118
24	160	169	141	148	135	120	179	180	108	107	100	117	185	127	153	138	128	114	142	173	143	160	136	0	119	102	122	116	134	106
25	150	159	159	137	123	154	150	129	107	134	115	121	157	157	107	114	98	102	86	164	106	97	139	119	0	83	105	131	140	69
26	127	132	139	108	103	146	122	110	83	152	103	97	135	154	82	84	75	120	83	146	87	90	137	102	83	0	87	115	125	77
27	145	134	154	141	115	161	125	114	103	164	105	124	129	166	92	90	108	143	109	136	94	109	156	122	105	87	0	110	119	94
28	118	106	111	129	130	90	108	118	134	100	53	134	91	78	119	129	133	99	145	71	77	129	93	116	131	115	110	0	85	119
29	154	144	147	163	146	122	127	136	148	124	69	165	110	99	134	146	145	119	172	90	86	147	110	134	140	125	119	85	0	134
30	119	127	127	109	98	125	137	125	86	107	104	97	143	121	105	95	79	109	74	148	104	82	118	106	69	77	94	119	134	0

Table 5.7. Commercial speed of the railway lines in the study zone after the introduction to high speed in the Czech Republic. Own elaboration

Analysing the table one can see that the average speed of railway trips among all the centroides is about 154 Km/h, this means, 64 Km/h higher than before. The fastest connections are those departing or arriving to Praha, Pardubice and Ústí nad Labem (195 Km/h) while the slowest ones are those departing or arriving to Wroclaw (95 Km/h), which continues being the worst one but gaining an average commercial speed of 23 Km/h to all the other centroides. The highest commercial speeds are 250 Km/h, achieved in the new constructed railway corridor from Plzeň to Katowice, as well as the stretch Praha – Dresden.

Besides commenting every situation separately, it is also very interesting to compare them and have a global vision of the main changes in commercial speed all together. Thus, we have compared the average commercial speed for all the trips for every centroid of our study zone before and after the introduction to high speed in the Czech Republic, obtaining the absolute and relative differences existing between them. The results are shown in the next table:

Zone		Average Before (Km/h)	Average after (Km/h)	Absolute Difference (Km/h)	Relative difference (%)	
20	Katowice	75	182	107	**142**	>125%
1	Praha	82	193	111	**135**	
4	Plzeň	79	185	106	**135**	
3	Ústí nad Labem	86	195	110	**128**	
2	Pardubice	85	195	109	**128**	
13	Ostrava	84	190	107	**127**	
7	Olomouc	87	190	103	**119**	100 - 125%
5	České Budejovice	74	158	84	**113**	
6	Dresden	88	185	98	**111**	
8	Brno	87	182	95	**110**	
10	Leipzig	94	172	78	**83**	75 - 100%
14	Berlin	96	174	78	**82**	
15	Bratislava	90	161	70	**78**	
16	Wien	93	160	67	**72**	50 - 75%
9	Linz	91	148	57	**63**	
12	Nürnberg	100	159	59	**59**	
19	München	104	157	53	**51**	
29	Warszawa	87	129	42	**48**	<50%
28	Lodz	75	109	34	**46**	
21	Trenčín	86	124	38	**44**	
18	Erfurt	96	138	42	**43**	
17	Salzburg	99	138	39	**39**	
26	Graz	82	110	28	**34**	
23	Hannover	113	151	38	**34**	
11	Wroclaw	72	96	24	**33**	
27	Budapest	92	123	30	**33**	
24	Frankfurt	107	137	30	**28**	
25	Innsbruck	98	125	27	**27**	
22	Stuttgart	108	133	25	**23**	
30	Zürich	90	108	18	**20**	

Table 5.8. Differences of the commercial speed for every connection in the study zone before and after the introduction to high speed in the Czech Republic. Own elaboration

One can see that the commercial speed increases in more than 100 Km/h in most of the places of the Czech Republic, representing a relative increase over 125% in the best cases and over 110% in the rest. Katowice is the city with the best improvement of its commercial speed, being about 142%, followed by Praha and Plzeň, both with 135%. In general, the increase of the commercial speed in the neighbor countries is also great, as much as the cities are closer to the Czech Republic and its high speed corridors. The lowest improvements are achieved in Zürich (20%), Stuttgart (23%), Innsbruck (27%), Budapest (33%) and Wroclaw (33%), being all of them over 18 Km/h.

5.4. Estimated changes of the transport modal distribution

Once the main affectations of the railway service after the introduction to high speed railway in the Czech Republic have been analyzed, we are going to study the expected changes in the transport modal distribution in the Czech Republic and the whole study region in Central Europe.

As we said when talking about the current Czech transport infrastructure (see fig. 2.3), only a 3,65% of the daily trips correspond to rail transport, while public bus transport supposes a 7,43%, air transport a 0,14%, inland waterway transport a 0,02%, private car a 44% and urban public transport a 44,76%. However, for analyzing the effects of the introduction to high speed railway, we will not take into account neither the urban public transport, as we are only studying the inter-regional trips, nor private car, as it is very difficult to distinguish between its urban and inter-regional use. In addition, we will not consider the inland waterway transport due to its low significance.

For the modal distribution estimation, we have used the formulas 3.33 and 3.34 of the modal split stage of the demand analysis, where we had considered the influence of the price, the accessibility, travel time, frequency and quality of the service of the different transportation modes for their election. Therefore, using them we can obtain the probability of choosing every transportation mode for every origin/destination connection in the Czech Republic and the whole study region in Central Europe, both before and after the introduction to high speed railway.

The results obtained for the trips among the Czech Republic are shown in the following graphics:

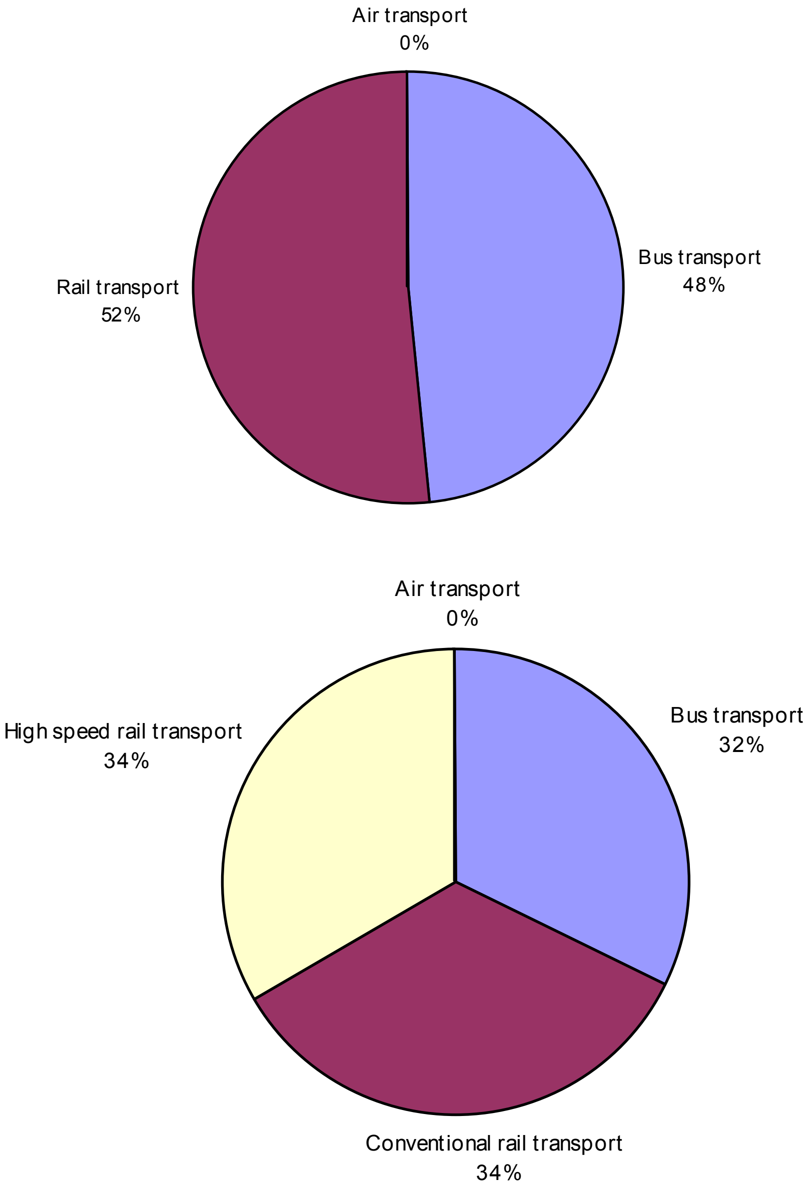


Figure 5.9. Inter-regional public transport modal distribution in the Czech Republic. a) Before introduction high speed. b) After introduction to high speed. Own elaboration

The estimation of the current modal split in the Czech Republic differs considerably from the data shown in the figure 2.3, as the estimated share between rail and bus is 52% against 48%, while the data from the Czech Ministry of Transport reflects a share of the bus transport over the double of the rail transport (7,43% for bus and 3,65% of rail transport). This is due to the fact that, in our model, we are only considering the trips between different regions (inter-regional trips) while the Ministry of Transport considered all the non urban trips done by bus, being noticeable higher. In both cases, air transport is approximately null, as the Czech Republic is a small country to carry out commercial national flights.

With the introduction to high speed railway in the Czech Republic, one can see in the second graphic how high speed rail service would obtain a big part of the public transport share, being equal to the conventional railway and slightly higher than inter-regional bus transport. This is explained due to the good communications among all the regions of the Czech Republic by high speed railway and reasonable fares regarding conventional railway and bus transport prices. It should be said, however, that conventional rail service would be slightly lower because of a reduced frequency of its service due to the coexistence of high speed and also because of the conversion of some of its railway network to high speed, what would be converted in a gain of high speed and bus transport share.

Regarding the whole study region in Central Europe, the results obtained are the ones shown in the following graphics:

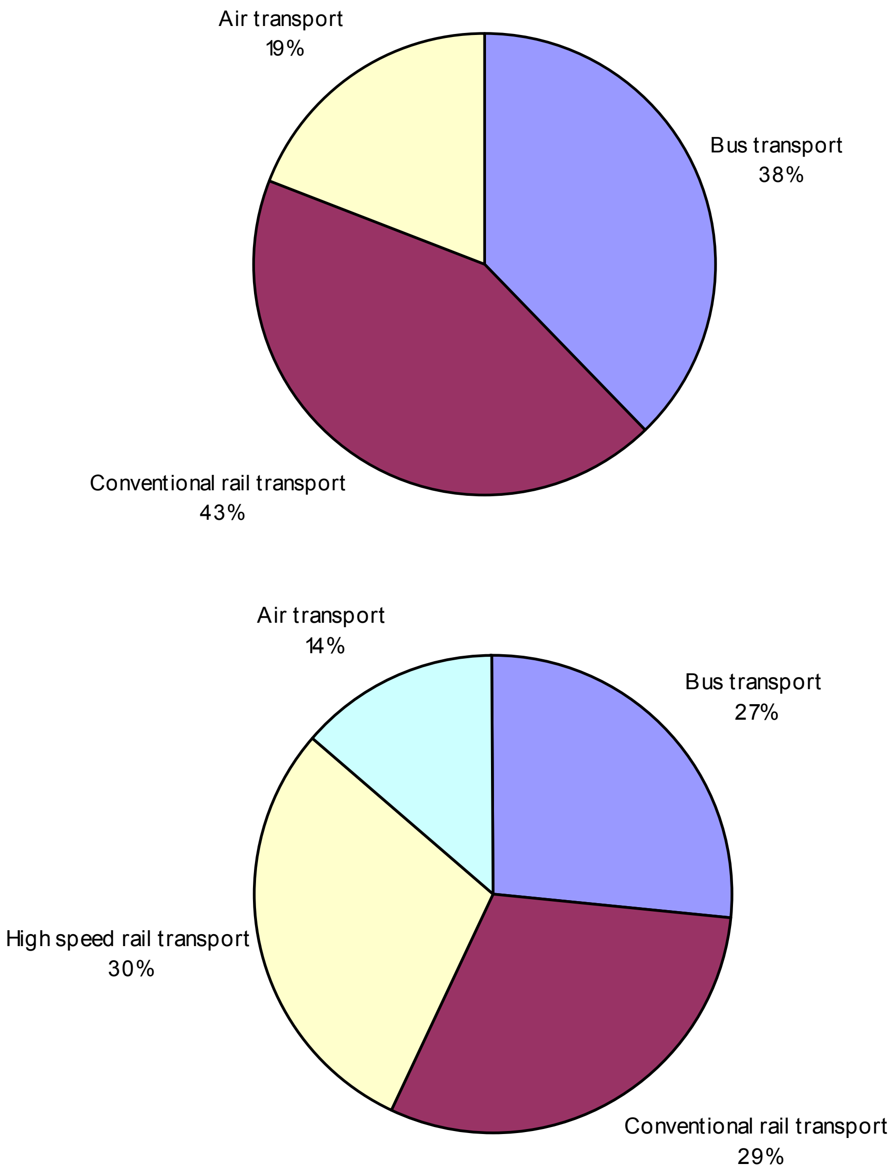


Figure 5.10. Inter-regional public transport modal distribution in the study zone in Central Europe. a) Before introduction high speed. b) After introduction to high speed. Own elaboration

Before the introduction to high speed railway in the Czech Republic and its connections with the neighboring countries, conventional railway is the transport system with the highest share (43%), followed by bus (38%) and air transport (19%), which now plays an important rule in the modal distribution, as the highest distances in the study region go up to 1500 Km. However, rail transport is the most elected one due to its better commercial speed in front of bus transport and lower fares in front of air transport.

With the introduction to high speed, the use of all them would decrease in favor of high speed service, which would be the most elected transport system with a 30% of the share, followed closely by conventional rail and bus transport, with a 29% and 27% respectively. Air transport would occupy again the last place in the ranking, with a 14% of the share. However, it should be mentioned that not all the centroides of the study zone are connected to the high speed network, so that there would be some trips without the possibility of choosing its services. Consequently, the share of high speed railway would be lower in favor of the other transportation modes, especially in the zones with worst connections to high speed network.

Nevertheless, one can say that the obtained modal split clearly reflects a great demand of high speed transport in the Czech Republic and its connections with the Central Europe's railway network, what would cause an important reduction of the traditional transportation systems.

5.5. Affectation to the freight transport

The introduction to high speed railway in the Czech Republic and its connections with neighboring countries would have several consequences on the freight transport, not only on the transport of goods by train, but also by road, as we will explain.

The current modal distribution of freight transport in the Czech Republic is:

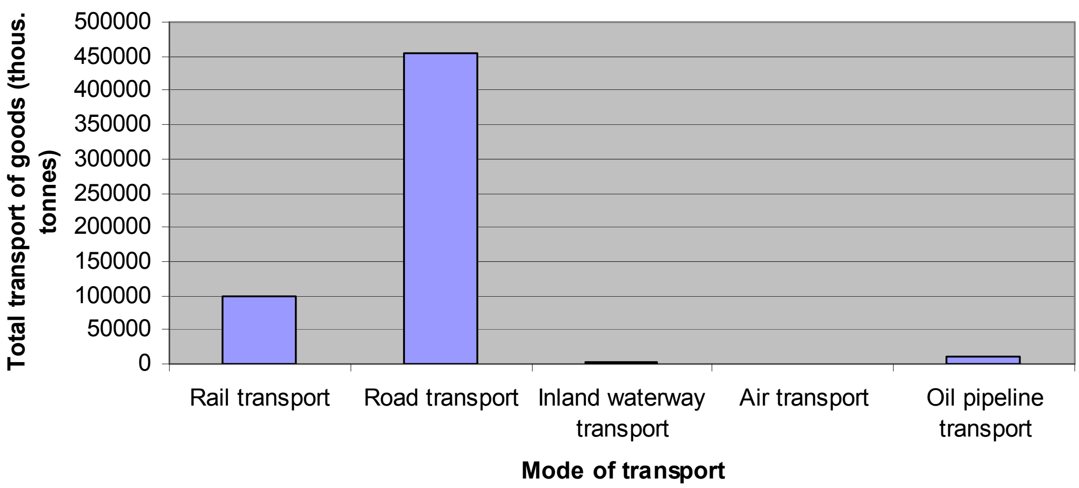


Figure 5.11. Current modal distribution of freight transport in the Czech Republic. Own elaboration from data of [6]

It can be noticed the huge difference between road transport and rail transport, being the volume of goods transported by road over 4 times the quantity transported by rail, while oil pipelines, air transport and inland waterways have volumes of goods transport almost insignificant. The main reasons for the big concentration of freight transport in the roads are prices and flexibility of its transportation, besides the lack of connectivity, capacity and competitiveness of the other transportation modes.

High speed passenger lines, however, may indirectly facilitate the rail flow of goods by freeing up more regular rail capacity on conventional lines. As we have considered the whole proposed high speed network able to carry out mixed traffic, the capacity of railway freight transport would increase substantially in all the trips going through the Czech Republic, leading to an expansion of national and especially international freight transport through them.

Regarding the national freight traffic, taking a look at the figure 3.24, one can see that the most frequent origins and destinations are Ústí nad Labem and the Moravian/Silesian region (Ostrava in our study model), having also a big importance the regions of Pardubice and Praha. All these regions would have high speed stations so the long-term connections could be done by high speed railway.

Regarding the international freight traffic (see fig. 3.25), the connections with highest volume of goods transport are those joining the Czech Republic with Austria and Germany, both of them with two high speed corridors, which would serve the freight transport to the Southern Europe via Linz and Wien, to the Western Europe via Nürnberg and München, and to the North of Europe via Berlin and Leipzig.

With the introduction to high speed railway, freight trains would run up to 160 Km/h, with an estimated commercial speed of 140 Km/h, working day and night on new and upgraded tracks. This would suppose a very big difference respect the current rail freight transport, which runs at a commercial speed of 30 Km/h in average with its frequency limited by passenger traffic. Road transport of goods has an average commercial speed of 80 Km/h, though it decreases considerably when there are traffic congestions or when travelling through big urban areas. In any case, high speed railway freight traffic would be much more competitive than lorries or trains running through conventional railways.

As a conclusion we can say that railway freight traffic would suppose a great gain against road transport, very needed to appease its continuous increase after the entrance of the Czech Republic into the EU.

6. ECONOMICAL STUDY AND INVESTMENT VIABILITY

In this chapter we will elaborate a very simplified economic study about the introduction to high speed railway in the Czech Republic. As the basic indicators of any economical study of a project are the expenses and incomes, we are going to talk about the estimated expenses of the construction and exploitation of high speed railway service and then we will talk about the expected incomes that this service would generate. Finally we will elaborate an investment viability analysis to know how profitable the project would be and the needed subvention of the State. In the whole economical study we will refer only to the high speed railway in the Czech Republic's territory regarding passenger traffic, as the freight traffic is much more difficult to quantify.

6.1. Expenses

The tendency of the Czech Republic in the last years has been investing more and more in road transport, neglecting the investment in rail and air transport. Thus, a lot of Km of new highways and motorways has been constructed while the expansion and maintenance of rail lines has been much more limited. In the next graph, the expenditure in road, rail and air transport of the last years are shown:

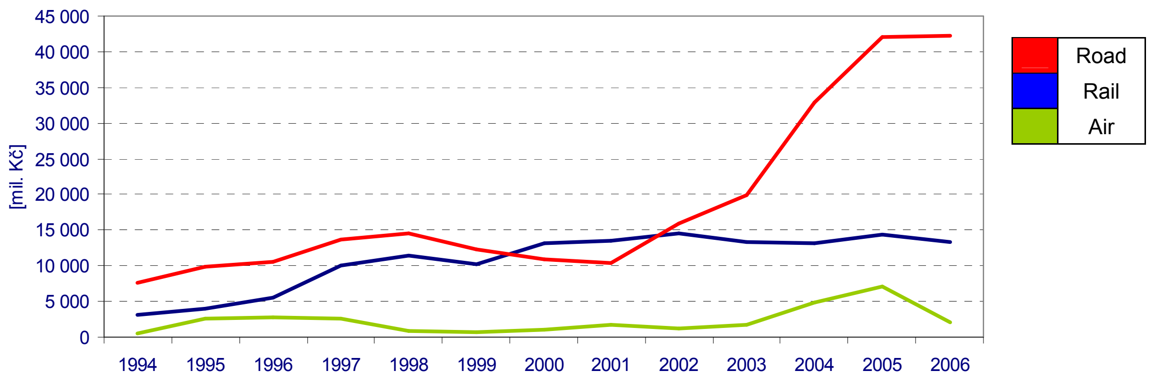


Figure 6.1. Evolution of investment expenditure in transport infrastructure in the Czech Republic in Czech Crowns (CZK) [1]

As one can see, road and rail transport investments were similar until 2002. Since then, however, while the investment in rail and air transport remained approximately constant, road investment has almost tripled. This reflects the tendency in modal transport distribution of the last years and the need of improvement of the railway service to gain competitiveness, where the introduction to high speed railway has a lot to say.

6.1.1. Construction costs

When talking about the construction costs of the high speed railway we are considering both the costs for the new constructed lines and the upgraded lines, besides the costs of the elaboration of the whole project.

Thus, the costs for the new constructed lines include the following:

- Earthmoving works, compaction and conditioning of the railway platform
- Fabrication and transport of all the necessary material: rails, ballast, sleepers, fasteners and base plates
- Installation of electrification and signaling systems
- Construction or adaptation of stations
- Supervising and testing of the high speed

The costs for the upgraded lines depend on how much profitable the old rail structure is. In any case, however, they can be classified in the following groups:

- Leveling of ground terrain and earthworks if necessary
- Adaptation of the railway superstructure
- Adaptation of the electrification and signaling systems
- Construction or adaptation of stations
- Supervising and testing of the high speed

For simplification, we will consider all the construction costs summed up, though distinguishing between new constructed lines and upgraded ones.

It is not true that building a high speed railway is capital intensive and the Czech Republic can not afford it with a large scale investment. The costs of implementing the whole project are significant, but compared to the volume of other structures undertaken in road transport are not exceptional. The construction unit costs (costs per Km) of new road and rail infrastructure have a comparable order of magnitude, being in the case of upgraded rail lines even approximately the half. In the following graph, the unit costs for the construction of roads and high speed railway have been represented in order to compare them:

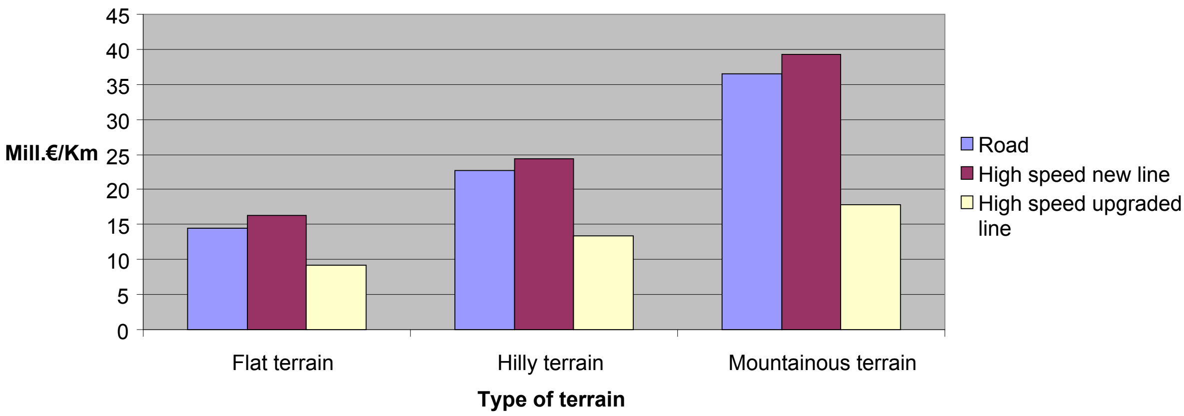


Figure 6.2. Comparison of unit investment costs for the construction of roads and high speed railway. Own elaboration from data of [1]

Note that the construction of high speed costs approximately the same as roads, and how the cost is reduced when upgrading existing rail lines. As more or less half of the high speed network would be upgraded from conventional lines and the designed network goes through flat and hilly terrain rather than mountainous, the expense of its construction would be completely viable.

Regarding the construction of high speed lines in the Czech Republic’s territory, the total investment for the first construction stage (see fig. 4.13) would reach about 2.500 M€, according to SUDOP A.S., excluding the stretch Praha – Ústí nad Labem – Petrovice (German frontier) and the section Praha – Beroun, which is already included in the budget of the third railway corridor. The cost of upgrading lines Brno - Břeclav, Brno - Přerov and Plzeň – Domažlice (German frontier) would reach about 2.000 M€, while the cost of completing the remaining sections of high speed railway is approximately 6.000 M€. [1]

In contrast, only in the years 2008 - 2015, the Czech Republic has invested about 12.000 M€ for the construction of new motorways and express roads. A simple comparison suggests that the costs for the first stage of construction and upgrading high speed lines, which is due to the needs of the railway network in the next 20 years, reaches only 40% of investment in new road infrastructure of the next 8 years.

These values are represented in the following graphic for a better visual comparison:

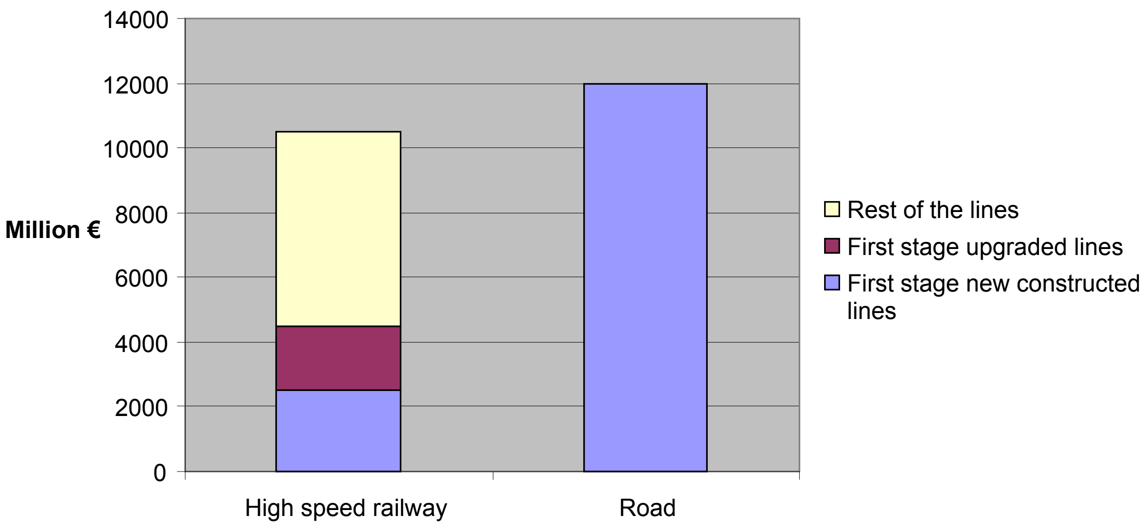


Figure 6.3. Comparison between investments of high speed railway and road infrastructures in the Czech Republic [1]

It should be said, in addition, that the financial impact of the construction works in a given year can be substantially eliminated by a more suitable method of construction stage across the high speed network.

6.1.2. Exploitation costs

When talking about the exploitation costs of the high speed railway service, one refers to the costs derived from:

- Energy: consumption of vehicles, signaling, lighting and all the installations
- Stations: Maintenance and operation
- Staff: on board and ashore
- Finances: Commissions, financial costs and ticketing
- Infrastructure: operation and maintenance of tracks, electrification, signaling, communication and telecontrol systems
- Vehicles: Cleaning, maintenance and depreciation of new vehicles...

Some of these costs are fixed, like part of the costs of maintenance of the infrastructures, while others are variable, in the sense that they depend on the use of the service, like the costs associated to vehicles, staff and others regarding the operation and maintenance of the service. However, we are going to approximate them all (fixed and variables) as a function of high speed railway use, expressed as a product of passengers · kilometers for all the trains (estimation obtained from [S]). Note that we are not considering freight trains due to the difficulty to estimate their traffic flow.

Considering the proposed operating lines of the high speed railway service shown in the figure 4.23, the frequencies shown in the table 4.24, and the railway distances shown in 3.11 regarding the Czech territory, we have compiled a table with the product passengers · Km for every stretch of high speed line, where we have considered a capacity of 400 passengers per high speed train and an occupancy rate of 70% (280 passengers per train):

STRETCH	KM	PASSENGERS PER TRAIN	TRAINS PER YEAR	PASSENGERS·KM PER YEAR
German frontier – Plzeň – Praha	173	280	12.410	601.140.400
Austrian frontier – České Budejovice – Praha	232	280	3.103	201.570.880
German frontier – Ústí nad Labem – Praha	143	280	24.820	993.792.800
Austrian frontier – Brno	59	280	12.410	205.013.200
Olomouc – Česká Třebová	86	280	6.205	149.416.400
Polish frontier – Olomouc	114	280	12.410	396.127.200
Brno – Olomouc	100	280	6.205	173.740.000
Česká Třebová – Praha	164	280	12.410	569.867.200
Brno – Česká Třebová	91	280	6.205	158.103.400
TOTAL				**3.448.771.480**

Table 6.4. Passenger·Km per year for the high speed railway service in the Czech Republic. Own elaboration

Note that the highest values are obtained in the lines connecting with Germany, as well as the main stretch linking Praha with the first railway junction in Moravia, Česká Třebová.

Assuming that the schedules for every day of the year are the same, we have elaborated the following table showing the unit costs and the obtained measurement of passenger · Km for every one of the exploitation costs in a year of service:

Concept		Unit costs		Measurement	Total (€)	% of total
		Value	Units			
Energy	Consumption	0,0049	€/pax·Km	3.448.771.480	16.898.980	7,47
Stations	Maintenance and operation	0,0033	€/pax·Km	3.448.771.480	11.380.946	5,03
Staff	On board and ashore staff	0,0096	€/pax·Km	3.448.771.480	33.108.206	14,63
Finance	Commissions, financial costs and ticketing	0,0056	€/pax·Km	3.448.771.480	19.313.120	8,54
Infrastructure	Maintenance	0,0224	€/pax·Km	3.448.771.480	77.252.481	34,15
Vehicles	Maintenance	0,0101	€/pax·Km	3.448.771.480	34.832.592	15,40
	Depreciation of new trains	0,0097	€/pax·Km	3.448.771.480	33.453.083	14,79
TOTAL (€)					**226.239.409**	**100**

Table 6.5. Estimated exploitation costs for the high speed railway in the Czech Republic per year. Own elaboration from previous data and [S]

As one can see, most part of the exploitation costs are due to the maintenance of the infrastructure and vehicles, being the total exploitation costs approximately 226 M€ per year, it means, a 2,15% of the total construction costs (10.500 M€). Moreover, taking a look at the figure 6.1, one can realize that the exploitation costs of high speed railway would represent approximately the 40% of the investment expenditure in railway transport in the Czech Republic of the last years (15.000 MCZK ≈ 560 M€). Therefore, the exploitation costs of high speed railway seem to be reasonable, excepting the construction investment, which would suppose a much greater effort.

6.2. Incomes

The other part of an economic analysis is the income expected from the implementation of the service. Regarding the introduction to high speed railway services, the basic expected incomes come from:

- Tickets issuing
- Advertisements
- Subvention of the Public Administrations

In our analysis we will only refer to the tickets issuing, as the advertisement incomes are very difficult to quantify. The Subvention of the Public Administrations will not be other but the necessary to cover the exploitation costs, as we are talking about a public service that may have deficit.

If we assume an average fare of the high speed railway service of 10€ per 100 Km, one can see the prices for every connection among the Czech Republic and the closest neighbor stations at the table 4.25.

Regarding these fares and the total passenger · Km per year in the Czech territory shown at the table 6.4 and considering that the demand does not vary throughout the timeframe of the service, the expected income coming from the ticket issuing can be estimated as following:

STRETCH	KM	PASSENGERS PER TRAIN	TRAINS PER YEAR	PASSENGERS·KM PER YEAR	TICKET ISSUING
German frontier – Plzeň – Praha	173	280	12.410	601.140.400	60.114.040 €
Austrian frontier – České Budejovice – Praha	232	280	3.103	201.570.880	20.157.088 €
German frontier – Ústí nad Labem – Praha	143	280	24.820	993.792.800	99.379.280 €
Austrian frontier – Brno	59	280	12.410	205.013.200	20.501.320 €
Olomouc – Česká Třebová	86	280	6.205	149.416.400	14.941.640 €
Polish frontier – Olomouc	114	280	12.410	396.127.200	39.612.720 €
Brno – Olomouc	100	280	6.205	173.740.000	17.374.000 €
Česká Třebová – Praha	164	280	12.410	569.867.200	56.986.720 €
Brno – Česká Třebová	91	280	6.205	158.103.400	15.810.340 €
TOTAL				**3.448.771.480**	**344.877.148 €**

Table 6.6. Expected high speed railway income per year in the Czech Republic due to ticket issuing. Own elaboration

As one can see, the expect income due to ticket issuing per year in the Czech Republic is approximately 345 M€, it means, a 50% more than the expected exploitation costs (226 M€). In addition, as we said before, there would be incomes due to advertisements, so the expected income would be considerably higher.

If one takes into account the estimated expenses and incomes obtained until the moment, we have:

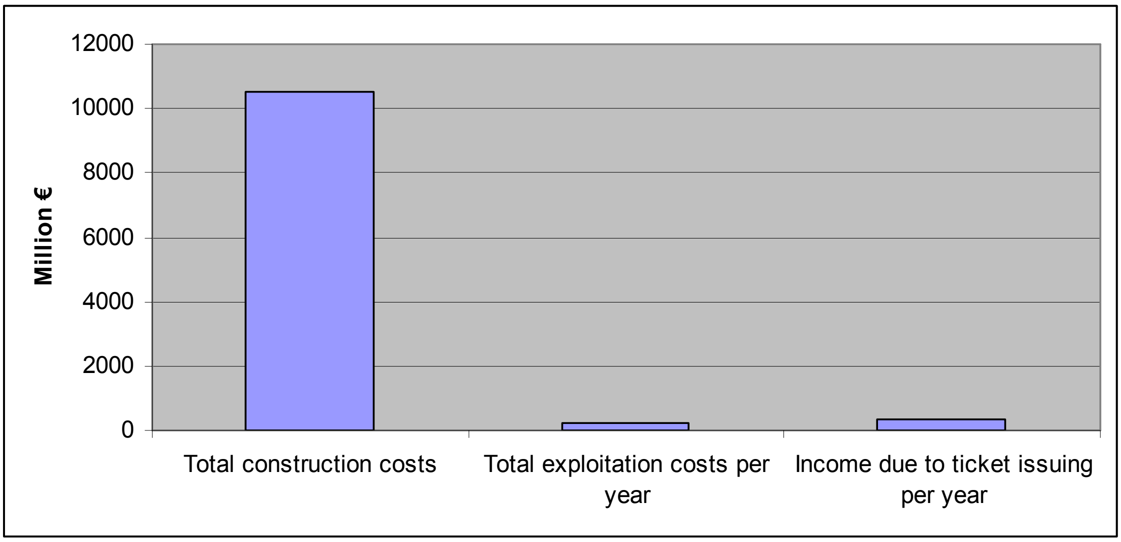


Figure 6.7. Estimated expenses and incomes for the high speed railway services in the Czech Republic. Own elaboration

One can notice the big initial investment for the construction of the infrastructure in comparison with the estimated exploitation expense and income per year due to its service.

In the next section we are going to analyze whether this investment is viable or not, considering all this information.

6.3. Investment viability analysis

Considering all the previous information regarding the expected expenses and incomes of the introduction to high speed railway in the Czech Republic, one should now analyze the viability of this investment.

The investment viability analysis has been conventionally carried out with two basic indicators:

- Net Present Value (NPV)
- Internal Rate of Return (IRR)

On one hand, the Net present value (NPV) or net present worth (NPW) is defined as the total present value (PV) of a time series of cash flows. It is a standard method for using the time value of money to appraise long-term projects. Used for capital budgeting, and widely throughout economics, it measures the excess or shortfall of cash flows, in present value terms, once financing charges are met. [E]

Its algebraic formulation is:

$$NPV = \sum_{t=0}^{T} \frac{R_t}{(1+i)^t} \quad (6.8)$$

where:

- t is the time of the cash flow
- T is the timeframe of the project
- i is the discount rate (the rate of return that could be earned on an investment in the financial markets with similar risk)
- R_t is the net cash flow (the amount of cash, inflow minus outflow) at time t

On the other hand, the Internal Rate of Return (IRR) for an investment is the discount rate that makes the net present value of the investment's cash flow stream equal to zero. A project is a good investment proposition if its IRR is greater than the rate of return that could be earned by alternate investments of equal risk (investing in other projects, buying bonds, even putting the money in a bank account). Thus, the IRR should be compared to any alternate costs of capital including an appropriate risk premium. In general, if the IRR is greater than the project's cost of capital, the project will add value for the company. [E]

Nevertheless, these indicators are good for private investments and services but they are not very appropriated to our case, as we are talking about a public service where the most important to take into account is the social benefit of the service rather than its financial results. Therefore, we will analyze the investment viability with a coverage system, it means, comparing the part of the expenses that are covered by the incomes and the needed subvention by the Public Administrations every year time.

Because high speed railway in the Czech Republic is a social need (as we analyzed in the second chapter) we can afford a negative financial result. However, which is the maximum permitted negative result?

Most of the public transport services consider a result acceptable if the coverage is over the 50%. This value seems quite low, as it means that even if the incomes are only half of the total expenses, the result is considered as good. However, in most of the cases, the main part of the incomes come from the transportation fares, so that obtaining a higher coverage means having to increase the prices of the service. This could be counterproductive, as the prices are fixed by the market, existing equilibrium between offer and demand. Thus, increasing the service fares does not necessarily mean to obtain more benefits, as the demand may decay and, therefore, the incomes.

The conclusion of all this is that public transport services are deficit systems and the Public Administrations must give subsides to the operator companies in order to cover the deficit. The Administration must assume these social costs in order to promote the public transport; otherwise, the fares of the public transport would be much higher and, consequently, their use would decay in favor of the private transport, what would suppose a greater social cost.

For the analysis, we will only consider the operator benefits, it means, the high speed railway constructor and exploitation company, excluding the social benefits and its externalities. Moreover, for the operator benefits we have only taken into account the ticket issuing, excluding the advertisement incomes, remaining in a safer position.

The construction investment has been taken from the figure 6.3 and proportionally distributed in the two main construction stages (see figure 4.13) starting in 2012, this is, the first stage from 2012 to 2016 and the second stage from 2016 to 2020, considering the third stage included in the second one. The whole time one refers only to the Czech Republic's territory.

We have assumed that the high speed service would start in 2016, though it would not be totally implemented until 2020 (the totally of the service would be implemented probably after 2020, however we consider this date as a simplification). Therefore, the exploitation costs and the incomes for the first 4 years of service (2016 – 2020) have been considered as half of the estimated in the figure 6.7, being considered them all after 2020. In addition, we have considered that the demand rate remains constant during the whole timeframe of the project.

With all these remarks, the obtained results for the first 30 years of service are shown next:

YEAR	Accumulated values in Million €				Coverage
	Construction costs	Exploitation costs	Total costs	Total income	(%)
2016	4.500	113	4.613	173	4
2017	6.000	226	6.226	345	6
2018	7.500	339	7.839	518	7
2019	9.000	452	9.452	690	7
2020	10.500	678	11.178	1.035	9
2021	10.500	904	11.404	1.380	12
2022	10.500	1.130	11.630	1.725	15
2023	10.500	1.356	11.856	2.070	17
2024	10.500	1.582	12.082	2.415	20
2025	10.500	1.808	12.308	2.760	22
2026	10.500	2.034	12.534	3.105	25
2027	10.500	2.260	12.760	3.450	27
2028	10.500	2.486	12.986	3.795	29
2029	10.500	2.712	13.212	4.140	31
2030	10.500	2.938	13.438	4.485	33
2031	10.500	3.164	13.664	4.830	35
2032	10.500	3.390	13.890	5.175	37
2033	10.500	3.616	14.116	5.520	39
2034	10.500	3.842	14.342	5.865	41
2035	10.500	4.068	14.568	6.210	43
2036	10.500	4.294	14.794	6.555	44
2037	10.500	4.520	15.020	6.900	46
2038	10.500	4.746	15.246	7.245	48
2039	10.500	4.972	15.472	7.590	49
2040	10.500	5.198	15.698	7.935	51
2041	10.500	5.424	15.924	8.280	52
2042	10.500	5.650	16.150	8.625	53
2043	10.500	5.876	16.376	8.970	55
2044	10.500	6.102	16.602	9.315	56
2045	10.500	6.328	16.828	9.660	57

Table 6.9. Estimated coverage of the high speed railway services in the Czech Republic per year. Own elaboration

Note that all the values are accumulated; this means that they consider the values of the previous years. One can see that the coverage of the high speed railway service would be higher every year, with greater improvements after the construction of the infrastructure has finished, in 2020.

The coverage would be about the 50% by 2040, it is, 25 years after its introduction. This is a very good result, as the useful period of the infrastructure is much longer, besides the fact that we are not considering the possible incomes due to advertisements in the trains and stations.

Considering that the Public Administration subsidizes the 50% of the uncovered expenses of the high speed railway service, the constructor and exploitation companies would have to carry out a great investment the first 25 years of its introduction, having a decreasing deficit until 2040, when they would begin having surplus in their financial accounts.

If one analyzes a little bit more the obtained results, extrapolating them and considering that the incomes and expenses remain constant during all the time (this is a very unreal estimation, as the demand, prices and exploitation costs may change considerably through all this period), one can see that we would need 90 years of high speed railway services to obtain a coverage of the 100%. This means that, without the help of the Public Administration, the constructor and exploitation companies would have deficit during 90 years, making it definitely unviable.

7. ENVIRONMENTAL IMPACT ASSESSMENT

In this last chapter of the minor thesis one pretends to expose a very simplified Environmental Impact Assessment (EIA) of the introduction to high speed railway in the Czech Republic.

The construction and exploitation of such a big infrastructure like high speed railway in a whole country cannot be free of important environmental impacts. The environmental impacts that are going to be considered can be classified in the next main groups:

- Occupation and affectation of soil
- Energy consumption
- Pollution
- Noise and vibrations
- Others: risk of accidents, explosions, electrocute and run animals, destruction of cultural and archeological sites, electromagnetic impact…

In the next pages, one will expose all these impacts besides giving some measures to reduce them, considering some preventive measures, as well as corrective and compensatory ones. At all time, one will refer to the impacts due to both the construction of the infrastructure and the exploitation of its services.

7.1. Occupation and affectation of soil

7.1.1. Description of the impact

The occupation of soil is the most visual impact of the infrastructures of such great dimensions like a high speed railway. Because of the high design speed for which the infrastructure is constructed, it needs a very generous layout with as many straight stretches as possible, using big radiuses in the curves (usually over 7.000 m). In addition, the longitudinal slope is limited to 40 ‰, reason why big cuts and embankments need to be done, besides tunnels and bridges.

All these engineering works cause a loss of vegetative cover, accentuating the erosive processes besides supposing a great barrier effect, as the high speed railway not only divides the landscape in two parts, but also models the terrain along its way. In addition, high speed railway must not have any level crossings along the routes so that necessary device has to be used to prevent the entry of persons and animals on the tracks, such as fences, making it even more a physical barrier to the whole environment and its fauna.

The width of the high speed bottom rail plain is about 13,7 m, needing below it the ballast bed with a thickness of 550 mm and a slope of 50% on both sides. Therefore, the minimum width occupation of soil is about 16 m, in those places where neither cuts nor embankments are needed. If they are, also a slope of 50% should be applied, with the consequent increase of the width occupation of soil. Because of this, cuts and embankments should not be over 5 m high in order to reduce the visual impact and the occupation and affectation of soil.

In the next picture one can notice the dimensions of a cut in the terrain to allow the way for a high speed railway line:

Figure 7.1. High speed railway cut in the line Madrid – Valladolid [T]

When the needed cut is too high to be carried out, the perforation of a tunnel or a construction of a false tunnel are good solutions. Tunnels offer much less visual impact in the landscape and a lower occupation of soil, besides avoiding the barrier effect in that part of the railway route. However, their construction is very expensive and need great volumes of concrete, which require a considerable exploitation of quarries with the impact it leads to.

Moreover, the soil extracted from the tunnels has to be placed somewhere. Double track tunnels are designed with a cross-section area of 82 to 95 m^2, while for simple track tunnels the area must be at least of 50 m^2; this means that for every kilometer of tunnel length there will approximately 100.000 m^3 of soil that will have to be extracted and either transported to embankments or deposited in a landfill.

Along the whole construction works of a lineal infrastructure like it is our case, the volume of earthworks must be compensated so that there is neither need of extra input of soil to fill the embankments nor need to transport the surplus earth of cuts and excavations of tunnels to landfills. Thus, in the project phase one has to design the layout of the infrastructure according to it.

When embankments are too high to be carried out, it would be good to construct a bridge. Bridges are not only useful for bridging the gap between the track and the field level, but also because they can cross rivers, ponds and lakes besides allowing the transfer of fauna, roads and other communication channels from one side to another of the tracks.

The construction of bridges is also quite expensive in comparison with earthworks. However, its benefits are much higher and the environmental impact much lower, as their occupation of soil is very small. Actually, bridges can be designed aesthetically in order to reduce their visual impact on the landscape, harmonizing the engineering work with the nature. In addition, travelers going through bridges have a great view over the landscape which makes the trip nicer.

In the next picture one can realize the great dimensions of some high speed railway bridges, in height and in length, and how they allow the transversal communication from one side to another along its length:

Figure 7.2. High speed railway bridge in the line Madrid – Valladolid [T]

Regarding the occupation and affectation of urban spaces, high speed lines are designed to run at lower speeds through them, though there is a minimum speed to be offered. Otherwise going through big cities would suppose a considerable increase of the travel time and a lack of competitiveness. Thus, straight stretches and big radiuses in curves are also needed, making it very difficult to locate the tracks on the surface.

As a result, high speed lines should go under the ground level in most of their way through urban spaces, minimizing their impact on the cities though increasing the construction costs significantly. This is the case of Brno, Ostrava and Plzeň regarding the Czech Republic. Other options are to locate the high speed railway stations at the outskirts of the city, connecting them to the city center with conventional rail lines, avoiding this way the expensive underground constructions. This is the case of Praha, Ústí nad Labem, Pardubice, Olomouc and České Budejovice.

At this point one should comment that all these engineering works occupy much less space when they are in service than in their construction phase. Thus, during the construction stage of the whole infrastructure, extra space is needed to locate the machinery and security elements, affecting more natural and urban space besides interfering in other services.

7.1.2. Measures to reduce the impact

The occupation and affectation of soil is something unavoidable. Nevertheless, there are some measures to reduce the occupation of soil due to the construction of a high speed railway. The main ones have been already explained, such as compensate the earthworks along the route of the high speed line, make cuts and embankments lower than 5 m high and construct bridges and tunnels when necessary to reduce the occupation of soil, as well as locating the tracks underground when going through urban spaces or locating the stations in the outskirts of the city.

Other measures are:

- Join tunnels and viaducts in order to reduce the geomorphologic impact
- Avoid routes through forests areas and natural parks (see fig 4.6 regarding the Czech Republic). If there is the need to cut trees, others should be replanted
- Avoid occupation of high-value farmlands and expropriations as far as possible (see fig 4.7 regarding the Czech Republic)
- Locate rows of trees on both sides of the high speed railway in order to hide the infrastructure on the landscape
- Keep distance from rivers and other fluvial areas
- Make tunnels longer to reduce barriers for fauna and landscape besides constructing underpasses for fauna every few distance
- Reduce the affectation and occupation of soil of other services during all the construction stages

7.2. Energy consumption

7.2.1. Description of the impact

The energy consumption is also a very important impact of high speed railway to be taken into account. For the introduction to high speed railway in the Czech Republic not only we have to consider the energy consumption during its service exploitation but also during its construction.

During the construction works the consumed energy includes all the necessary for the performance of the machinery regarding the construction itself, transport of material, explosives, signaling, lighting devices and others, requiring energy coming from fossil fuels, petrol, gas or electricity, depending on each machine. The major part of the energy consumption in this stage depends on the construction procedures and the efficiency of the machinery.

Regarding the service exploitation, all the transportation modes require energy coming from fossil fuels, petrol, gas, electricity or others, being the energy consumed by high speed railway basically the electricity. One could think that its energy consumption is substantial higher in comparison with conventional electrified railways, as the required commercial speed is much higher and, therefore, the frictional forces to overcome. It should be said that energy consumption is proportional to the cubic power of the speed, meaning that keeping all the factors constant, by doubling the speed, the energy expended becomes eight times greater.

However, high speed energy consumption per transported person is not so high in comparison with conventional railway (considering conventional trains running at a fast speed), as it can be explicated with the next arguments:

- Some properties of high speed trains such as less aerodynamic and mechanical resistance, less weight and higher energetic performance
- Steel wheels on steel rails are smooth surfaces that provide very low friction. Wheels are held by steel ball bearings for this purpose
- Less stops (less accelerations and braking) and higher occupancy rates
- Minor resistance in curves and major coefficient of tunnels due to their bigger cross-sections, more homogeneous profile of velocities, less need to brake in the slopes, higher electrification voltage (less losses) and less time using auxiliary services
- Greater possibilities to carry out an economic driving and the possibility of tapping the energy of the regenerative braking
- Shorter distances and travel times (less time consuming)

Because of these reasons, high speed railway is more efficient not only than conventional railway, but also than all the other transport modes, becoming the transport mode that less energy consumes per person in a given distance. [21]

In the next graphic, a comparison of the energy consumption by transportation mode is shown in order to notice the difference in the order of magnitude and the actual position of high speed railway:

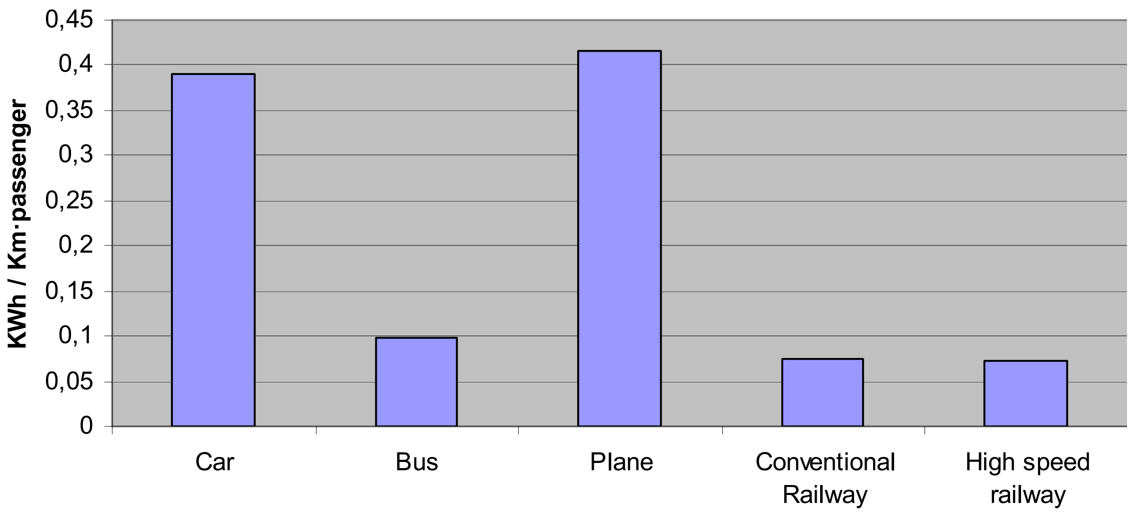


Figure 7.3. Comparison of the energy consumption by transportation mode [21]

As one can see, high speed railway transport is the most efficient one, comparable to bus and conventional railway, while private car and air transport are consume substantially much more energy.

However, regarding high speed railway, there is still a great consumption of electricity that has to be taken into account. This would not be much problem if the generation of the electricity was completely clean. Nevertheless, though the electric consumption is the "cleanest" one, electricity has to be produced, being some part obtained by green sources but the rest by thermal and nuclear power stations, with the pollution that it leads to. In addition, the renewable sources such as wind parks and hydroelectric power stations occupy a lot of terrain and cause visual impact on the landscape.

Moreover, the electricity for high speed railway has to be transported from the generation sources to the high speed tracks with the adequate electric transport systems for very high voltage, provoking a great occupation of soil and a visual impact on the landscape, besides the risk that such great voltage supposes for the whole environment.

7.2.2. Measures to reduce the impact

In order to reduce the energy consumption of the high speed railway service and construction there are several measures that can be carried out, such as:

- Use appropriate construction procedures and efficient machinery to minimize the energy consumed during the construction phase
- Improve the aerodynamic shape of the trains to reduce the air resistance
- Decrease the weight of the trains as far as possible
- Design the new lines with few changes in the commercial speed in order to reduce the number of accelerations and braking
- Reduce the number of trains at the expense of increasing their occupation rate
- Design new lines with even shorter distances and travel times to reduce the consumption time
- Do maintenance works often in order to keep the contact wheel-rail smooth enough to reduce friction

7.3. Pollution

7.3.1. Description of the impact

When talking about pollution one immediately thinks about noxious air emissions. However, high speed railway would not only generate air pollution, but also liquid and solid waste mainly during its construction stage.

Regarding the air pollution, it should be said that, because of the commented efficiency of high speed trains, the pollution they generate due to the energetic consumption is very low, especially if the electric generation comes from green sources. However, during the constructive stage the energy consumed comes from other sources like fossil fuels, petrol and gas, being the emissions considerably higher.

The main parameter for assessing the air pollution is the emission of CO_2. Thus, in the next graphic the CO_2 emissions for the exploitation of the different transportation modes are shown in order to compare them:

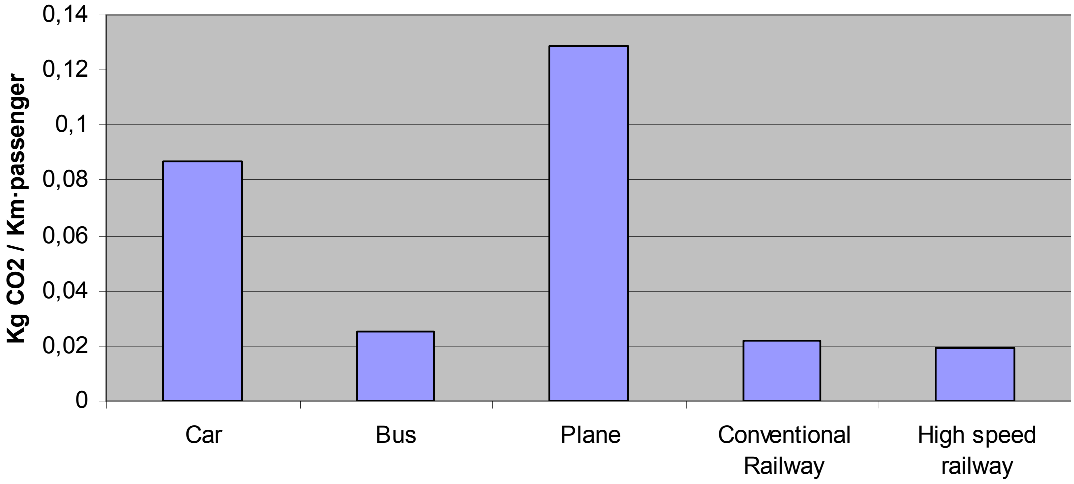


Figure 7.4. Comparison of CO_2 emissions by transportation mode [21]

As one can see, again high speed railway is the most sustainable transportation mode regarding the emissions of CO_2, with emissions under 20 g per passenger · Kilometer. Conventional railway and bus produce slightly more emissions while private car and airplanes are the ones that most contribute to the air pollution.

At this point it should be said that with the introduction to high speed railway in the Czech Republic, traffic of other transportation modes would be reduced and induced to high speed railway, so that air pollution would decrease considerably.

The construction works of high speed railway can cause also some problems regarding liquid pollution. Some oil, petrol and other fossil fuels used for the machinery can be spread into the terrain causing the pollution of surface water and underlying soil and aquifers. Moreover, when constructing tunnels, some underground watercourses may be intercepted, causing filtrations in the tunnel along its way, and polluting it with all the construction materials of the tunnel. In addition, due to the use of explosives, some aquifers and other water spaces can be even destroyed or fulfilled of rocks.

With the construction of high speed cuts and embankments, some canalizations of water and other underground flows may be interfered, making it necessary to divert them through another way or construct a concrete tube to channel them. All these operations dealing with water sources are complicated and risky, as the possibility of polluting the hydrologic systems increases noticeably.

During the construction works solid pollution is also an important aspect to take into account, as the earthworks and tunnel explosions causes a lot of dust, besides the waste caused by the machinery and material used. Moreover, the volume of earthwork that cannot be placed in embankments has to be deposited in landfills, being the most important solid waste of the high speed railway construction.

7.3.2. Measures to reduce the impact

In order to reduce the generation of pollution of the high speed railway construction and exploitation there are some measures that can help, such as:

- Take especial security measures when using explosives for the tunnel excavations in order to prevent vibrations and earth movements
- Waterproofing of installation surfaces
- Avoid constructing in the proximities of watercourses as far as possible, trying not to intercept canalizations and underground flows
- Compensate earthwork volumes. If it is not possible, earth surplus should be deposited in controlled landfills.

7.4. Noise and vibrations

7.4.1. Description of the impact

Noise and vibrations can be considered as very important factors affecting the environment, especially in urban spaces. They take place in all the transportation modes, being their size and influence different for each one. Thus, noise and vibration affects railway stations, airports, housing estates, passengers, pilots, drivers, the surroundings located in close proximity to the transport resources…

Regarding high speed trains, the parameters that characterize their noise are:

- Acoustic signature: the form in which the level of effective sound pressure produced in a point evolves with time. It can be up to 20 dB/s

- Sonorous maximum level: corresponding to the highest stretch of the acoustic signature, specifically to the measured noise when the train is passing by the observation point. It depends on the type of train, its current speed and the distance to the track

- Sonorous equivalent level per train: sonorous constant equivalent level that characterizes the measured sound energy of the train in the observation point during the time of exhibition.

- Directivity: a train does not emit noise in all the directions equally, but there are some differences in the noise emission towards one side and another of the train, as much in the vertical as in the horizontal plane.

Railway noise is discontinuous in the time, as it corresponds to discrete phenomena with a determined frequency. This makes it more unbearable for most of the people.

It has to be said that due to the medically known adverse effects of noise on humans, which can lead to chronic disorders, the internal and external noise of high speed railway trains are treated with very strict standards, like the standard UIC 133 and the Decree of the Ministry of Health, which suggests to keep the value of noise in below the range of 65 to 75 dB. [14]

Because of this, high speed railway must be designed to produce the lowest possible levels of noise outside and inside the vehicles, in order to affect as few as possible the environment and people on board. Dissemination of ambient noise is usually prevented by building noise barriers while the spread of the internal noise is obtained by insulation walls including the use of special materials.

There are three sources of noise that have to be treated independently:

- Rolling noise: coming from the contact wheel-rail. It is the main one
- Driving noise: coming from the vehicle itself due to its springs, joints, electrical systems, engine, brakes, chassis…
- Aerodynamic noise: due to the aerodynamic resistance of the car chassis and the collector (pantograph). It appears in speeds over 280 Km/h

Rolling and driving noise can be successfully reduced with protection walls, but noise coming from the collector is more difficult to be reduced.

In the next picture it is shown a high speed line going through an urban area with noise protection walls:

Figure 7.5. Noise protection walls in an urban space [U]

At this point one should say that freight trains are much noisier than passenger trains, even if they are running through high speed lines, as they are much heavier and, consequently, their rolling noise is higher, as well as their driving noise. Nevertheless, as their speeds are significantly lower, they do not generate aerodynamic noise, being it easier to reduce their noise spread in urban areas with protection walls.

High speed trains, as conventional trains, not only generate noise but also they transmit vibrations through the rail superstructure, ground and buildings in the surroundings due to their contact wheel-rail. Vibrations can be really annoying for people besides originating important damages to the buildings, depending on their frequency. Base-plates located between the rails and sleepers can contribute significantly to reduce the vibration caused by high speed trains.

7.4.2. Measures to reduce the impact

High speed railway noise and vibrations can be reduced by:

- Better aerodynamic shape of the car chassis to reduce the aerodynamic resistance
- Better geometric quality of rails and wheels to reduce rolling noise
- Shorter vehicles running 2 or 3 times faster, reducing the exposure time
- Construct new lines at a minimum distance of 250 m from populated areas
- Locate high speed railway lines underground when going through urban spaces to avoid the noise spread and locate high speed stations in the outskirts of the city (as it would be the case of Praha)
- Collocation of noise protection walls in the urban corridors
- Construction of tunnels and false tunnels to avoid the noise spread in urban areas
- Planting of trees along both sides of the railway corridors to reduce the noise spread in natural areas
- Location of base-plates between rails and sleepers to absorb vibrations
- Use of more flexible materials in the structure to reduce vibrations
- Use of rubber and other noise reducer materials along the high speed rails

7.5. Other impacts

7.5.1. Description of the impacts

There are other less frequent impacts that should be taken into account, such as:

- Risk of accidents
- Risk of explosions inside tunnels
- Destruction of cultural and archeological sites
- Risk of running and electrocuting animals

- Risk of electromagnetic impacts on people and animals, resulting on disturbances in the production of hormones and proteins, affecting the immune system and causing cancer and leukemia

7.5.2. Measures to reduce the impacts

The measures to reduce the before exposed impacts are:

- Investment in security systems in the whole infrastructure
- Proper ventilation of tunnels and use of especial security and signaling systems inside them
- Careful election of the high speed route, avoiding possible cultural and archeological sites founded during excavations
- Protection and isolation of the electrification system along the line to prevent people and animals to be electrocuted
- Total fencing of tracks to avoid mishaps with animals
- Emplacement of high speed railway as far away as possible from population centers without profit on it to avoid possible electromagnetic impacts

8. CONCLUSIONS

From the study of the introduction to high speed railway services in the Czech Republic one can draw several conclusions, which are going to be shown in the following pages.

After the Czech Republic's accession to the European Union, railway transport lost one major advantage over road transport: the ability to cross international borders relatively quickly. Meanwhile, the development of a modern motorway network in the Czech Republic is being successful and builds on the European network, a majority of trucks from the Balkans, Austria, Slovakia and Poland go solely through the Czech territory causing unprecedented environmental degradation, frequent environmental accidents and other problems. This makes us think about the need to change the modal transport distribution to achieve a more sustainable way of the Czech development.

The introduction to high speed railway in the Czech Republic would offer many social benefits in comparison with other transportation modes, as we have studied, like a reduction of pollution and CO_2 emissions, better energy consumption efficiency, more capacity for the same territory occupation, reduction of traffic levels and many other externalities of the transportation systems. In addition, high speed railway would draw peripheral regions closer to the EU's geographic, political and economic centre, being especially crucial for the Czech Republic and peripheral regions in Eastern Europe where the main impetus for development will have to come via political initiative rather than existing economic demand.

Studies show that high speed links maximize profitability in medium distance travels, between 200 and 500 Km, requiring large population density at either end, high existing market demand based on current and projected traffic flows and journey times under 3 or 4 hours duration, beyond which they can no longer compete successfully with airlines for business passengers. This is especially interesting for the Czech Republic, because of its medium territory extension and the market distribution based on its strategic situation in Central Europe. Moreover, the Czech Republic has a well distributed population throughout all its territory with one of the densest conventional railway system in Europe, making it ideal to introduce high speed corridors along the most populated areas, establishing connections with the conventional rail lines in its stations.

The effect of high speed railway would be to increase the flow of national and international passenger traffic bringing a visible and direct benefit to the increased mobility of the Czechs and Europeans, even if the majority of those still serve the domestic markets. Moreover, development of high speed railway offers intriguing possibilities for successful commercial application of advanced technologies. Instead of traditional neglect of conventional railway, high speed rail can help the European Union endeavor to maximize the advantages of the Single Market.

As it has been studied in the offer and demand analysis with the creation of a model study zone in Central Europe and assuming the main proposed parameters of frequency, speed and fares for the high speed railway service, the expected trip distribution by high speed in this zone would be great enough, with approximately 10 million trips in the most demanded lines, reflecting a clear demand of high speed railway, representing about the 30% of the total carried out trips.

The proposed network would have approximately half of its extension made by new constructed lines, while the rest would be built by upgrading the existing rail lines. The route would go through the valleys of the main rivers of the Czech Republic, avoiding the mountainous terrains, connecting with Germany, Austria, Poland and Slovakia. The first construction works should start in 2012 with the connection to the Western European high speed network for then continuing along the national Czech territory in 2016. The whole proposed high speed network should be finalized in 2020, running over 250 Km/h in the new constructed lines and over 200 Km/h in the upgraded ones, with eight stations in the main cities of the Czech Republic and four operating lines connecting Central Europe from West to East and North to South crossing the Czech territory.

It would be necessary to maintain the two railway networks: conventional and high speed railway. This way, the classic rail network will be used for freight and passenger trains for the carriage of urban, suburban, regional and exceptionally long distance connections, while the high speed railway line will be designed for medium and long distance trains carrying passengers and goods. Freight transport going through high speed lines would be mostly carried out during night in order to interfere as few as possible with passenger traffic.

High speed railway offers a lot of benefits to the customers in comparison with other land transportation modes that would cause a modal distribution change, as the commercial speed would be much higher and so it would be the safety and the comfort of the service. In comparison with air transport, comfort and safety would be similar, though the commercial speed would be lower. However, high speed service would not need bookings besides its stations would be located in the city centers or in their outskirts but fast connected to the centers, gaining a lot of time and making it much more competitive than air transport for medium distances.

Although the accessibility of the high speed network would be similar than the existing with the conventional railway network, the reduction of travel time and the increase of commercial speed would be much more noticeable. Thus, as we have analyzed in this minor thesis, considering the base point in Praha, the travel times for the trips going to most part of the study region in Central Europe would be reduced over the 40%, achieving reductions over the 60% when traveling to the Western part of the Czech Republic and the closest zones of Germany and Austria, especially where the high speed corridors would be located. The scope of the railway service in less than 2 hours travel time from Praha would reach the whole Czech territory as well as the main foreigner cities close to its frontiers.

Commercial speed would become much higher, as much as the trips include longer stretches of high speed railway corridors, like in the Czech Republic and its closest zones of Germany and Austria, where the gain in commercial speed would be even greater than 125% with respect to the current rail speeds.

This way, high speed railway would gain traffic from all the other transportation modes, especially from inter-regional bus and conventional rail transport through the Czech Republic and Central Europe. In addition, it would replace some continental flights across Central Europe, freeing the air transport capacity for long-distance and intercontinental flights.

As it has been studied in the economic analysis, the construction of high speed railway in the Czech Republic would need a big investment, though it would suppose less expense than the construction and maintenance of motorways during the next eight years. Considering the income due to ticket issuing and neglecting income coming from other sources like advertisements, with an average fare of 10€ / 100 Km of service the expected income would be a 50% greater than the maintenance and operation expenses Thus coverage of the service would reach the 50% of the total costs in 25 years time, making it a viable investment. The rest would be subsidized by the Public Administration, as it is a social cost of the public transport.

Moreover, the introduction to high speed railway services in the Czech Republic would cause other social drawbacks and externalities besides the environmental impacts that should be considered during the study phase, its construction and its exploitation, like the soil occupation and affectation, the creation of a landscape barrier, the pollution emission, the great energy consumption, the noise spread and other impacts and risks that should be assumed.

Nevertheless, the investment viability and all the social and customer benefits derived from the introduction to high speed railway in the Czech Republic and its connections with the neighboring countries are enough to justify its construction and operation and, hopefully, to begin a new era in the transportation system in Central and Eastern Europe.

9. REFERENCES

Sources

[1] Conference SUDOP 2007. *High Speed Railway Transport in the World and in the Czech Republic.* Hotel Olšanka Kongress Centrum, 14-15, Prague, Czech Republic. November 2007

[2] ROSS J.F.L.: *High-Speed Rail: Catalyst for European Integration*. Journal of Common Market Studies, p. 191-213, Vol. 32, No. 2, June 1994

[3] Railisa – *Rail Information System and Analysis*, UIC Statistics Database, International Union of Railways, Paris

[4] INTRAPLAN-IM-TRANS-INRETS, *Étude Trafic Passagers 2010-2020*, March 2003. München-Arcueil

[5] *High Speed Trains in Europe*. Community of European Railways, Brussels, 2002

[6] Ministry of Transport of the Czech Republic. Transport statistics

[7] KÖRNER, Milan. *High speed rail transport and its relation to population and economic performance of regions*. SUDOP 2007

[8] COUTO, Antonio & GRAHAM, Daniel J. *The impact of high-speed technology on railway demand.* Springer Netherlands, p. 111-128, Vol. 35, No. 2, January 2008

[9] ABRAHAM, John K. *Mode split.* Wayne State University handout.

[10] NEJEZCHLEB, Mojmir. *Preparation for the construction of high-speed railway lines in the Czech Republic*. The Railway Infrastructure Administration. November 2007

[11] KUŠNÍR, Henry*. Costs and benefits of broadband services in the Czech Republic*. Ministry of Transport. SUDOP 2007.

[12] BOHUMIL, Kubat and TÝFA, Lukas. *Relationship between upgrading railway lines and construction of high-speed lines in the Czech Republic*. SUDOP 2007

[13] LÓPEZ PITA, Andrés. *Infraestructuras ferroviarias*. Edicions UPC, 2006. ISBN 978-84-8301-877-4.

[14] PALÍK, František. *Progressive solution of introduction of high speed railway and its vehicles in the Czech Republic.* University of West Bohemia Pilsen. Association of high-speed rail transport. SUDOP 2007

[15] Economic Commission for Europe Inland Transport Committee*. European Agreement on Main International Railway lines (AGC)*. Genova, 31 May 1985.

[16] Situation and Prospective Report: Soil. Ministry of Agriculture Prague, August 1996

[17] REZEK, *Michal from "FSC Working Group Czech Republic" and DUHA, Hnuti from "Friends of the Earth Czech Republic".* Forests of the Czech Republic*. August 2006*

[18] Ministry of Agriculture of the Czech Republic. April 2009

[19] COUTHARD, Iwan, VAN COTTHEM, Alain and HICK, Servais. Engineering Geology for Infrastructure Planning in Europe. Springer Berlin, p. 475-484, Vol. 104/2004, ISBN 978-3-540-21075-7. April 2004.

[20] Ministry of Foreign Affairs of the Czech Republic

[21] GARCÍA Álvarez, Alberto. *Consumo de energía y emisiones del tren de alta velocidad en comparación con otros modos.* Anales de Mecánica y electricidad, Vol. 84, Fasc. 5. September – October 2007.

Web sites consulted

[A] Railway characteristics in the Czech Republic:
http://www.czech.cz/en/czech-republic/transport/railway-characteristics?i=
[B] Pendolino: www.scpendolino.cz
[C] SUDOP: www.sudop.cz
[D] Transport statistics of the Czech Republic: http://www.sydos.cz
[E] Wikipedia: http://www.wikipedia.org
[F] České Dráhy: http://www.cd.cz/
[G] Jízdný řády: http://www.idos.cz
[H] Deutsche Bahn: http://www.db.de
[I] Cad Forum: www.cadforum.cz
[J] Institute of Transportation Engineers: www.ite.org
[K] Index Mundi: http://indexmundi.com/map/
[L] Transportation Engineering:
http://www.cdeep.iitb.ac.in/nptel/Civil%20Engineering/Transportation%20Engg%20I/CourseObjective.html
[M] Topographic map of the Czech Republic:
http://maps.grida.no/go/graphic/czech_republic_topographic_map
[N] Geologic map of the Czech Republic:
http://departments.fsv.cvut.cz/k135/wwwold/webkurzy/obrazky/mapa.jpg
[O] Land uses map of the Czech Republic:
http://www.econ.muni.cz/~maryas/ISKRES/
[P] Geology of the Czech Republic:
http://www.showcaves.com/english/cz/index.html
[Q] Climatology of the Czech Republic:
http://www.chmi.cz/meteo/ok/infklime.html
[R] National Union of Rail, Maritime and Transport Workers
http://www.rmtbristol.org.uk/
[S] Ferropedia: http://ferrocarriles.wikia.com/
[T] Urbanity: www.urbanity.es
[U] Vida Digital: www.vidadigitalradio.com/

Software used

AutoCAD 2007
Google Earth
MatLab 7.0
Microsoft Office 2003