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Erasing Borders

European Rail Passenger Potential

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By

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in partial fulfilment of the requirements for the degree of

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Summary

1. *Introduction*

With the decrease of border controls and the provision of free movement of people, trade and services in the EU, the possibilities for international train travel seem to have decreased paradoxically. The European institutions (parliament and commission) are pushing for an increase cooperation between train operating companies, which are protective and afraid of losing market to competition. This report tries to provide an insight in the size of the market given that cooperation is initiated and barriers are taken down. The main research question:

Where and how in Europe does, currently and in 2030, the biggest potential of international train passenger travel exist, based on passenger-trip potential (demand) and seating capacity potential (supply)?

Of all the different actors in this problem, nobody is willing or able to take ownership of it. The users are unable, the train operating companies (TOCs) and infrastructure managers (IM) are not willing and institutional stakeholders have different priorities. This leaves the provision of solutions to the external stakeholders, NGOs and public interest groups like Train2EU, with as goal to promote and increase European international train travel, ultimately Erasing Borders!

The scope is defined as the Schengen area with in addition UK and Ireland and 14 external cities, like Moscow and Istanbul. Countries without a rail connection are left out. Two time frames are included in the report, the current potential situation (2015) and the future (2030) with 3 scenarios (decline/divergence, status quo and growth/integration). These scenarios are based on policies of the EU (European Commission, 2012a). Potential for this report denotes the difference between actual current situation and the modelled reality in the research.

2. *Methodology*

The report and research have been structure to the flowchart depicted in Figure 0.1. This provides also the framework for the assessment of network potentials. Four major parts can be distinguished, input: system of interest, Passenger-trip potential (demand of travelling passengers), Seating capacity potential (supply of connections and unserved demand) and preliminary core network to capture the potential.

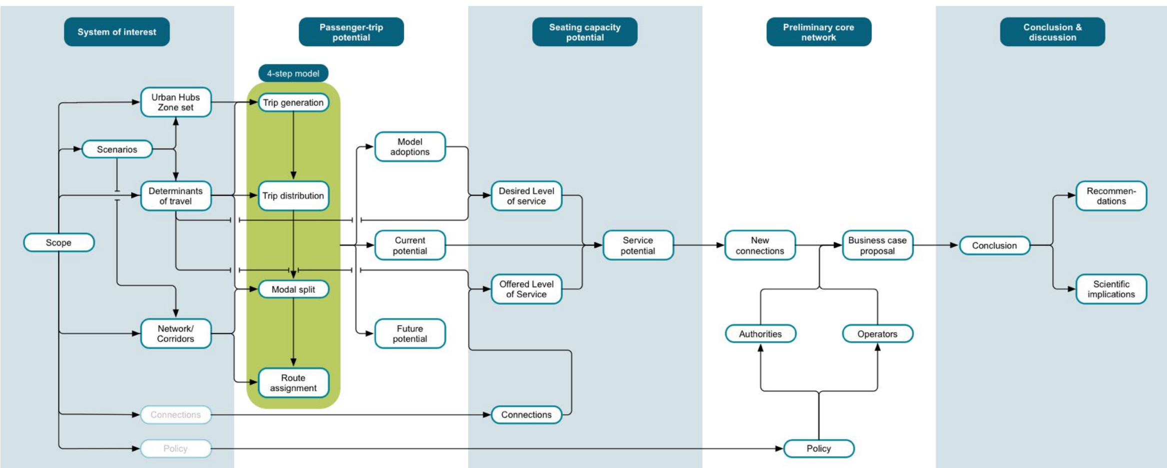

Figure 0.1 – Structure of the research

As *input* to the models a set of 125 cities is selected based on their performance on population, metropolitan GDP and percentage of high educated people, these are the so called Urban Hubs. The selection of this separate set is necessary to limit the number of OD-pairs (scope), and unify the meaning of cities (statistic units and data integrity) and still select the most important/relevant cities. Additionally, several determinants of travel are defined for choice making, based on literature. These are GDP/Capita and population for trip generation; city production, perceived barriers and distance for trip distribution; travel time (door-to-door) sensitivity for mode choice and shortest travel time for route choice. For service selection the following indicators are selected: frequency, transfers, travel time performance, service level & seating capacity. The used network is modelled because insufficient data is available to use the real infrastructure data within the scope. 3 networks and 5 modes are defined, road (car and bus), rail (hst and conventional), and air (including additional waiting time at airports). Both airports and rail need access and egress to/from the infrastructure entry point. The model is built on constructing a direct link graph between nodes (urban hubs and, for proper route length/travel time approximation, 50 additional network nodes). Network distance and travel time are determined by relation great circle distance detour factor and average speed (both mode specific). This network approach provides a model fit of 98% on route lenghth and 85% on door-to-door travel time. The network is supplemented with city-airport links, for access/egress of airports, as well as ferry connections for complementing the road and rail networks without fixed links.

The *passenger-trip potential* uses the traditional 4-step transport model (Ortúzar & Willumsen, 2011). Trip generation assumes that the yearly production and attraction of a city are symmetrical and equal. In addition to the 125 cities, additional zones (countries), to model the areas outside the selected metropolitan areas, are necessary. Trip generation is based on the willingness to travel *t*, stating that the average European undertakes 9 times/year a long-distance tour (Goeverden & van Arem, 2010). The ratio between the mean GDP/capita of all Urban Hubs and the individual city GDP/Capita determines the average *t* for each inhabitant of a city, multiplying with the population will result in the production. Trip distribution, distributes the production over the cities and external zones. This is based on the basic gravity model, being very suitable for the task, easy extendable and does have the best fit for modelling exercises (Doganis, 2010). It is easily expendable (Anderson & Van Wincoop, 2003) with additional barriers, being: country borders, language borders, Schengen (trade) borders and federalism. All barriers directly affect the distance between OD-pairs.

In this model there is no simultaneous distribution and mode choice, so both are perfomed independently. Calculations is based on Random Regret Minimisation (Chorus, Arentze, & Timmermans, 2008), instead of the more common Random Utility Maximisation. This choice is based mainly on the fact that RRM also takes into account the performance of other alternatives to determine the regret avoided by choosing an alternative. Given a more suitable modelling technique for the reaction of actors, users, to the differences in door-to-door travel time. Additionally, RRM has a better fit on observed market share and adherence to reality on shorter distances in the report.

Route assignment is done based on Dijkstra Shortest Path algorithm and all-or-nothing assignment to the route with lowest travel time. For the future scenarios all 4 steps are repeated on scenario specific evolved networks. For decline and growth, different willingness to travel and barrier values apply. Decline results in lower willingness to travel and higher barriers, growth the opposite.

For the *seating capacity potential,* a method is used where the different indicators are assessed relative to the desired level of service. The performance is translated into the effective offered seats on the international links. The focus for services is on international links, this creates a clear interface for collection of service data. The indicator data for service is loaded on the network to asses link performance. For frequency the airline concept of average displaced schedule is used, providing an indication to what extent a passenger should adjust the schedule to use a connection, 15 minutes is acceptable. Transfers are only allowed when the connection is optimised, better than the travel time plus the average waiting time (half headway) for each transfer. Service level is a quality indicator, 5 categories in an attempt to lift the services from their marketing infused descriptions, only HST, IC+ and IC are long-distance, night train and ferries are different markets and regional services are unacceptable for long-distance. Travel time performance is assessed based on the expectations of the infrastructure speeds (passenger-trip potential), every indicator is simultaneous assessed to adjust the offered seating capacity, which is determined by the nominal (notional) frequency based on a 14 hour operating day and average trainset running the service.

Preliminary core network is determined based on the inquiry of the applicable policies (European legislation packages). Connections are based on the existing and future relations (air, TEN-T corridors) as well as the interconnectivity (Takebayashi, 2016) and network effect. This provides input on the proposal for 12 new cross European connections. Additionally network hierarchy is addressed and the opportunity gap, not captured by incumbent TOCs.

3. *Potential, results*

The results are based on the selection of only 125 cities. Adoption towards the complete European market would result in a total of 1,4 billion trips vs 1,1 billion trips in the current actual situation (Amadeus, 2013), This is a potential bigger market for the current situation of 22% and an incredible potential to growth in the future. The share of international travel is 25% of 1,4 billion trips, (currently 6% of 1,1 billion trips), most of the growth would be seen on the international segments. The modal split in the current potential situation results in 43% for rail products. For both the current potential and the future potential the results in modal split remarkable as presented in Figure 0.2. The overall perception that the bus will be a great competitor to the rail industry is unfounded. Travel times of bus are very uncompetitive that only with extremely low prices the market share can be improved. Additionally, the modal split would suggest an incredible amount of trips by plane. The plane does capture a large share of the market, the market itself is however smaller, because of the avoidance of longer distances. The incredible shift from air to rail is resulting from the network effect of new connecting HST infrastructure. This would result in the reduction of 28 million tonnes CO2, yearly, even though the amount of pax & paxkm is higher than in 2015.

In Figure 0.3 the route assignment for 2015 and 2030(int) are shown in a single map with the implications on the network loading. The growth of 2030 will shift the centre of gravity towards North and Eastern Europe. Links lower than 250.000 trips annually are not shown, these are unlikely to be viable in the current economics of railway operations.

Results for the service, supply, potential show a discrepancy between the potential travel demand and provided services of 58,6 million trips almost 60% of the total international demand. taken into account the level of service. Main links of interest are those with an annual unserved demand of one million trips or higher, links of 500.000 unserved trips can be of interest given the current economics of railway operations.

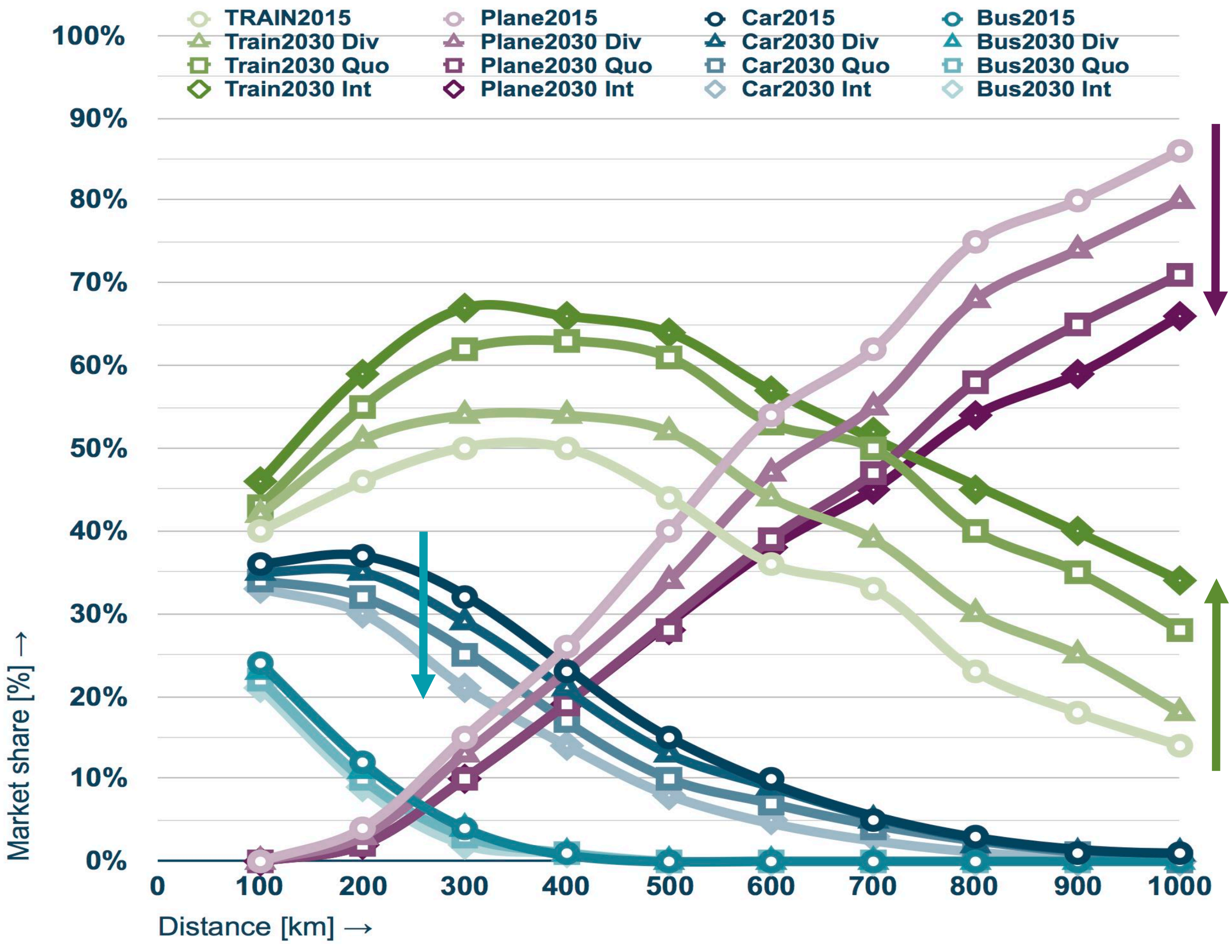

Figure 0.2 – Modal split in different scenarios, (Div=divergence decline, Status Quo, Int=Integration growth).

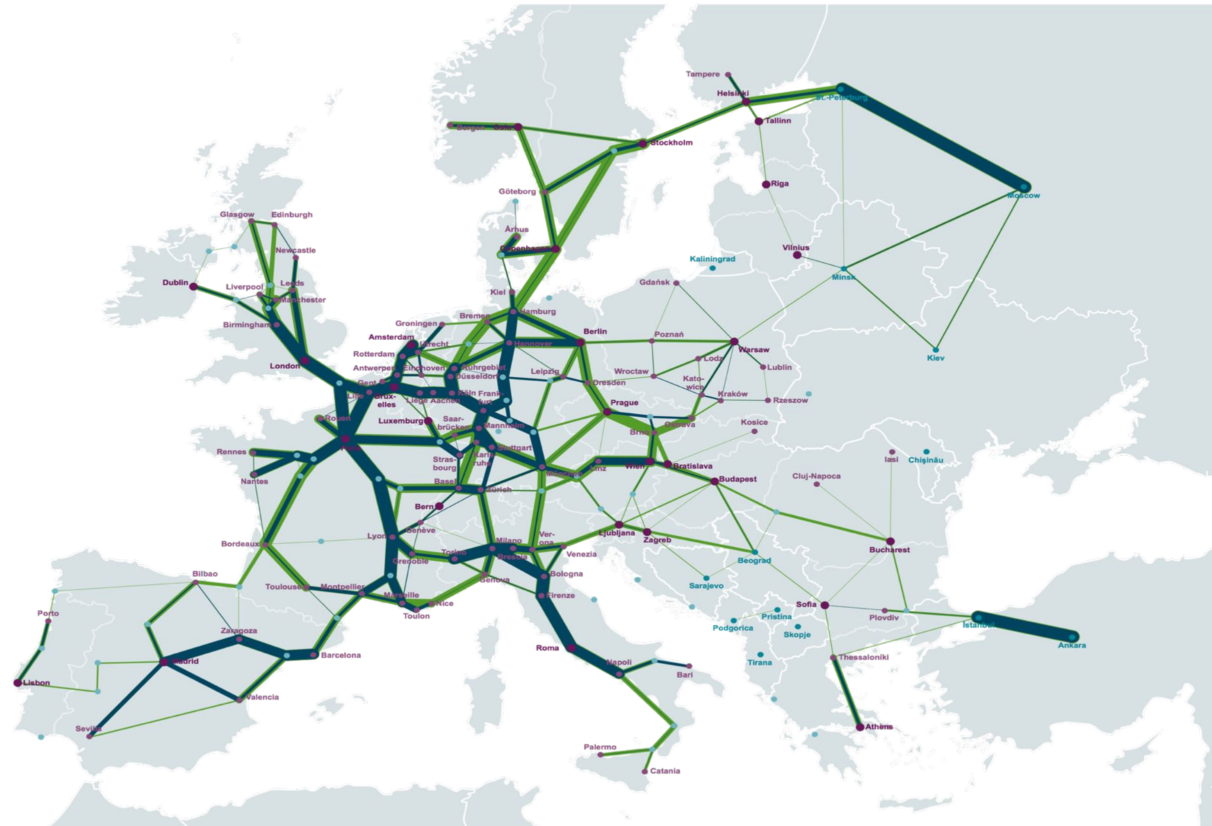

Figure 0.3 – Network loading of potential, 2015 (Blue), 2030 Integration (Green)

4. *Implications on market*

Based on passenger trip potential and the gaps in effectively offered seats a network of connections is proposed as a coherent solution. Based on the assessments in trip potential and seating capacity, 12 new European connections are proposed. The new connections should adhere to the minimal desirable level of service in order to materialise the unserved demand. The actual preliminary core network of the European railway market depends on the complete business case of new connections. The market consists of the passengers willing to travel with connections that are competitive on multiple levels, not only travel time, but also frequency, travel time performance, findability and transparency. It is no longer about the characteristics of the connections on themselves, but the complete user experience.

5. *Conclusion highlights*

Based on the methodology, results and implications to the market in this report the following points have been found as main findings.

- Significant observation of barriers on trip distribution, barriers defined: Country, Language, Free trade area (Schengen) and Federalism.
- Potential amount of trips, passenger-trip potential, is according to the model 240 million higher (22%) compared to the current actual situation. Increasing international share of trips from 6% currently to 25% as potential.
- Maximum growth scenario to 2030, a potential trip growth to 2,6 billion (+91%) and increase of international share to 37%. On paxkm development would be +120% and an international paxkm share of 50%.
- Maximum growth scenario would provide potential reduction in CO2-emmission of 28 million tonnes (7,5 coal-fired power plants) as result of train-plane shift. Shift result of network effects on complementary high speed infrastructure networks across Europe.
- Level of service indicators (frequency, transfers, travel time performance, service level), translated into effectively offered seats. Reduction of -40% as result low insufficient level of service, 58,6 million trips unserved on international links.
- Effective framework for assessing the potential of existing infrastructure/transport networks with created or easily removable (operational) barriers.

6. *Discussion*

Although the research has been performed with great integrity, as a result of limits in scope, time and data availability some considerations should be made about the interpretation of the results. These are the main points of discussion and recommendations of this research.

- Data. The main challenge in the research, especially reliable, consistent, openly accessible data. This necessitated some aggregations.
- Single mode choice attribute. Travel time is a good indicator for mode choice, although preference in modern transport models is to include more attributes, RRM performs well.
- Nesting effects. Modes should be significantly different to prevent generating nesting effects, especially with HST running on conventional track, restrictions have been added.

- Long-distance travel. The scope of only long distance traffic eliminates all regional traffic. It also resulted in to the aggregation of some metropolitan regions.
- Complete elimination of areas and population and other attributes outside the 125 cities in the scope. No tourist travel to rural areas, which can account for a significant flow.
- GDP/Capita and avg. willingness to travel (*t*) as main indicators for trip. Also using the willingness to travel for non-EU countries. Justified by adoption to ratio of GDP.

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Preface

This thesis investigates the possibilities of the European passenger rail market when perceived barriers and protectionism is taken out. Reflecting the possible result that would and could be when the visions of so many will become true. As such this thesis is my personal Magnum Opus, for now at least, to conclude the MSc Transport Infrastructure and Logistics of the Delft University of Technology.

I would like to thank Royal HaskoningDHV and Train2EU for providing me this wonderful opportunity. As part of my duties as Commissioner Activities & Career of the board of Dispuut Verkeer (2015-I & 2015-II), I had the opportunity to meet Royal HaskoningDHV during one of the Friday afternoon seminars. This started a chain of opportunities resulting in the completion of this report. Starting out with a very simple and short question, from that question this thesis was worked into a research proposal. Only based on the proposal some, thought the topic was bordering the impossible and strongly discouraged going forward with it. Dedication or maybe utter desperation interfered with this well meant advise, a determination to defy preconceptions of things being impossible. Although it may look like so many thesis reports, the content at least is unique, combining techniques from many fields in a way they never have been brought together.

Furthermore, I would like to thank personally, my committee:

- Bert van Wee being in being so enthusiastic about the opportunities from the start.
- Wijnand Veeneman for creating time although being so busy.
- Oded Cats, for his incredibly detailed, enthousiastic and constructive way of feedback and showing me even more opportunities.
- Hans Marinus for always being critical and asking the difficult out-of-the-box questions and having time whenever needed.

As well as:

- Sylvia Korpershoek and Marije Poel for keeping track of the vision of Train2EU and introducing me into the corporate world of RHDHV.
- The board of Train2EU for trusting me with the task of showing the European railway market where their potential is, as well as introducing me to European parliament members and putting me front-row at the TEN-T days.

Many thanks to all others who supported me in any way, accepted me whenever, helped me with whatever and especially inspired me. “If you can dream it, you can do it.”

Barth Donners,

August 2016

Figure 0.1 – Advertisement of the Orient Express, Winter timetable 1888-'89, (Public domain).

1 Introduction

"The train is due in at 6:55 and one has to cross the Bosporus and catch
the Simplon Orient Express the other side at nine o'clock.
If there is an hour or two of delay we shall miss the connection."

Murder on the Orient Express, Agatha Christie (1934).

Train travel in Europe still has some romance to it, remembering times gone by when trains were the portal to new exotic worlds. The train being the first mean of mass transportation and opening continents to people. Providing new possibilities to many, to explore and to trade in new unknown markets. Times have changed nevertheless, maybe even most noticeable when reading the romanticized view of the world in Christie's book, starting with an early winter morning in Syria, Aleppo to take the luxurious Taurus Express to Istanbul. Something unimaginable today, unfortunately.

Although romanticized and many people having fond memories of the past, challenges of the future are ahead. The relative ease of which people could take trains in the past across the European continent has somehow perceptually diminished and made train travel irrelevant on long-distances. Cooperative networks between the European national train operating companies since the 1950's consisting of Trans Europe Express (TEE) and later EuroCity (EC) services have decreased to single trains daily, joint-ventures and joint-operating companies independently managed. The orient express being one of the most iconic international trains in history, providing a daily direct train between Paris Gare de l'Est to Istanbul Sirkeci in 3 days (71h 10m). The connection by train has been speed up since 1888 taking now 'only' 47h and 25 minutes however with a minimum of 5 transfers. With the decrease of border controls and the provision of free movement of people, trade and services, the possibilities for international train travel seem to have decreased paradoxically. The European institutions (parliament and commission) are pushing for an increase in dwindled cooperation between train operating companies. However, all are protective and afraid of losing market to competition. This report tries to provide an insight in the size of the market given the fact that one would cooperate and barriers are taken down.

In order to tackle the problem, the introduction will provide the outline for this report. First the different stakeholders/actors for the problem are discussed. This is followed by defining and pinpointing the problem and sub-problems. To cope with the developed problem questions, a structure is provided and the introduction is concluded with the methodology used for providing answers, in a chapter by chapter overview of the problems.

1.1. Stakeholders & actors

This first section identifies the different stakeholders and actors involved in the report and research. It provides a limited set of the affected actors, involved in the problems and opportunities of this report and is not a complete stakeholder analysis in itself and should not be interpreted in this way. Identification of individual stakeholders is done based on a categorical approach, grouping individual actors together. The main actors most involved in the problem are the travellers, transport providers/-managers and governmental authorities (institutions) involved in the transport process or policy. This classification holds on high abstraction level and across geographical and political borders. As a result, this distinction is used for the main categorisation. In addition, several external stakeholders are affected by the problem/solution area. A problem owner should be defined in order to get a grip on the possibilities in the solution space.

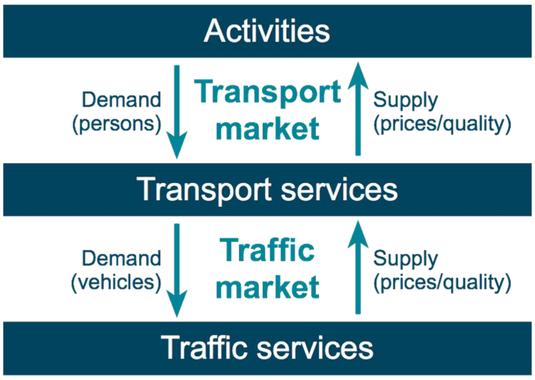


Figure 1.1 – Layer model of the transport system, (van Nes, 2002), *adopted from:* (T.J.H. Schoemaker, Koolstra, & Bovy, 1999).

In the understanding of the stakeholders, the general schematisation of the transport system provides some insight in how stakeholders relate to one another. The generalised form is shown in Figure 1.1. Three different layers are defined, the activities, transport services and traffic services. The activities are the origins or destinations of passengers, the transport services are means of transport and traffic services is infrastructure for the transport. Between the layers, two distinctive markets are defined. Transport market, the competition of different ways of transport and the traffic market of different infrastructure elements. (van Nes, 2002) Based on this the different stakeholders can be organized.

1.1.1. Traveller stakeholders

The users of a system are in general the first stakeholder considered. Not necessarily because they make the policy decision about the services, however they provide their insight after all due to the way of using, or in some cases not using a system, service or product. Placement within the layer model would be on the transport market as demand for transport services, directly influencing the market equilibrium. Travellers as a user base can be divided into more specific groups, based on mode, destination or distance categories.

- Distance: Long/short distance travellers
- Mode: Train/plane/etc. users
- Users: Origin A/Destination B

1.1.2. Transport providers/managerial stakeholders

The service providers are the second stakeholder group directly involved. This can be split between operators and managers as well as into the different modes of travel involved. The operators supply services to the travellers in order to get from A to B. Operators are as a result the transport service layer. Providing the supply in the transport market and the demand of the traffic market. The managers supply infrastructure to the operators to supply their services on and as a result more linked to the authorities. They are as a group the traffic service layer and providing the supply within the traffic market.

- Operators:
    - Train operating companies (TOCs)
    - (Long distance) bus operators
    - Airlines

- Managers
    - (National) Infrastructure managers: providers of infrastructure and traffic management for open access operations
    - Airport authorities
    - (National) Safety authorities

1.1.3. Institutional stakeholders

Resulting from international setting of the problem, transcending the national governing bodies, the main institutional stakeholder would be the European Union, as international organisation, represented with multiple governing bodies. Not directly within the layer model of transport system, the institutional stakeholders could be seen as a skin around the model, affected and toughing all elements in the model. The following list are the directly involved institutional stakeholders.

- European Commission & Council for the European Union: initiating legislators and promoter of Single European Rail Area and Open access operations to stimulate public transport across Europe.
- European Parliament: Democratic representatives of the citizen of the EU.
- National governments (28): responsible for introducing European regulation into national legislation and enforcement of EU directives. In case of TEN-T they are obliged to implement TEN-T policies.
- National parliament (28): national democratic representatives.

1.1.4. External stakeholders

Not directly affected as stakeholders themselves, however indirectly affected due to the policy, by their interests or concerns are the external stakeholders. Although some represent directly affected stakeholders in order to provide a community or platform for discussion. This point of view places the external stakeholders completely outside the layer model, however provides them the opportunity to replace one of the internal stakeholders and look after the interests of one of those stakeholders on their behalf.

- Train2EU: Association with the goal to promote European international train travel.
- Royal HaskoningDHV: Supporter of Train2EU in order to fulfil their corporate social responsibility duties to society.
- Passenger/public interest groups: providing users of the system a unified voice.

1.1.5. Problem ownership

The apparent problem of a perceived lack of cross border rail transport would most evidently be a problem of the user. The user would not be able to take a connection towards a desired destination across the border. However, the desire in general is large enough that alternative modes are found or ultimately alternative destinations, which serve the user with the least regret for not being able to reach the first desire.

This transfers the problem towards the provider of services which does lose potential customer base, not only towards the destination, also on links towards it. Making services of the provider less attractive due to a loss in network effect. Limited experience with network effects for TOCs does however reveal a limited understanding in the potential. The institutional stakeholders are next to transfer problem ownership. Currently the stated stakeholders have different priorities, which are much more focused on technical infrastructural issues then on the actual services provided by (semi-) private operating companies.

This leaves the external stakeholders, NGO's like Train2EU (as well as Natuur&Milieu) and engineering consultants as Royal HaskoningDHV to take up problem ownership. Not necessarily due to the actual personal affected situation, more as a result of the lack of ownership and an idealistic view on the world. Nevertheless, it still is a problem that would be solved for the users of the system and provide opportunities for the operators of this system. The transferred problem owner is also not directly affected by the positive outcomes of the changes in the system.

1.2. Problem definition

The actual problem owner would be the customer itself or the EU as a governing body, as already described in the previous section. However, the problem owner for the research is Train2EU, supported by Royal HaskoningDHV, with the aim of identifying market failures and hence potential for introducing new services in order to erase borders and provide profitable services. The motive of the report is the perceptual lack of international service in Europe.

1.2.1. Objectives of the report

With the increased ease of travel and access to information it should become easier to traverse Europe by train and provide a competitor to (cheap) air travel, focusing on long-distance international relations. The infrastructure is already available and the geological and demographic distribution of Europe would make train more attractive than air travel for passengers. All the decisions made by the European institutes had in mind that the rail market should become a single open market, similarly to the aviation market. The dependency on safety system for rail are different from those for aviation. Rail needs a unification of safety systems first (European Union, 2012), whereas this is dealt with in aviation later via SES and SESAR (European Commission & Eurocontrol, 2011).

The objective of this research in accordance with Train2EU objectives, to provide the travel and seating capacity potential of the truly European passenger rail market, blurring the borders of operations and with the main focus being the customer without losing the market reality out of sight. More specific the long-distance rail travel in competition with air travel. Tough an improvement of the regional international travel is desirable as well, this is not (directly) an objective of this research. This directly provides the two main focus areas of the research, the potential demand and the quality of the connections and the relationship between those two, it also includes the quality of travel information (availability and accessibility).

1.2.2. Research question

The main research question for the research combines both the demand (passenger-trips) as supply (seating capacity). The combination of these two will indicate the existence of potential on which the location and manner of capturing can be based. The main research for the research is:

Where and how in Europe does, currently and in 2030, the biggest potential of international train passenger travel exist, based on passenger-trip potential (demand) and seating capacity potential (supply)?

1.2.3. Research sub-questions

In order to be able to answer the main research question, several sub questions are formulated on the different fields of interests. The answers on these questions will provide a complete picture of the problem and solution space within the scope of the research.

- A What is the system of interest for this research?
  - a What level of aggregation is necessary to provide a clear & detailed outcome?
  - b What are the preferences and characteristics of travellers to make a choice with regard to destination, mode and service?
  - c What scenarios can be used to provide an estimation for 2030?
  - d How are the railway corridors in the European railway network defined?
  - e What connections (trainroutes/-services) are offered?

- B What is the passenger-trip potential, demand, of the European railway market?
  - a How many people will travel between destinations (trip distribution)?
  - b What is the expected modal split between destinations (mode choice)?
  - c How are the different destinations bundled in corridors (route choice)?
  - d How will the amount, modal split and corridors change in the future (2030)?

- C What is the seating capacity potential, supply, of the European railway market?
  - a How can level of service be assessed
  - b What is the level of services offered in the market (current)?
  - c What is the level of services to meet potential demand (desired)?
  - d What is the discrepancy between connections and passenger-trip potential?

- D What is the preliminary core network for the European railway market?
  - a What is the policy-framework for offering international railway services, on an authority and TOC level?
  - b Where are the current and future bottlenecks (market)?
  - c Why are TOCs so reluctant to fulfil the apparent potential (opportunity)?
  - d How would a core network relate to the existing operational reality?
  - e How can this network be realised or made viable?

1.2.4. Time scope

Scope in time is based on the most recent data by Eurostat. This data is captured between 2011 and 2015, the most recent entries are used. Only population data for is Greece lacking, as a result 2009 will be used. The general assumption is made that all retrieved values are valid for the year 2015 as the base for the research. This will provide a single base point in the research and mitigates the necessity to adjust values on individual base. Introduced errors because of this approach are not significant on the aggregate level used for this research.

In addition to the current situation, this research aims at assessing also the potential in future for train travel. The year for prediction is 2030. Predictions for a 15-year time-frame are still able to stay close to reality and many policies and developments that are now implemented do have a time horizon of 15 years. The TEN-T infrastructure improvements plans all have the aim to provide Europe (EU) with a consistent (quality) core network in 2030. In order to make any predictions for the future the three scenarios of the Global Europe 2050 report (European Commission, 2012a) will be used.

1.3. Structure of the report

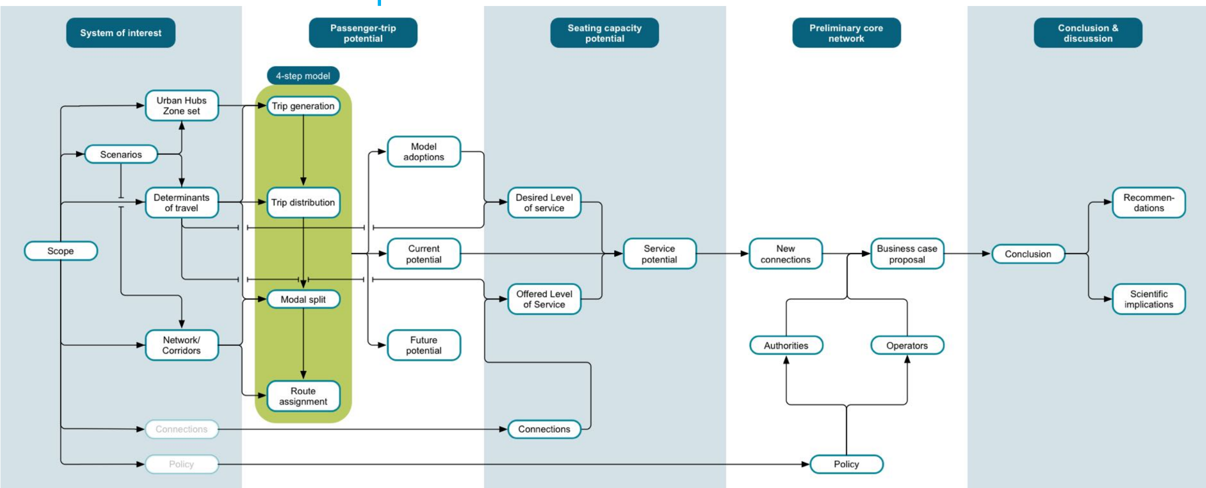


Figure 1.2 – Flow chart of the report, simplified.

Answering the main research question and subsequent sub questions can only be done in a clear way when performed in a structured manner. The overall structure is schematically represented in Figure 1.2. The individual chapters will elaborate further on this schematic to also reveal the more detailed components in the chapters themselves.

The structure of the report is strictly linear, each part provides the input of the next part, there are no feedback loops within the structure of the report. However, the framework of potential assessment, drawn up for this research, shown in Figure 1.3, does allow a feedback between the potential network and passenger willing to travel. The input from network to passengers resembles the service input of different modes into the traditional transport network. The passenger-trip potential (demand) will be used to assess the seating capacity potential, on which the preliminary core network can be build. The feedback towards trips is outside the scope of this research.

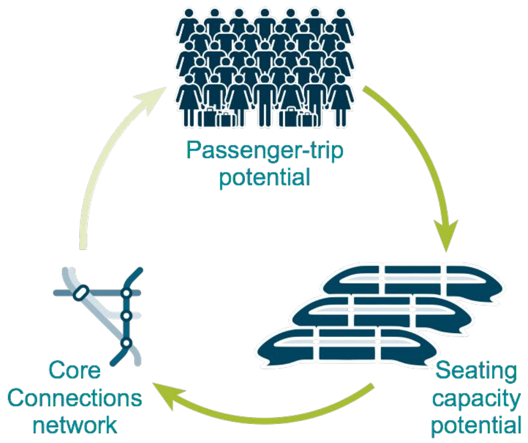


Figure 1.3 – Framework for potential assessment and different report parts, (own adoption).

The report will first set the scene and determine the scope, boundaries and limitations in the system of interest. This chapter (2) will provide all main input for the following chapters and determine the status-quo on which this report is based. In chapter 3 the passenger-trip potential is determined, for both time-frames. The next chapter, 4, will deal with the seating capacity potential, focussing on the provision of connections and physical transport options. The combination between passenger-trip potential and seating capacity potential will be made in chapter 5 and will provide an assessment framework to come to the potential core connection network. These core connections will provide guidance where business cases for train connections are located and how they can be realized. The report will be concluded in the conclusion & discussion, chapter 6, with conclusion, scientific implications and recommendations.

1.4. Methodology of the research

For all the parts in the structure a methodology is used to provide the answer of the questions at hand in the respective part. For each block the methodology is provided in the list below. This section of methodology is actually a summary on the used methods for each part and provides an overview on what can be expected. The main methods are the 4-step transportation model and level of service assessment, based on the literature study and data collection performed in the first stages. For literature the complete list is provided in the references, other resources are included in the list of data sources.

Overall

- System of interest: Literature study
- Passenger-trip potential: 4-step transport model # potential trips
- Seating capacity potential: Level of service assessment # effective seats
- Preliminary core network: Policy review

1.4.1. Passenger-trip potential (4 step-model)

The passenger-trip potential is assessed via the classic transport model, four-step or -stage model (Meyer & Miller, 2000). which will be adjusted to the methods and scope of the research. All steps are strictly separated from each other, no simultaneous choice processing. The implication of this strict separation are explained in chapter 3, at the individual steps.

Step 1: Trip Generation

The trip distribution concentrates on the amount of travellers actually wanting to travel within the given scope. The primary assumptions for this specific research are the symmetrical distribution between cities, production equals attraction, and trip based generation. The input data as well as desired output are on an aggregate level, additionally the long-distance trips modelled are much more point to point oriented compared to urban trips. As a result, a trip based modelling approach is much more suitable then the more advanced tour-based (Timmermans, Arentze, & Joh, 2002). The generation itself is based on production factors like the absolute population of the metropolitan region and GDP/capita within the region. social economic characteristics of the cities. Selection of cities is performed based on similar criteria.

Step 2: Trip Distribution

The trip distribution is filled by the OD-matrices generated with an adjusted gravity model. The standard or basic gravity model (Ortúzar & Willumsen, 2011) only takes into account the attraction of a city and the measure of distance between cities. This is a translation of direct (great-circle) distance with addition of travel “costs”. These additional factors are included by multiplying the great-circle distance with the characteristic parameters. Some of those costs can be directly related to barriers like borders (French, 2015) and languages, or other social economic factors (Salas-Olmedo, García, & Gutiérrez, 2015). The great circle distance is determined by the Haversine equation. Differences in distances due to detours as a result of geographical barriers only apply on a mode level, which should be taken into account in the independent step of mode choice. Distribution is also independent of the offered level of service by the different modes (inelastic demand and no simultaneous mode choice). Additionally, the distribution is symmetric, due to the production equalling the attraction of a city. The inelastic demand, provides the possibility to really assess the potential, from a traditional point of view to the model this could be a limitation because traditionally the goal is to model actual transport behaviour given the service characteristics in place.

The choice for the gravity model is based on the fact that a gravity model is able to provide an incredible accurate estimation of the possible demand potential with limited detailed input. The airline industry (Doganis, 2010) does use Gravity models in a similar way to provide OD-estimations based on limited amount of data, and the focus on long distance travel between bigger OD-pairs then the traditional zones in transport models. According Table 1.1, a gravity model is particular suitable for estimating the impact of growth (future scenarios) and new routes (services/connections). The poor performance on reaction (changes in the offered services) stems from the implied independence of level of service from the potential demand. Table 1.1 also lists all other demand estimation models. Although the table lists the forecast time as relatively high for gravity models, this is mainly dependent on the collection of input data. Gravity models require much more external data compared to the other methods which rely more on historical operational data. Additionally, comparison studies for transport model analogies have shown that the laws of gravity score best to explain transport behaviour (Lenormand, Bassolas, & Ramasco, 2016).

Calibration and validation assessment of the model will be done by the limited amount of international long-distance transport studies available, this includes work by Royal HaskoningDHV and others, (Brietzke, 2015) and (Goeverden, 2007). Additionally, the provided services on optimal routes will be used to assess the actual trips.

		Qualitative methods		Time-series projections			Causal methods	
		Executive judgement	Market research	Annual average growth	Linear trend	Linear w/ moving averages	Regression analysis	Gravity model
Accuracy	Short-term (0-6m)	Good	Good	Fair/good	Fair/good	Good	Good	Good
	Long-term (>6y)	Poor	Poor/fair	Poor	Poor	Poor/fair	Fair	Fair
Suitability for forecasting	Growth	Good	Good	Good	Good	Good	Good	Good
	Reaction	Fair	Good	n.a.	n.a.	n.a.	Good	Poor
	New Routes	Poor	Fair	n.a.	n.a.	n.a.	Fair	Good
Ability to identify turning point		Poor/fair	Fair	Poor	Poor	Poor/fair	Good	Poor
Days required to produce forecast		1-2	90+	1-2	1-2	1-2	30-90	20-60
Cost of implementation		Very low	Very high	Low	Low	Low	High	Moderate

Table 1.1 – Demand model assessment (based on: Doganis, 2010)

Step 3: Mode choice

The regarded networks within the research are road, rail and air, supporting car, train and plane. Complete multi-modal trips are not included in the research. Literature shows little evidence for the existence of multimodal trips on the regarded distances and city scope.

Demand is regarded inelastic to service characteristics, because of the potential assessment and objective. Modal split and mode choice are estimated based on potential characteristics not directly related to the service but to the cities or countries (Buehler, 2011). The method to implement the assessment is similar to the empirical curve for market share estimation. Traditionally the empirical curve is implemented based on the travel time ratio. The limitation to only travel time would be service dependant, which is excluded from the passenger-trip potential. However, distance in this case is mode dependant (geographical detours for car and train) and is regarded a substitute for time, so can the relative performance of other “costs”.

Obtaining the values for mode choice will rely on data collection with regard for the city characteristics. The relative performance of “costs” are based on calculations. Distance will include standard detour factors on the great-circle distance for land-traffic and for certain OD-relations an added penalty for the geographical features encountered. With these obtained distances it is also possible to calculate travel time (door-to-door) performance based on average infrastructure speed.

Step 4: Route choice

Route choice is based on an all-or-nothing (AON) assignment on the European network with an additional focus on the TEN-T network defined by the European Commission. Transfers are not taken into account because of the potential assessment. The optimal route would be a direct train from origin to destination. Overall this will result in the amount of trips (#) that would potentially travel over a certain link in the network.

1.4.2. Seating capacity potential

The seating capacity potential is an assessment of the existing services/connections (current state of affairs) compared to the necessary services for the passenger-trip potential (desired level). A normalisation should be performed on these service to determine an objective level of service indicator. This indicator should reflect the minimum service level (Rothbauer & Sieg, 2011) acceptable for travellers to regard a service sufficiently convenient. Literature or frameworks for service level assessment are limited or non-existent. In general services are assessed on their actual performance, and meeting standards set by (operating) agencies (TRB, 2003). Nevertheless there is extensive evidence that mode choice preferences and level of service characteristics are very similar (Birago, 2014). This should provide a base for the assessment of current services and the desired service indicator based on the passenger-trip potential. The characteristics are similar to mode choice for level assessment. (Litman, 2015). The main characteristics that will be taken into account are offered seating capacity, frequency, transfer on a connection, service level and travel time performance. These are all factors that proof to have a great effect on demand and would provide elastic behaviour. Data can be obtained from ETIS+, HAFAS and Rome2Rio. In order to unify the data and determine the extent that the performance is affected by the individual indicators, the performance is translated into the amount (#) of effectively offered seats.

1.4.3. Preliminary core network

The preliminary core network is the difference between the seating capacity potential and the actual reality of offering connections. For the methodology an approach is necessary that reflects the needs of the travellers and the surrounding market effects (Marti-Henneberg, 2015). The integration has to reflect the wishes of the European Union (European Commission, 2013b), as well as the daily reality of open access operations, operating trains on the open market without franchise or tender restrictions (Bergantino, Capozza, & Capurso, 2015). A passenger core connections network is proposed based on these constraints and requirements. In order to come up with these connections, existing relations between cities are assessed, providing insight in important travel patterns. Each connection can be assessed on multiple of its attributes to determine effectiveness. The passenger core connections will not determine the complete business case for the connections found, however will provide a starting point to build the cases on.


Deutsche Reichsbahn
RICHARD FRIESE
LONDON
AMSTERDAM
HOEK VAN HOLLAND
KÖLN
BADEN-BADEN
BASEL
LUZERN
Mit dem
Rheingold
schnellste Reiseverbindung
von der Nordsee zu den Alpen
Auskünfte geben alle Bahnhöfe und Reisebüros

2 System of Interest

The system of interest determines the boundaries of the research, provides the scope and places the foundation for the assumptions and input in the research. It will set the scene of the report and providing the necessary preliminary information.

The chapter in itself will provide the answer to research question A, What is the system of interest? and the specific sub-questions. The sub-questions are dealt with in the respective parts of this chapter. First the scope is determined, the cities of interest are defined, the preferences with regard to the passenger-trip potential model and the provided services are assessed and the existing network for the model determined. Final part of the chapter is the definition of the scenarios for future analysis. The overall position of the chapter and parts are provided in Figure 2.1, additionally this shows how the parts relate to other items in the report.

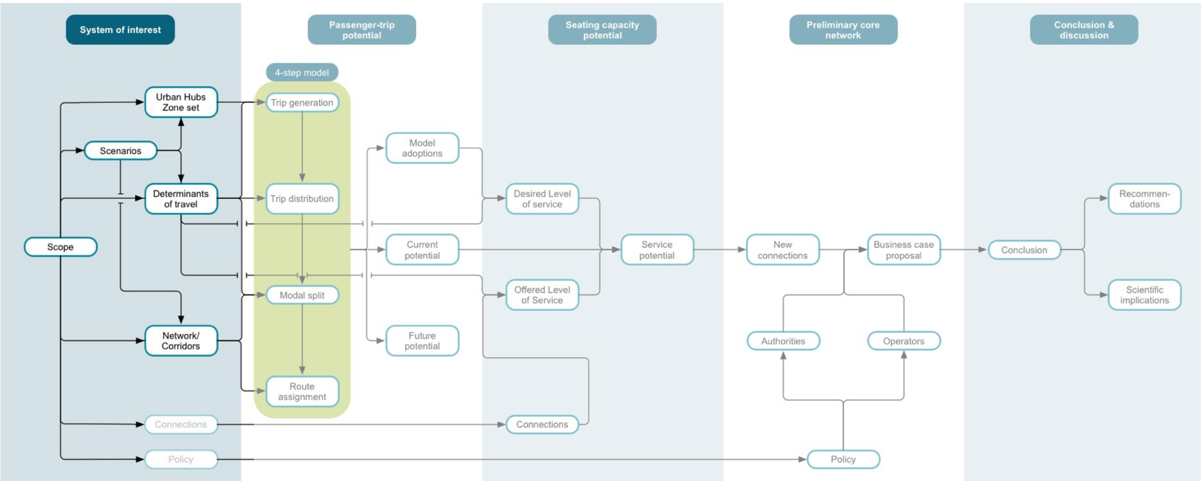


Figure 2.1 – Flow-chart of the report and position of the System of interest.

2.1. Scope of the research

The scope determines the broad boundaries of the research. They can be defined in multiple areas. The two main areas are the geographical scope and scope in time. In addition to these two areas several other more general limitations are of great importance in the research. The time scope is determined in chapter 1.2.4. This consists of two time steps, 2015 (current potential) and 2030, with three scenarios in order to estimate future developments in Europe.

2.1.1. General scope

The research question itself states international train travel, leaving all possibilities for cross-border rail connections open. However, the research is limited to long-distance connections by rail accessible destinations. A common definition does exist in research for long-distance, direct or great circle distance between origin and destination greater than 100km.

One of the main objectives is the assessment of the competiveness of rail towards air travel. This is both an explanation of the distance scope that is chosen but also provides a starting point for the modes that have to be taken into account. The infrastructure that is taken into account is limited to rail, road and air. For modes this can be divided into train (high speed and conventional), car and bus and planes. Ferries are taken into account as if they are infrastructure on connection without fixed links.

2.1.2. Geographical scope

The geographical scope is limited to the European continent, more specifically to the Schengen-area including prospective countries (Romania, Bulgaria and Croatia) with the addition of Great Britain and Ireland, as well as, the capitals and major metropolitan areas of the neighbouring countries. Excluded are Iceland and Cyprus. See Figure 2.2 and Table 2.1.

Countries			Cities	
Austria	Great Britain	Norway	Ankara (TR)	Moscow (RU)
Belgium	Greece	Poland	Belgrade (RS)	Podgorica (ME)
Bulgaria	Hungary	Portugal	Chisinau (MD)	Pristina (XK)
Croatia	Ireland	Romania	Istanbul (TR)	St. Petersburg (RU)
Czech Republic	Italy	Slovakia	Kaliningrad (RU)	Sarajevo (BA)
Denmark	Latvia	Slovenia	Kiev (UA)	Skopje (MK)
Estonia	Lithuania	Spain	Minsk (BY)	Tirana (AL)
Finland	Luxemburg	Sweden		
France	Monaco	Switzerland		
Germany	Netherlands			

Table 2.1 – Scope, countries & external cities

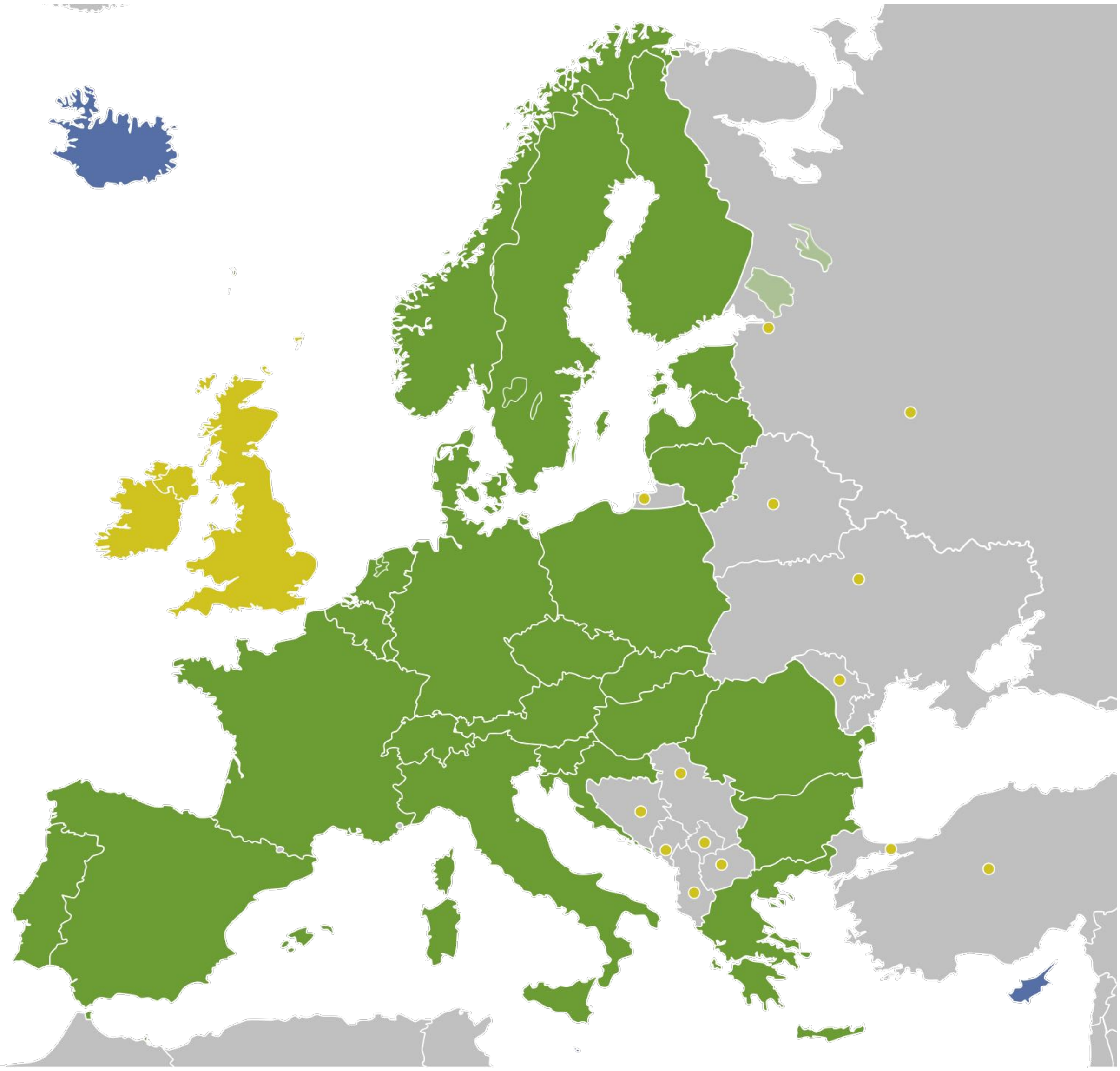


Figure 2.2 – Geographical scope. (Green = included Schengen countries, Blue = excluded Schengen countries, Yellow = additional non-Schengen areas). (Own elaboration)

2.1.3. Definitions in the scope

The report uses multiple terms, concepts and jargon in order to discuss the problems of the research. As a result of the broad range of topics in the report, from merely transport related to much broader psychological and economic to clarify the choices of people in the transport process, terms and concepts can have different interpretations in different fields of research. In order to clarify the used definitions for a term or concept, in Table 2.2 an overview is provided with the used definitions in this report.

Term	Definition
Connections	Trains operated and provided on a certain OD-relation (train services), distinct due to assessment in level of service.
Detour	Deviation from the direct line, as the bird flies, distance between two points in the network.
Potential	Possible and/or ultimate outcome. Potential is viewed in this report as a utopian ideal situation with a limited amount of operational barriers to travel. Similar to the customer experience of air travel.
Potential, passenger-trip	Possible and/or ultimate outcome with regard to the **demand**. Expressed in the amount (#) of trips between OD-pairs.
Potential, seating capacity	Possible and/or ultimate outcome with regard to the **supply**. seating capacity assessment based on the level of service offered by a connection (see connections definition). Expressed in the amount (#) of effectively offered seats by a connection.
Preliminary core network	Proposal on a possible and/or ultimate outcome with regard to the passenger core connections. A network of train services providing a backbone network in Europe. Proposed passenger connections equivalent of the Rail Freight Corridors (RFCs) and infrastructure TEN-T core network corridors (TEN-T).
Preferences	Determinants in choice and decision making, both applicable on travel behaviour as well as service choice.
Service	Officially: "Economic activity with an immaterial exchange of value". Interpreted also as value added offers to travellers, direct connections, ticket sales and timetable provision.
Travel time	Travel time in this report can generally be defined as average door-to-door travel time between OD-pairs, if not door-to-door it is stated.
Trips	A single journey between origin and destination, return journey is a new and separate trip.

Table 2.2 – Definitions in the report. (Own elaboration)

2.2. Cities considered in the research

The aim of the research is to identify the locations where (international) train services can be viable. To determine this potential demand, modelling techniques are used. It is the aim of every model to approach reality as close as possible, some constraints are necessary to keep the model feasible to develop. The sub question that is being answered in this part is: "What level of aggregation is necessary to provide a clear and detailed outcome?" Train travel is mainly limited between large urban areas (Goeverden & van Arem, 2010). As a result, the interest is only in city areas which are connected by rail. Several institutions have different definitions on cities, so first this has to be assessed. None of the definitions provide a complete or concise list cities to use for this research, in order to come up with such a list several criteria are necessary. Based on the criteria set a selection of major metropolitan areas will emerge.

2.2.1. The urban node as city definition

Every institute does have their own nomenclature conventions for their selection of cities of a certain size or importance. The definition “Urban Node” is included in the TEN-T regulation (European Parliament & Council of the European Union, 2013), “metropolitan region” as well as “larger/functional urban zone” and “greater city” are used by Eurostat, the European statistics office. Especially for the latter two definitions, Eurostat leaves the interpretation to the respective member states. This creates a situation where some metropolitan areas are only registered under their boroughs (London, Paris and Porto) instead of the actual perceived city areas.

The “Urban Node” definition from TEN-T is legally included in the regulation and as such does bear great importance for the policies surrounding the TEN-T project. Nevertheless, a definition or interpretation is nowhere provided, leaving unclear, why or what determines an urban node. The used urban node cities are also directly linked to the TEN-T corridors of the regulation, as a result this excludes important urban areas that are not directly linked to the corridors.

Eurostat does define metropolitan regions (Eurostat, 2011) that are more clearly defined. They are composed of multiple or the NUTS3 region(s) containing urban agglomeration (using larger/functional urban zone definitions) that exceed the inhabitant count of 250.000. NUTS3 (Nomenclature of Units for Territorial Statistics) being the lowest level statistical division of member states in the union. For statistical purposes this definition provides the most consistent answer. The amount is still very large for the purpose of this research and some metropolitan areas are incredibly large in area (Gothenburg), due to the way they are defined by their administrative boundaries. Finally, restricting the definition to population does leave out some important cities from an international point of view, for instance several capitals (Luxemburg). Figure 2.3 provides an overview on the different definitions and the way they are constructed.

Urban areas in general, especially in countries with less strict urban planning laws, have the tendency to exceed their administrative or even statistical boundaries. All together this makes selecting cities based on the existing definitions very difficult and arbitrary. In order to provide an objective choice set, a new, on statistics based, definition is introduced: “Urban hubs”.

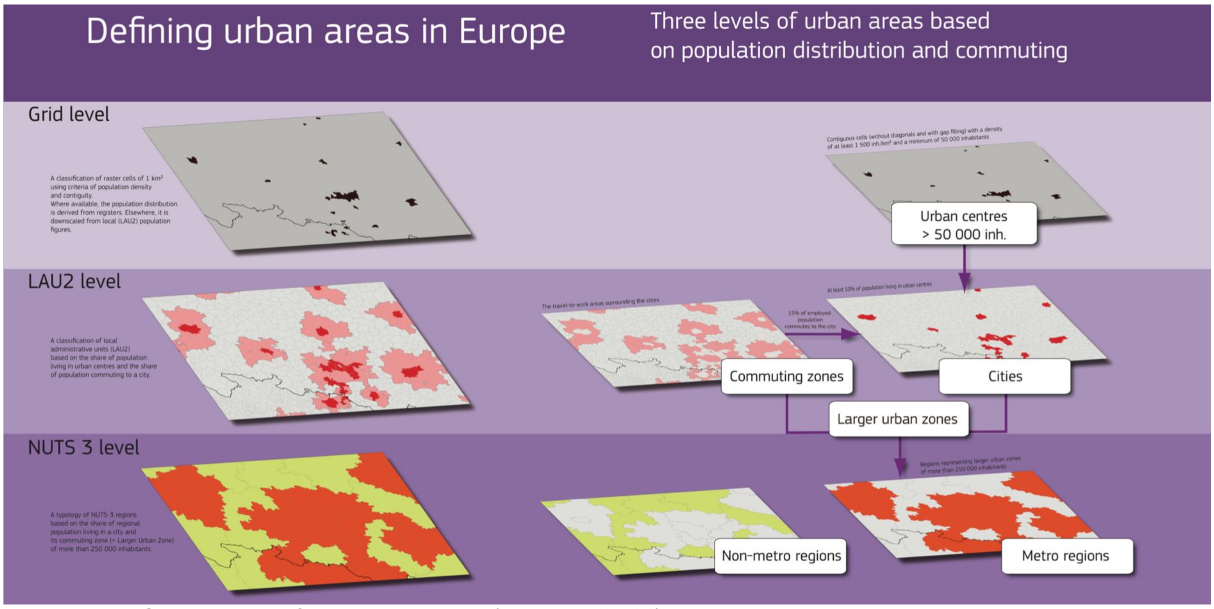


Figure 2.3 – Construction of statistical zones, (Eurostat, 2011)

2.2.2. Criteria for city selection

The most common criterion for selection is just city size based on population. This is regardless of the area of a city and resulting density. More people will result automatically in more trips. Population is as a result related to the potential production of trips between cities. The population of a city is very much related to the used definition of the city, as already described before. Although the amount of statistical information available on the level of the larger/functional urban zone (LUZ), population is consistently reported. LUZ includes the actual city proper (administrative), greater city (if the core is bigger than the administrative zone) and the commuting area. This determines the population in the direct influence zone of a city and approximates with greatest significance the amount of people choosing the city as point of origin in long-distance travel. Especially when selecting an airport or train station when not travelling by car.

The second criterion is the regional GDP. Economic activity also results in a willingness to travel in order to enact economic activity or trade (McNally, 2007). So a large GDP does increase the attractiveness of a city. Unfortunately, this is not recorded for the LUZ area. However, it is available on the level of the metropolitan regions (collection of NUTS3 areas). Cities are centres of economic activity and regional GDP reflects this relation.

In addition to the size of the city and the economic activity in a city or area a different criterion is necessary in order to measure a different kind of importance of a city. Research activities in countries are located around universities with great concentrations of students. Additionally university and their student populations are major generators of trips (Lovejoy & Handy, 2011; Whalen, Páez, & Carrasco, 2013). The third criterion is a derivative of universities and students in a city and is the percentage of high educated population in a city. Higher education is registered at the core and greater city level in Eurostat statistics. Additionally, the definition is standardised by the International Standard Classification of Education (ISCED). Level 5 and 6 are internationally recognised as high educated, university level and higher.

Although different definitions for the territorial units are used for the collection of the statistical information, all candidate cities are evaluated on the same territorial levels. Every chosen territorial unit does fit the criterion it represents in the best possible way and provides the information in the most accessible and reliable way. The cities that are preliminary selected (external cities), are not assessed on the criteria, selection is based on scope.

2.2.3. Urban Hubs, a new city definition

Every criterion is assessed based on relevance or significance with respect to the EU or the respective country. The following equations capture the process.

$$Rel_{iq} = \begin{cases} 0 & Cr_{iq} \leq \mu_{qc} \\ 1\ \mu_{qc} < & Cr_{iq} \leq 2\sigma_{qc} \\ 2\ 2\sigma_{qc} < & Cr_{iq} \leq 4\sigma_{qc} \\ 3 & Cr_{iq} > 4\sigma_{qc} \end{cases} \quad ; \forall\ c \in \boldsymbol{C}, q \in \boldsymbol{Q}\ i \in \boldsymbol{N}$$

$\boldsymbol{Q}$: set of countries
$\boldsymbol{C}$: set of criteria
$\boldsymbol{N}$: set of cities

Cr_q: Value for criterion q and city i
μ_{qc}: Average for criterion q and country c
σ_{qc}: Stand. Dev. for criterion q and country c
Rel_{iq}: Relevance for criterion q and city i

$$Score_i = \sum_{q \in Q} \alpha_q \bullet Rel_{iq} \quad ; \forall \ i \in \boldsymbol{N}$$

α_q: Weight factor for criterion q $Score_i$: Total score of city i

Assessment is based on the performance towards the criterion scores within the country (significance of a city within the country itself) and for the complete dataset of the EU, testing the significance of the city to the EU. This is done for every country (including EU), every criterion and every city. To get the overall relevance or significance of a city the criterion relevance scores are summed with a weight factor. Literature has a preference for population, then Regional GDP and the least common education. The weight factor is introduced to prevent that very small cities with high student populations (e.g. Leuven) outweigh large important economical hubs (e.g. Antwerp) due to the simplicity of the relevance score.

A minimum threshold score of eight is set for a city to be considered. This threshold value is determined on the size of the resulting set. This process provides a subset of 111 cities. The focus of the research is on long-distance travel and it can be assumed in accordance to practice in the airline industry (Doganis, 2010), that close centres of importance act as single zones. Common practice is to use perimeters of 25-30km for catchment areas of HSR-stations (Marti-Henneberg, 2015). As a result, a minimum distance of 30km is used between unique entries, eliminating 6 cities as unique entry. However, their properties are integrated into the greater city of the pair. These cities are, Rotterdam (elimination of The Hague), Cologne (Bonn), Mannheim (Heidelberg), Leeds (Bradford), Birmingham (Coventry) and the cross-border pair Copenhagen (Malmö).

In addition, some countries are underrepresented, with their capitals being insignificant on European scale or by limited sets of secondary cities. This results in the addition of Riga (Latvia) and Luxemburg (Luxemburg) as capital cities. Some secondary cities are added for Slovakia (Kosice), Finland (Tampere), Austria (Linz) and Norway (Bergen). The previously mentioned 14 cities outside the Schengen scope have to be added as well. Bringing the complete list of cities to 125. Nine cities score remarkably high compared to the other cities, London, Paris, Madrid, Barcelona, Berlin, Warsaw, Rome, Milan and Ruhrgebiet. In Figure 2.4 on the next page, an overview is provided of the defined Urban Hubs. Additionally, the TEN-T core network is included, this shows that most of the hubs do correspond with urban nodes and the network itself. In Appendix A: Urban Hubs a list is provided of all the cities.

The answer to the sub question what the level of aggregation should be to provide a clear and detailed outcome, was not found in the existing definitions of cities ("Urban Nodes", large/functional urban zones "LUZ", "metropolitan regions" or "greater cities"). Neither could it be found in direct subsets based on the existing criteria. The level of aggregation that is able to provide the clear and detailed outcome are the Urban Hubs, based on the three criteria, population Regional GDP and high education level. Providing a total set of 125 of the most important cities across Europe.

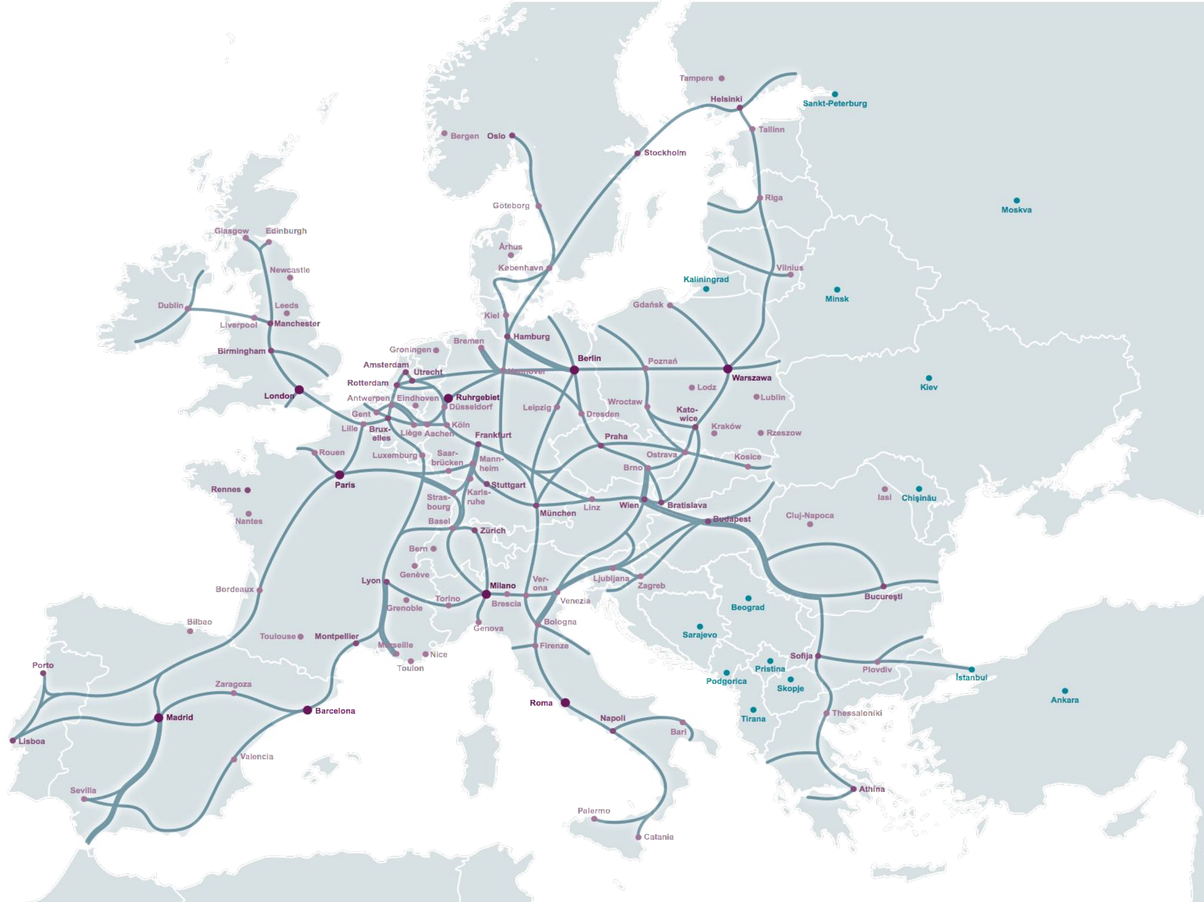


Figure 2.4 – City selection: Urban Hubs (purple dots) and external cities (green dots), (own elaboration). TEN-T network (lines) for illustration of EU corridor infrastructure. (Based on: European Parliament & Council of the European Union, 2013)

2.3. Travel/choice attributes

For the preferences that are applicable in this research, first an assessment is made on the current practices of preferences used in transport modelling studies. Based on this a selection is made according to the available data for the scope of the report.

2.3.1. Current practice in attribute selection

Long distance travel is not very well covered in transport modelling research or displacement surveys. Partially this can be explained by the relatively small percentage of long-distance travel in daily routine and the focus on problem solving which occurs most commonly as a result of commuter congestion. In the Netherlands the topic of long-distance is hardly relevant with the longest distances within the continental country never exceeding 400km, resulting in redefinition of long-distance to larger then 50km (Limtanakool, Dijst, & Schwanen, 2006). Even in larger countries, general research is limited. The research that is performed focusses on mode specific cases (Aarhaug & Fearnley, 2016), or new infrastructure projects (Mabit, Rich, Burge, & Potoglou, 2013). Rarely the research takes into account more than a handful of countries, leaving out border affects, and assessing already well established links. The problems with the lack of sufficient research on long-distance travel and the lack of sufficient data has been described multiple times (Aultman-Hall, Harvey, LaMondia, & Ritter, 2015), (Goeverden & van Arem, 2010). Even for the airline industry, open access scientific research is limited or limited available (Jorge-Calderón, 1997). Freight transport and trade-research has much more, in-depth, research available on general preferences or attractors for trade (Santana-Gallego, Ledesma-Rodríguez, & Pérez-Rodríguez, 2015).

Depending on the kind of research, the specific mode or the specific case, the preferences are in general very well developed. Nevertheless, they are difficult to generalise for a broader fit. This problem has been signalized by the European Commission as well. One of the first researches was DATELINE, followed by the European KITE project, ETIS+ and still running programs for more unified (national) travel surveys, also including long-distance travel (Christidis, European Commission, & JRC, 2011). However, the basics and motivations to make choices in travel and trips are still more or less valid for long-distance trips. Research on the motives of train choice on long distances (Goeverden, 2007; Goeverden & van Arem, 2010) and high speed rail project assessments (Cascetta & Coppola, 2014) does reveal some interesting general preferences that are also present in the more specific cases.

Characteristics can be divided in to multiple groups, being trip characteristics, passenger characteristics and city characteristics. The trip characteristics include preferences or sensitivity for travel time, travel costs (based on individual's value of time) and purpose. More detailed preferences or explanatory factors that can be included, however are hard to get data on, like trip duration (number of nights), trip participants or time of year (season). The latter factors are only used in detailed studies. For the city characteristics, explanatory factors are the city attraction of the origin and destination location. In general attraction and production is the result of size and economic power, however for long-distance travel a different explanation can be found in tourist activity, especially for rural location, which never would justify high travel demand based on the other factors. Other city specific preferences are the location (domestic or abroad and the main language). Passenger preferences or explanatory factors are the economic prosperity of the individual or household, the age, gender and employment characteristics. All previously mentioned preferences are applicable at all stages of decision making in the transport model. However, the focus is on the reason to travel and the choice of destination.

Modal split preferences, also for long distances are mainly based on trip characteristics and the relative performance to other modes. The importance of the relative performance is assessed by the sensitivity of passenger or the availability, access, to other modes. The availability of a car for instance increases the chance of choosing the car for the trip tremendously. Nevertheless, for generalised assessment the trip specific performance is most commonly used.

2.3.2. Attributes selected in the research

Resulting from the scale and scope of the project, the available data is collected on an aggregated level. Protectionism of national governments and authorities as well as commercial interest of existing transport providers limits the accessibility to more specific data sources. In addition to the barriers created, the currently gathered data via EU initiated transport surveys (e.g. KITE) is insufficiently significant to serve as input to a full transport model for the EU. With only single digit trips between large city pairs (e.g. Vienna–London) over the course of 1,5 years. These sources can however be used for guidance, validation, calibration or fine-tuning of parts of the system, but not as input. Even adjusted data as used for recent European research (van Goeverden, van Arem, & van Nes, 2015) is insignificant on a city pair base. As a result, the selection is driven by the availability and accessibility to data. In addition, one of the underlying problems during the research is the lack of open access to trivial information. This report strives to use openly available data as much as possible.

The main explanatory preference factors for travel can be linked to the available data and the phase of the model/report. In the trip generation, preferences are based on passenger info. The amount of possible people travelling represented by the population and the likelihood of travelling based on a GDP per capita ratio, reflecting the constant time travel budget. For distribution the country, language and economic area barriers in addition to size and attraction from cities are most important. Other indicators like trip purpose or tourist info have incredibly limited data resources or inconsistent data. Especially inconsistent data is troublesome if the comparison should reflect real life choices. The mode choice is exclusively based on the travel time. Relative ticket price can be related to the choice but is dependent on the (city or country specific) value of time. In the optimal potential situation costs are not differentiated. The service selection will also include more traditional mode choice factors, like frequency, service quality and travel time performance in addition to offered seating capacity.

Main explanatory preference factors for travel are summarized in Table 2.3. The headers in the table refer to the different parts of the research.

Trip Generation	Trip Distribution	Mode choice	Service selection
GDP/Capita	Attraction	Travel time sensitivity	Frequency
Population	Country		Transfers
	Language		Travel time performance
	Economic area		Service level
	Distance (sensitivity)		Seating capacity
			Additional indicators

Table 2.3 – Preferences or determinants of travel used in the research for the different choices in the model.

2.4. Network

The current network for the research is based on the three considered infrastructure types, road, rail and air. Each infrastructure type supports one or multiple modalities, which need their separate network representation. Putting multiple interchangeable networks together does create a simplified super network.

As a result of the chosen methodology and the unprecedented scope it is almost impossible to use a complete model of the actual network. To overcome this limitation, the network is built upon connecting the cities with direct links and method is developed for detour factors and average mode speeds to approach the actual travel distances as close as possible. To ensure proper representation additional network nodes are added. Further assessment of the network properties and implications for the model are discussed in the respective chapters, 3.1.3 Modal split and onward. Existence of a link between cities is done based on actual infrastructure that currently supports long-distance or the respective city to city traffic.

2.4.1. Infrastructure networks

Three networks do exist in order to support the 5 defined modes. The networks are divided over infrastructure, road, rail and air. The road network and its properties are applicable to the modes car and bus. The same holds for the rail network, supporting high speed train (HST) and conventional trains (conv.). The networks are shown in Figure 2.6 and Figure 2.6, the adjacency graphs as developed to represent respectively the road and rail network. In order to get a good representation of the rail network an additional 50 nodes (cities) are necessary to model large detours properly. For the road network a total of 33 additional nodes are necessary, all included in the rail network as well. Appendix E: includes the additional nodes.

Figure 2.5 – Modelled railway network 2015. (Dark green = HST, orange = conv., blue = ferries), (Own elaboration).

Figure 2.6 – Modelled Road network 2015. (green = road, blue = ferries), (Own elaboration).

Air network and plane mode

Air infrastructure is somewhat different and only supports a single mode, the plane. The city selection did take into account the accessibility of a city by rail, however no such condition was used for air accessibility. The Urban Hubs are matched with IATA-listed (IATA code available) airport in order to ensure that airports are operational for commercial flights. As a result every city is matched with a single airport. Traffic is possible between all defined airports. Transfers (hub-and-spoke operations) are assumed to be none existing. This would increase the amount of possible routes to almost infinite and transfer times are greatly dependant on the transfer facilities of the airports and services provided by airlines.

Some cities however do not have a sufficiently large airport to support significant air transport. Furthermore, city pairs should at least be 150km (great circle distance) be apart to support OD air traffic and have a demand of 25.000 (±70 passengers/day), else air traffic is deemed economically unfeasible. The full list of conditions applicable in selecting airports and allowing traffic from a city's airport are listed in the modal split step of the transport model, chapter 3.1.3. The calculation of the travel time takes into account idling time at airports (taxiing, checks, clearance) and passengers waiting time for flights and baggage.

Airports are the entry points for planes into the city, in contrary to trains, these are almost always located (far) outside cities. This should be properly represented in the network. Airports are represented in the network as separate nodes, distanced from their respective cities. The link between the airport and the city is comparable with the road and rail network, however with their own supplement characteristics.

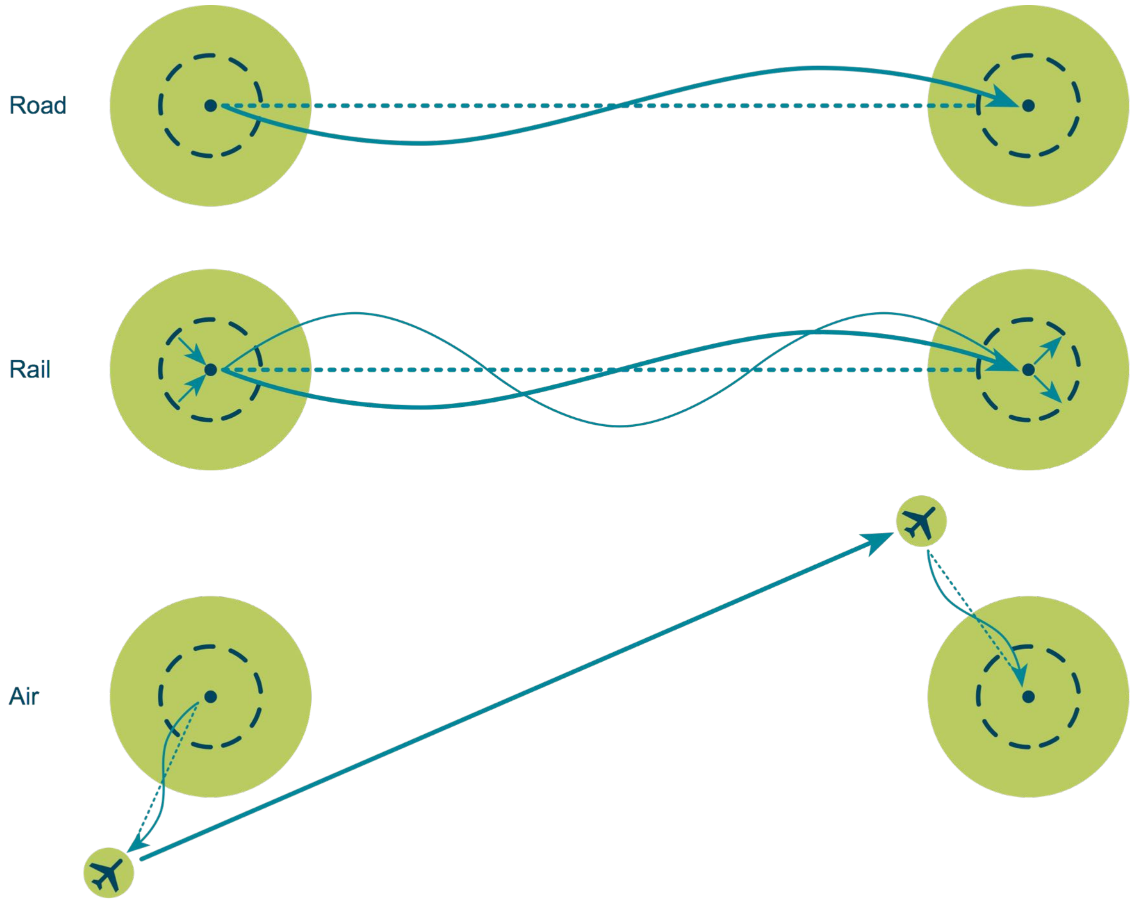


Figure 2.7 – Network schematisation used in the research. Direct (great circle) distance dotted, modelled distance with detour factors. Access and egress modelling of rail and air networks to infrastructure entry points. (Own elaboration).

2.4.2. Supplements to the networks

In addition to the defined networks and modes some supplements are necessary to support several vital links. Already described is the airport supplement, linking the airport location to the city centres for access and egress of the airports. A similar supplement exists for stations, where the average city first has to travel to the station within the city before actually starting the long-distance journey.

The final supplement is one of a completely supporting mode, ferries. As a result of the non-fixed nature the network characteristics of both rail and road are not applicable. It is however assumed that ferries are operated in an optimal service environment and that no additional waiting does exist in usage. For many through operations (e.g. Hamburg – Copenhagen) this is also the case in reality.

2.4.3. Network conclusion

Figure 2.7 provides a schematisation of the trips and the components in the networks. Dotted links the direct distances, with the detour calculated routes crossing them. Additionally, the access and egress parts for the rail and air networks.

2.5. Scenarios for future assessment

Predicting the future is an uncertain business. Little changes in any variable can result in large changes in the outcome, beautifully explained in the weather analogy where a wing-stroke of a butterfly can be the cause of a hurricane on the other side of the earth. To overcome the uncertainty of the future and make predictions about what the possibilities are for the developments in the future three scenarios are developed. These scenarios capture a range of possibilities based on different assumptions on how policy, economy and other factors will develop in the future. The scenarios are based on the Global Europe 2050 report (European Commission, 2012a). The usage of these pre-formulated scenarios ensures consistencies with predictions across Europe and adoptability on multiple governmental levels. Each scenario, with the core assumptions and adoptions for this research will be explained separately, a summary with the overall differences on key indicating factors is provided as a conclusion. A schematic representation of the economic growth in the different scenarios is provided in Figure 2.8.

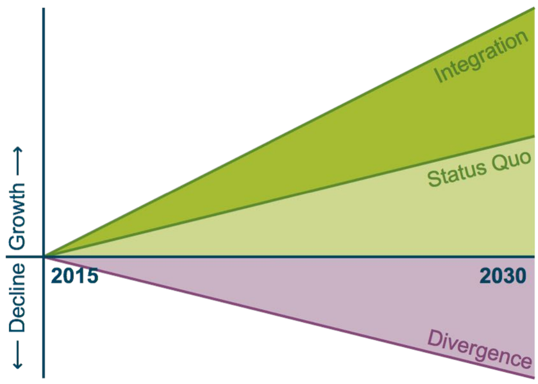


Figure 2.8 – Schematic representation of scenario effects on economic growth. (based on: European Commission, 2012a; own elaboration)

2.5.1. Divergence, decline scenario

The divergence scenario (Div) is the scenario of decline, slowdown or even downturn. This is not only the case for the EU as a geographical and economic entity and union but for the complete global economy. The Union is disintegrating and reduced barriers in the present situation are becoming once stronger. The world faces several challenges and none are resolved in a sufficient manor and the effects of the challenges will be felt broadly. Infrastructure developments stop and the network will not see any development compared to the present one. Large scale projects are stopped if public support is deteriorating. Only almost complete engineering works will be completed before 2030. As a result of aging infrastructure and lack of maintenance the risk does exist for network deterioration instead of development. In some parts of Europe this threat is already more urgently looming (Rech, 2016).

The economy will slow down significantly and more structurally. This will result in significant decreases in the GDP per capita and population. Although the general tendency for the population is a significant decline because Europe faces an ageing and shrinking population. The cities within the research scope specifically will see only minor decreases in population as a result of the ongoing urbanisation and reliance on cities for economic prosperity. The willingness to travel will reduce as a result of uncertainty and unrest in many countries. In addition, the single market that was created in the Schengen-treaty is no longer valid and border controls are reinstated.

2.5.2. Status Quo scenario

The Status Quo (Quo) scenario is the scenario most resembling the existing state. Little structural changes are applicable to the different factors. Especially the political frameworks within the union will keep a similar structure as it is currently. This is mainly a result from the lack of visionary leaders and ideas or the willingness to go above and beyond the difficult questions the Union faces. It is the believe that the same lack in vision reduces the possibility for economic growth and growth in welfare. Though growth does exist, it will be low, as was the case during the beginning of this decade. Public support for change on many topics is low, not only topics related to the Union. Additionally, broader questions like climate change enjoy little support. As a result, the push towards more sustainable ways of transport is limited as well.

Nevertheless, factors do not deteriorate further. On average every European is equally eager to travel, and the existing barriers are equally applicable. The only real difference for the prediction will be the country specific changes in population and GDP per capita. There is a further push for urbanisation, comparable to the other parts of the world. Energy and environmental constraints do however create opportunities to further develop the networks. The TEN-T network is completed according to the plans and on time in 2030. This ensures a level playing field with regard to the quality of infrastructure available in the Union.

Overall Quo is a scenario with little difference to the present situation, no structural changes are applicable, no real economic growth. The EU is unable to integrate further and erase borders in a significant way.

2.5.3. Integration scenario, growth scenario

Present day challenges are overcome and the spirit of integration and cooperation is once more sweeping across Europe in the Integration scenario (Int). Threats to global policy, democratization, economy and environment are overcome resulting in thriving economies and communities. In order to overcome the environmental challenges a big push towards more sustainable forms of transport is apparent. As a result, the network for road transport will see limited development, rail network will see a big push towards high-speed and connectivity. The TEN-T core network is finished in time and ambitions for a finer grained core network are moved forward from 2050.

The economy thrives as a result of the innovative solutions provided to the challenges at hand. The GDP per capita increases significantly and willingness to travel overall is larger as well. In addition, the urbanisation is still going strong and overall population will grow. Existing institutional barriers will be reduced and a push in education will provide better understanding of cultures and languages. This will perfect the internal market of the EU as if being a true domestic market. In addition to reducing the borders within the union, the union will expand in the south and east according to the current negotiations.

2.5.4. Scenario conclusion

Three scenarios are presented, a scenario of decline (Div) a scenario of status quo (Quo) and scenario showing optimism and growth (Int). Even some years after presenting the Global Europe 2050 report the path of each scenario is still viable. Although the referenda in the Netherlands and UK on the functioning of the EU seem to be a push on European disintegration. For this reason, the Div scenario includes more barrier specific changes to fit the result of an actual disintegration. In Table 2.4 a summary is provided on the different factors how they will be affected. A – (minus) indicates a decrease and a + (plus) an increase, the | denotes no change for this factor at all and will stay the same across all time frames.

Theme	Factor	Divergence	Status Quo	Integration
Economy	GDP	-	-/+	+ +
	Population	|	|	|
	Infrastructure	-/+	+	+ +
Travel	Average trips	- -	-/+	+ +
	Time sensitivity	|	|	|
	Mode preference	|	|	|
Institutions	Country	+ +	-/+	- -
	Language	+	-/+	-
	Schengen	- -	-/+	-/+

Table 2.4 – Scenario effects. (based on: European Commission, 2012a; own elaboration)


TEE
trans
europ
express
ENTRE 80 VILLES D'EUROPE

3 Passenger-trip potential

The first step of determining the potential of the railway infrastructure in Europe is an assessment of the demand in the system. The demand is denoted by the amount of people willing to travel creating the amount of trips. This demand is defined as the passenger-trip potential.

The determination of the passenger-trip potential is based on the standard 4-step model (Ortúzar & Willumsen, 2011) and provide answer to sub-question B, What is the passenger-trip potential, demand, of the European railway market? The structure of this chapter, (see Figure 3.1) closely relates to the traditional transport model as well. Following the four different stages in the model, with their respective input and execution. First the trip generation, followed by the trip distribution. Separately, the modal split and the model concludes with the route assignment, providing the passenger-trip potential with regard to mode and route between respective origins and destinations.

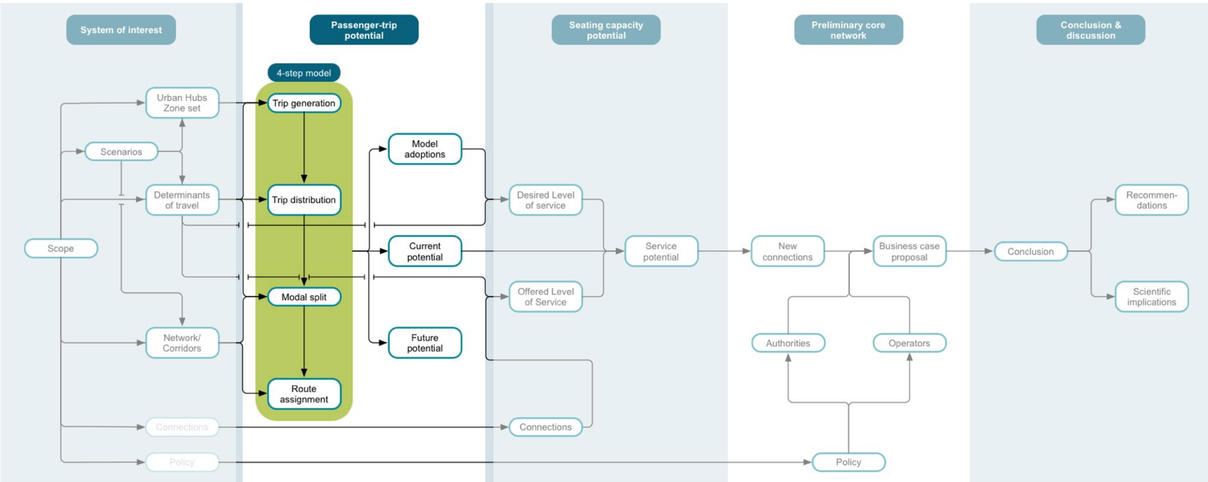


Figure 3.1 – Flow-chart of the report and position of the Passenger-trip potential.

3.1. 4-step model, traditional transport model

In order to make an estimation of the passenger-trip potential or the willingness of people to travel to a certain destination, a transport model is very helpful. Multiple levels and stages in the development of such a model are possible. From very detailed, agent based to more aggregate and general. An aggregate version of the 4-step model is used in order to determine the passenger-trip potential, although the 5-step model is more sophisticated, by addition of the choice of day. This last choice, for determining the passenger-trip potential on a yearly base on long-distances does add little additional or useful information.

The main focus in the model is on the potential to travel to the set of European destinations given that current practical and operational barriers to travel become less intrusive compared to the current situation. This kind of market research within transport models is in general only used for new modes (Cascetta & Coppola, 2014), infrastructure (Sanko, Morikawa, & Nagamatsu, 2013) or connections (Jorge-Calderón, 1997). Unique to this research is the use of the 4-step transport model to determine the demand without service characteristics in itself. The airline industry uses this approach already for multiple years, however on a private base.

The passenger-trip potential assessment does not take into account the barriers created by currently offered services. It does only takes into account the restrictions that are a result of the available infrastructure. Technical restrictions are also considered insignificant due to the long-term aim at technical interoperability within the European Union.

The four step model is a series of four choices or steps, hence it name. The start is in the willingness to travel, generation of traffic from all origins. The second is the destination choice based on the experienced or perceived barriers to the destination. The third choice is the mode choice, barriers in usage also are important in this choice. The last choice is the route choice, what route to take in order to arrive at the destination. This first section of the passenger-trip potential chapter will follow the 4-step model closely. Every step is further divided into the necessary information and assessments on each step itself. The output of every step is used as input on subsequent choice steps.

3.1.1. Trip Generation

The first step, generation focusses on the willingness to travel. For this research the scope has been determined to be long-distance, larger then 100km distance between city-pairs. This definition is the starting point for the trip generation. In literature few examples of strictly long-distance models can be found. This results from the use of transport models as predictors of congestion and spatial development on relative small distances. There is consensus in the literature (Goeverden & van Arem, 2010), (Aguiléra & Proulhac, 2015), (Mabit et al., 2013)that the choice in order to make a (specific) long-distance trip does differ from the choice of general, daily, trips. First the relevant zonal data has to be captured, any additional parameters and then it is possible to generate all the trips in Europe, for long distance travel.

Zonal data of the Urban Hubs

Transport models make use of so called zonal data. This is the aggregated data that represents the characteristics within the boundaries of the zone. In this research the zones consist of the Urban Hubs and external cities. All the Urban Hubs that are located within the European Union, are also part of the so called metropolitan regions. This makes the capturing of statistical information much more convenient, compared to all the other available boundaries and definitions. In order to have the data as consistent as possible, including definitions and exemptions all EU data is retrieved from Eurostat. Data for Norway and Switzerland, both non-EU countries is a hit and miss exercise within the database of Eurostat. Where possible the Eurostat entries are used, otherwise the latest data of the national statistical authority is used.

For fourteen external cities, data collection is much harder. Some of the countries are part of the OECD (e.g. Turkey), making recent data more accessible and usable. The national statistical authority of Turkey collected the most recent available data online in 2001. Other countries, like the former Yugoslavian republics, have limited data available via the world bank, IMF or external sources. For each country the most relevant source is selected and used.

In addition to the defined cities, each European country, Schengen and EU, is assigned a rest zone. These zones consist of the properties of the respective country minus the included population in the represented cities in the country. People are generated to travel to and from these zones, as well as distributed. These zones will not be loaded on the network due to the great range captured, included both additional cities and country side areas. The population included in the rest zones is further fine-tuned to provide sufficient relieve in the distribution process, greatly dependent on the role of the selected cities within the respective countries.

Parameters, determinants to travel

The equation that is used for the distribution, see below, has several parameters included. Additional explanation of some of the parameters is provided after the equation.

$$A_i = P_i = \frac{GDP_i}{\overline{GDP}} \bullet t \bullet Pop_i \quad ;\forall\ i \in \boldsymbol{N}$$

$\boldsymbol{N}$: set of cities

A_i: Attraction of city i

P_i: Production of city i

GDP_i: GDP/capita of city i

$\overline{GDP}$: Mean GDP/capita for $\boldsymbol{N}$

t: Yearly trips of average European

Pop_i: Population of city i

Production and attraction of a city are equal (A_i=P_i). In practice this means that an equal amount of people travels in both direction (symmetry), especially on a yearly base a safe assumption. GDP is taken as a measure or extent to which people are willing to travel. Household income is a very common indicator in the trip generation equation (Ortúzar & Willumsen, 2011). Furthermore there is sufficient evidence that there is a clear correlation between GDP, GDP/capita and the actual amount of trips a person will undertake (Schäfer, 2007). The GDP per capita, at current market prices, provides a measure to the extent of economic capacity of every individual. Dividing this by the mean of the data set (€31,192,-/capita) does result in a GDP-ratio. This ratio provides information on the extent that the average city inhabitant is above or below the economic capacity of the European average. The Urban Hub selection did include high education levels, this however is not included in the trip generation as a result of the limited and inconsistent data available on the Metropolitan region statistical level especially for the additional cities. Substitute indicators for education, like number of institutes are deemed unreliable and are extremely uncommon to be included in transport models, especially on trans national scale. Some countries prefer a multitude of small institutes, other single large ones. Additionally, in statistics, some educational institutes are recorded multiple times as a result of multiple locations or faculties, others only get a single entry, although having even branches in other cities. This results in an incredible inconsistency and unreliability and making it unfit to put significant reliability for the model in.

The parameter *t* is the annual long-distance trip average for every European. Derivative from this is that an average European will travel the amount *t*. As a result, *t* is used as the actual generation parameter for the amount of trips that are undertaken. The parameter is determined based on literature and the results that have been found by the European KITE-project. This found that average amount of journeys is between 8 and 9 (Goeverden & van Arem, 2010). Due to the symmetric assumption in the generation, this equals in 8 to 9 trips per inhabitant. The willingness to travel *t* is a figure that holds for the EU and Schengen, due to the scope of the research that has provided this number, and does capture long-distance trip to all destinations, not only the selected Urban Hubs, hence the rest zones. Additionally, both Istanbul and Moscow with their very large populations are much more focused towards respectively the Middle-East and Commonwealth of Independent States (CIS), which creates some limits to the adoptability of the model. As a result, it necessitates adjusted willingness to travel (*t*) values, to prevent unrealistic attractions.

Generation of trips

The generation itself does provide some interesting insights in the relative economic power of the urban hub city set. In total, 2,23 billion trips are generated by the Urban Hubs (exactly 9 on average) are generated on a yearly base, 6,1 million trips on a daily base. The complete list with GDP/capita and used population is represented the cities are categorized in 7 categories with size relative to the generation. The map representing these categories for the urban hubs is show in Figure 3.2, with both size and colour denoting the amount of generated trips from each city. The concentration of the trip generation in the Blue Banana economic area (Brunet & Boyer, 1989) is remarkable however expected. The most trips are generated in London, Paris with both great populations and higher GDP/capita than average. They are real statistical outliers being 3 times as being as the third and fourth biggest generators, Madrid and Milan. The least amount of trips can be observed in the external cities in the former Yugoslavian area, where both GDP per capita and absolute amount of inhabitants is very small. Several cities generate much more trips per capita than the average assumption. This as a result of the high GDP per capita compared to the European mean. These are cities like Basel, Rotterdam and Copenhagen which in themselves are very internationally oriented, with Basel and Copenhagen directly at the border and Rotterdam with the harbour complex. The economic power of Istanbul and Moscow is remarkable on the European scale, though expected.

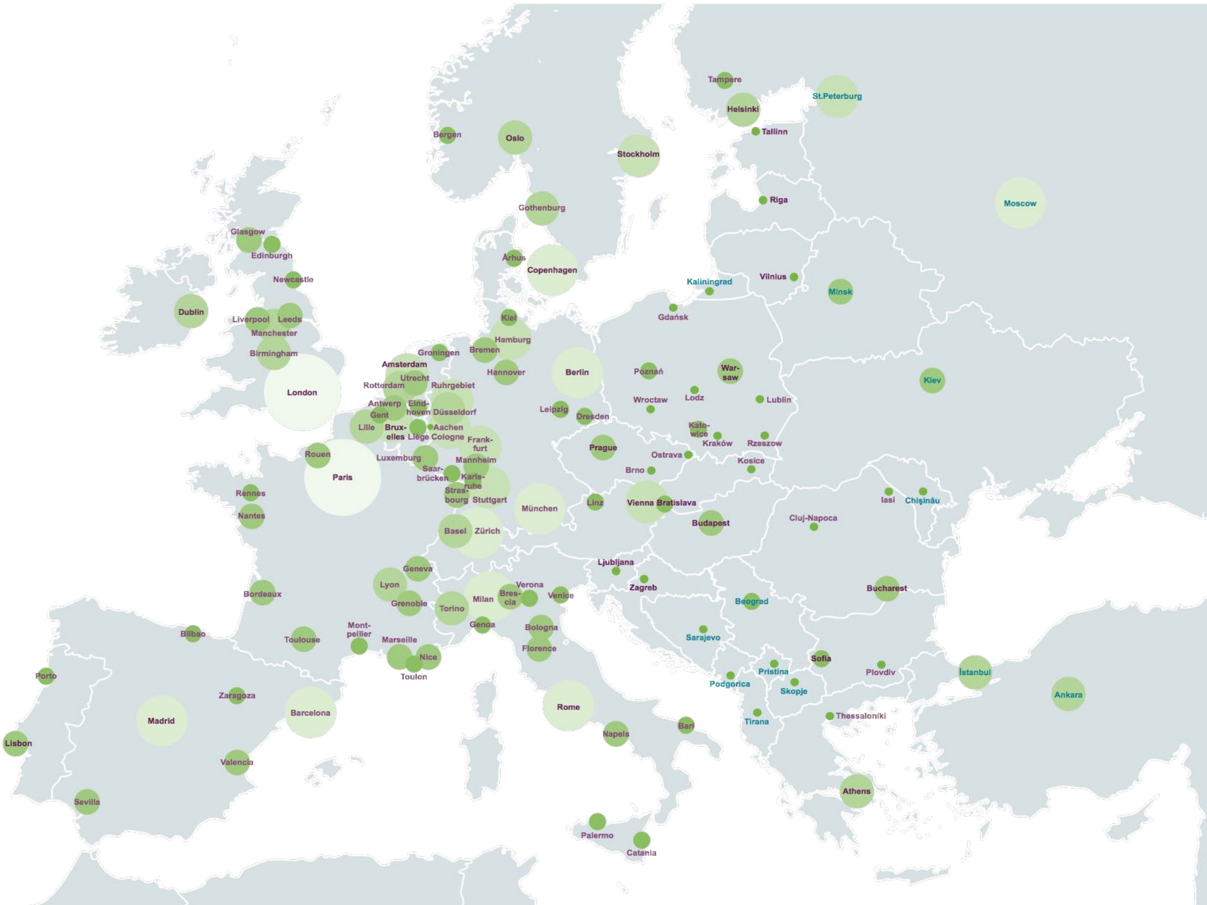


Figure 3.2 – Trip generation 2015, circle size and colour denote amount of generated trips, (Own calculations).

It is important to note that this research has the limited scope of only 125 Urban Hubs. The population of those metropolitan areas represents 40% of the total European population. The amount of trips generated for the EU28 Urban Hubs is 1,9 billion. Accounting for 48% of the total trips in Europe. The discrepancy between population and amount of trips, can easily be explained by the greater GDP/capita in the cities compared to the rural areas. In comparison with aggregated existing values for travel and trips, this should always be taken into account. The assessment is only performed with a limited though very important part of the population in the model.

3.1.2. Trip Distribution

The trip distribution models the choice of destination for all the generated trips. This is done independently from the mode choice and only based on the relation between the origins and the destinations. For the trip distribution, a gravity model is used, which takes cues from Newton's law of universal gravitation. This describes the force (trips) that is directly proportional to the masses (production) of two particles (cities). The first use of the gravity analogy in traffic engineering is done in 1955 already (Casey, 1955). It provides the opportunity to estimate the trips between origins and destinations without knowing the existing traffic on these relations, which is necessary for older techniques like growth models, most commonly used in railway traffic engineering and estimation.

Traditional gravity models for distribution estimation only take into account the distance or costs perceived between two destination pairs. These costs can be a conversion of other factors, like time or money into a generalised unit. As a result of the strict separation between mode choice and distribution, only distance is perceived as a cost factor. The strict separation is based on the fundamental assumption that services are no limitation in the choice of destination. However, especially for international travel, certain barriers do exist. The gravity model can be used to include these kind of barriers (Anderson & Van Wincoop, 2003), as mainly demonstrated for freight trade modelling.

Barriers for destination choice

After all the effort that the EEC and the EU have put into eliminating borders in order to promote free movement of people, goods, labour, capital and services, it could be expected that borders no longer form a barrier to travel. Unfortunately, research does show differently. Borders still are a perceptual barrier. Trade researches do suggest that the barrier is being reduced tremendously, (Salas-Olmedo et al., 2015). It should nevertheless be captured in order to get a realistic representation especially for the international travel behaviour that this report is assessing. Not only have country borders been found as barriers, also other important borders have been observed in research, like language (Santana-Gallego et al., 2015), geography (Bellekom, Donners, & Heiligers, 2012) or trade areas (Bergstrand, Larch, & Yotov, 2015).

For this research four barriers are defined as being distinctive and sufficiently documented in order to make an assessment on their effects. These are country borders (*C*), language borders (*L*) and trade area (Schengen) borders (*S*) as well as a federal borders (*F*) for countries with federal structure. Each barrier is represented with a dummy variable being either 1 or 0 if a barrier is present. Although travelling by land modes would require crossing multiple of these barriers, it is assumed that only the barrier between origin and destination do exist. This assumption is made on two grounds. First, the alternative is travelling by air and then only a single barrier between origin and destination is actually experienced. The second ground is that the multiple barriers are also represented in the distance between cities. The equation that is used, including the barriers is shown on the next page.

$$V_{ij} = l \bullet \frac{P_i \bullet P_j}{\beta_{ij} \bullet D_{ij}^k} \quad ;\forall\, i,j \in \boldsymbol{N}$$

$$\beta_{ij} = \sum_{b \in \boldsymbol{B}} \beta_b \bullet \mathrm{B}_b \quad ;\forall\, i,j \in \boldsymbol{N}$$

$$\mathrm{B}_b = \begin{cases} 1 & \text{if barrier present} \\ 0 & \text{otherwise} \end{cases} \quad ;\forall\, b \in \boldsymbol{B}$$

$$D_{ij} = 2 \bullet r \bullet arcsin\left(\sqrt{sin^2\left(\frac{\varphi_j - \varphi_i}{2}\right) + cos(\varphi_i)cos(\varphi_j)sin^2\left(\frac{\lambda_j - \lambda_i}{2}\right)}\right) \quad ;\forall\, i,j \in \boldsymbol{N}$$

$\boldsymbol{B}$: set of barriers
B_b: Barrier C, L, S or F
V_{ij}: Volume between city i and city j
D_{ij}: Great-circle distance between city i & j
β_{ij}: barrier-value between city i & j
l: Constant value
k: distance control value
$\varphi \& \lambda$: geodetic coordinates

Production and attraction are assumed to be equal, as already stated in the trip generation. GDP/capita as generator is a traditional production value of a city. Attraction could be possibly calculated with tourist attractions, square meters of convention centre or the amount of overnight/hotel stays. Unfortunately, this information is inconsistently available and not correctly recorded across Europe. The result is that distribution is only based on production related factors. This would leave the possibility for a skewed distribution for cities that are small in production (low inhabitant levels or low GDP/capita), but have a high attraction level, like Lourdes, France. Given the selection of Urban Hubs this is however assumed not to be the case and the introduced error in the model is not greater than the overall goodness of model fit (R^2).

Fine-tuning the distribution functions

Fine-tuning is performed based city pairs of which the traffic flows are known and, preferably the modal split is also known or predictable. Appendix D: Trip Calibration provides an overview of the used city pairs for the calibration. The calibration requires multiple stages, first the general parameters should be calibrated, like the constant and the effect or sensitivity for distance. Calibration for each barrier is done on a subset of cities on which travel data is available. Main source of information is Eurostat “detailed air passenger transport by reporting country and routes (avia_par)”, (Eurostat, 2015). Other sources are market share values of high speed trains (Eurostar, Thalys and AVE) as well as passenger numbers of certain high speed city to city connections (Nash, 2010; Vickerman, 2015).

Door-to-door travel time indications are taken from multimodal route planners like google maps (if public transport is available), rome2rio.com, goeuro.com and the HAFAS-database via DB.de. This multisource search ensures that all the possibilities are fairly and most realistically covered. This also ensures proper travel time provision for air travel due to the addition of waiting times at airports. Based on this data the total amount of people travelling yearly between city pairs is extrapolated. The trip distribution model should fit this number of total travelling passenger on city pairs as closely as possible.

The constant (l) in the calculation is estimated based on domestic cases, when no other barriers exist except the distance. Domestic travel has the advantage that for certain relations more data is available on modal split capacity and travel demand given the current services. This provides the opportunity to determine the sensitivity to distance (k) and other capacity related variables. A set of twelve city pairs (eighteen unique cities) is used of countries, sufficiently large that interference of car travel on relations is minimised. Car interference or share of capacity is the most difficult to predict, especially on shorter (<100km) distances. An anomaly does show for countries with a federalist political system, people are less likely to travel domestic across federal borders, the barrier is small, however large enough to be consistently present in the calibration.

After these are sufficiently estimated, the values (*beta*) for the dummy variables of the barriers (*C, L, S* & *F*) can be calibrated. Fine-tuning for each barrier is done on a subset of cities on which travel data is available. First the country barrier is determined with a set of ten city pairs, thirteen unique cities. Only country is different, language between the cities is the same. Language of a city is determined by the official languages spoken in a city. No further indication for the federalist effect is found in the language barrier. Additionally, ten city pairs, fifteen unique cities with both language and country difference, inside the Schengen area. For city pairs where only language differs, no significant or reliable data is available, nor can be extracted. A deduction method is used to get the barrier value for language.

In a similar way the Schengen barrier is determined. A set of (7) well-established city pairs, e.g. London – Paris, does reveal a valid barrier for Schengen. Nevertheless, a different set of pairs (especially including Balkan capitals) has deviating values, either the barrier is extremely high, or relatively low. An explanation can be found in the fact that for the Balkan area these cities are 1) forced into the set, 2) The capital is (one of the) only proper entry points into the country for air traffic. This latter point results in air traffic aggregation from areas that are not included for other city pairs which explains the observed low barrier.

	Variable	Calibrated	R^2
k	1,4		
l		0,00001366	91%
Beta C		4,03	98%
Beta L		6,50	83%
Beta S		2,02	90%
Beta F		1,00	
Total		13,55	90%

Table 3.1 – Parameter values distribution, (Own calculations).

In Table 3.1 the values for the different parameters are presented and there goodness of fit for the iterated model. For all defined barriers significant barrier values have been found in contrary to previous research stating otherwise (Brietzke, 2015). The difference can be found in the assumptions of the previous researches, where long-distance travel automatically involved language and border changes. This incorporates the barriers into the constant values of the equation. All values as a result of the calibration are unitless and do not bear any meaning in real life values. Nevertheless, their relative difference does bear a meaning. Changing a language border is a bigger barrier than only a country border. Apparently, and probably as a result of the EU policy. It is however remarkable, how limited the detected barrier of border control is. Although Schengen borders always coincide with a country borders.

Something remarkable happens on several relations. In the search for OD-pairs, Dusseldorf – Istanbul was included. However, based on the amount of aircraft seats annually offered on this relation the defined border and language barriers would be non-existent. This can be explained by the relatively large Turkish population in the catchment area of Dusseldorf airport (including parts of Cologne-Bonn and the Ruhrgebiet). It is not possible nor desirable to adjust the model for these kinds of anomalies in demographic and sociologic features of cities in this report.

Distribution, destination choice

The overall goodness of fit of the developed model R^2=90,5% for all the available data of city pairs. With a set of 125 cities, a total 7750 unique OD-pairs do exist in the trip distribution and no traffic is generated within a city, because of the internal distance equal to zero consistent with the trip generation. International trips count for 38,4% of the total trips distributed, however 93% of the pairs are international. From the 7750 pairs, 248 generate more than a million trips (both directions) annually, of which 86 pairs are international. The apparent preference for domestic trip is a logical result due to the smaller distances for most domestic trips, and more importantly the (limited) amount of barriers perceived to get to a destination regardless of the modes available. It should be noted that this is specific between origin and destination and does not yet include the bundling over infrastructure. The main conclusion from the discrepancy between domestic and international destination choice is that lack of international travel is more related to country, language and Schengen barriers. In contrary to the believe that the barrier is created only by the lack of availability of alternative modes compared to road transport and the resulting resistance in mode choice.

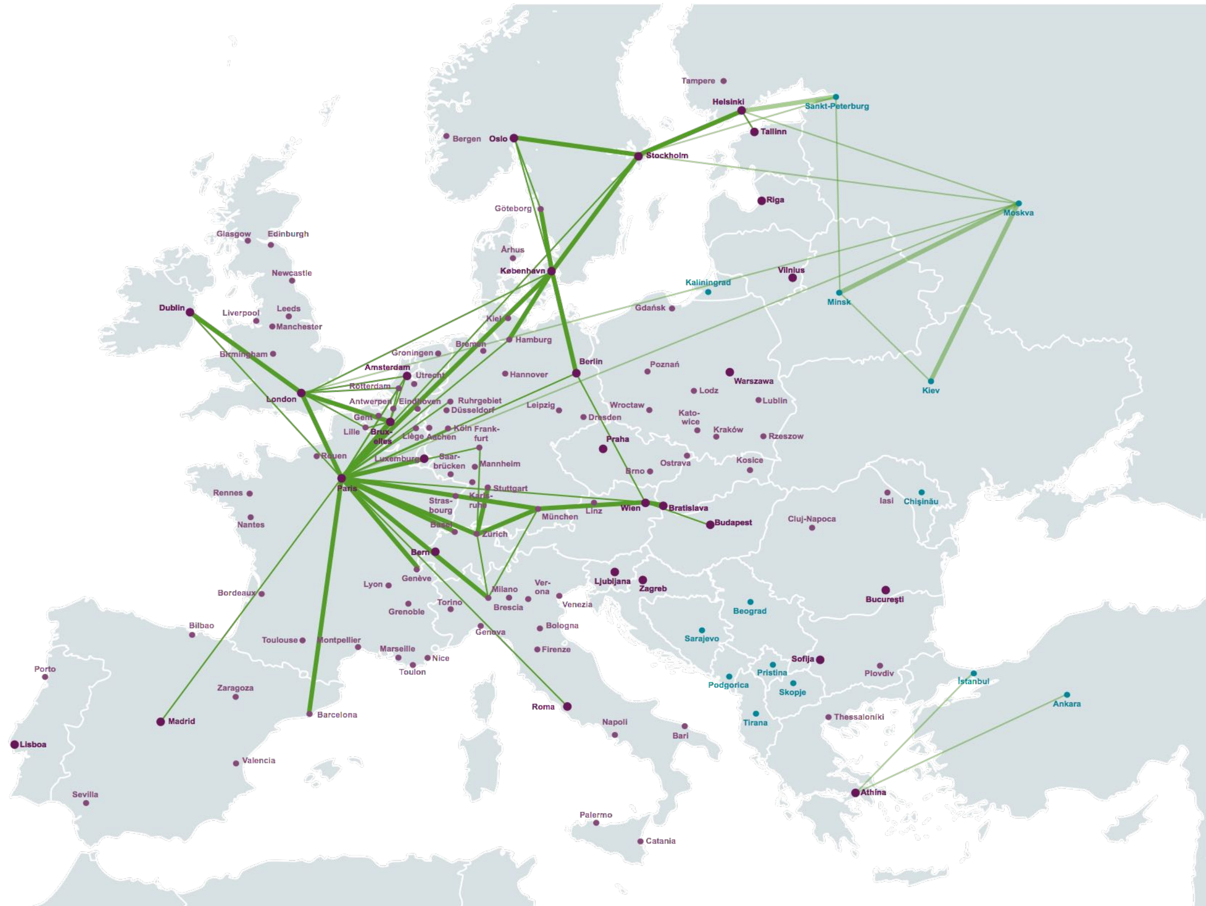


Figure 3.3 – Desire lines, destination choice, for international destination pairs, top 50 Europe (63 overall, thick lines is top 25), (Own calculations).

In Figure 3.3 an overview is provided of the OD-pairs in the European top 50 International pairs as well as the extra European pairs in the range. The least is Milan-Munich with 643.530 annual; trips in each direction (1.287.060 in both). Given the size of London and Paris it is no surprise that this has the highest desire of 10.808.559 trips in each direction. Once more the presence of the Blue banana is remarkable due to the direct relation between production (in trip generation) and distribution.

3.1.3. Modal Split

The modal split models the mode choice of the distributed trips. The choice is determined based on mode specific attributes and performance. As a result of the focus on potential, the potential performance should be taken instead of the actual service. This requires some additional data to base the mode choice on. First the approach and mode data will be discussed, followed by the method for determining the actual choices and finally outcomes.

General approach for mode choice

The method for choice determination is reminiscent of the performance ratio (VF) or empirical curve. This method uses the relative performance of a mode to the other mode to determine the likelihood of choosing a mode. Performance is a generalised perception of ‘cost’ encountered in a mode for a given OD-pair. For this report the performance is solely based on the actual travel time.

Mode choice is based on the differences in travel time for each mode. The fine-tuning of the trip distribution already used travel time as an explanatory factor for the market shares of each mode. The mode choices for both domestic and international trips can be very well explained by the mode performance on travel time (Ortúzar & Willumsen, 2011; Román et al., 2014; Schäfer, 2007). Other explanatory variables like (ticket) costs have a high correlation with travel time via the value of time (Buehler, 2011; Mabit et al., 2013; Whalen et al., 2013). It is however very difficult to determine the actual travel costs without detailing the underlying service and business models. Alternative attributes like transfers are disregarded because of the assumed optimal functioning and ideal network configuration for each passenger to really determine the potential. Given the fact that travel time has a good performance in the calibration and the possibility to provide the necessary aggregated and generalised information independent of existing service practices this is the only attribute for mode choice. As a result, determination of the mode travel times should be sufficiently accurate to capture the actual travel times experienced by average passengers between city pairs.

Mode data and network model

In chapter 2.4, the network as applicable for this report is discussed. This already described the distinction between different networks based on infrastructure and a further distinction on mode performance on these networks. Three infrastructure types are defined, road, rail and air. Road and rail both support two different modes and air only a single mode, planes. The distinction on infrastructure networks is made due to different availability in infrastructure connections. Each network has been built with adjacent link matrices notifying connections between cities. The distance and travel time is a function of the direct distance between cities (great circle distance) with a mode specific detour factor and a mode specific average speed. This results for each link in a link cost equal to the travel time over the link. The formula is provided below.

$$TT_m = \frac{D_{ij} \cdot \varsigma_m}{v_m} \qquad ;\forall\, m \in \boldsymbol{M}$$

$\boldsymbol{M}$: set of modes
TT_m: Travel time for mode m
D_{ij}: Great-circle distance between city i & j
v_m: Speed of mode m
ς_m: Detour of network for mode m

Network speed and detour factors

Chapter 2.4 discussed the network structure, with Figure 2.6 and Figure 2.6 (page 20) representing the road and rail networks. Each mode has its's own model schematisation for access and egress, with travel times for access and egress depending on the city characteristics. See Figure 2.7 (page 21) for a schematical representation of the different trips. In order to determine the detour factor and average mode speeds a regression analysis is performed on links in the network that closely relate to optimal operation.

In the 2015 network only 30 High speed rail links are available for regression, sufficient for a statistical significant data set. In addition, 30 conventional rail links are selected and based on these 60 selected relations as much data as possible for bus and car is collected. In Figure 3.4 an overview of the detour regression, in Figure 3.5 the overview for the speed regression. Overall fit for detour is R^2=98%, for speed it is lower due to distance estimation R^2=85%. Given these results for network performance and travel time, this could be an alternative method to make ex-ante estimations of new infrastructure, especially in the early planning stages with little knowledge of the routes. This could eliminate the structural over-estimation as found in ex-post studies (Kelly et al., 2015). Table 3.2 and Table 3.3 provides the overview of the results and used factors of each network as well as the supplements to the core network.

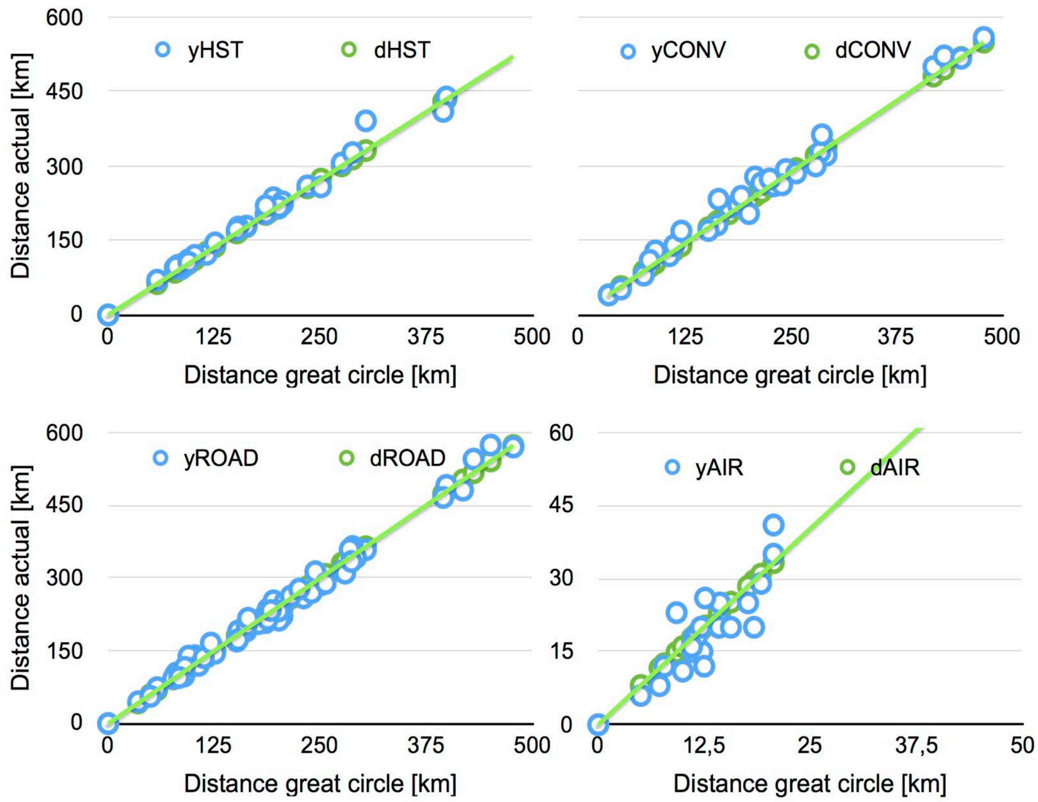


Figure 3.4 – Detour regression analysis. yXX (blue) = observed distance, dXX (green) = Modelled distance, (Own calculations & research).

	Train HST	Train C.	Plane	Car	Bus
Vgem [km/h]	220,00	110,00	700,00	100,00	65,00
Detour [-]	1,09	1,15	1,00	1,20	1,20

Table 3.2 – Main network characteristics for travel distance and -time. (Own calculations & research).

	Ferry	Airport	City
Vgem [km/h]	50,00	60,00	30,00
Detour [-]	1,00	1,61	1,10

Table 3.3 – Main network supplement characteristics for travel distance and -time. (Own calculations & research).

Airport and station access travel time

Access time for the airports is determined in similar fashion as the mode travel times, with the great circle distance between city centre and the airport location. Airports are selected on IATA designation of serving city. For cities with multiple airports, (e.g. London), only a single airport for each city is modelled. The modelled airport always represents the biggest airport of the city. Eliminating the possibility that a favourably located, but unable to handle all the potential traffic airport is selected.

Some cities do have airports with IATA-codes so are regularly served by flights. However, in order to ensure a proper representation of possibilities some limitations are presented if an airport is used in the model. Airports with less than 500.000 passengers annually where assumed to be too small to have regular possibilities to link cities. Cities left without an airport (e.g. Antwerp have been linked to the closest airport that does match the criterion. Additionally, if the trip distribution, without model split has less than 25.000 passenger between city pairs, an air link is very unlikely to succeed profitably, these journeys via air have also been detoured to bigger airports. These precautions result in more realistic travel times for plane travel.

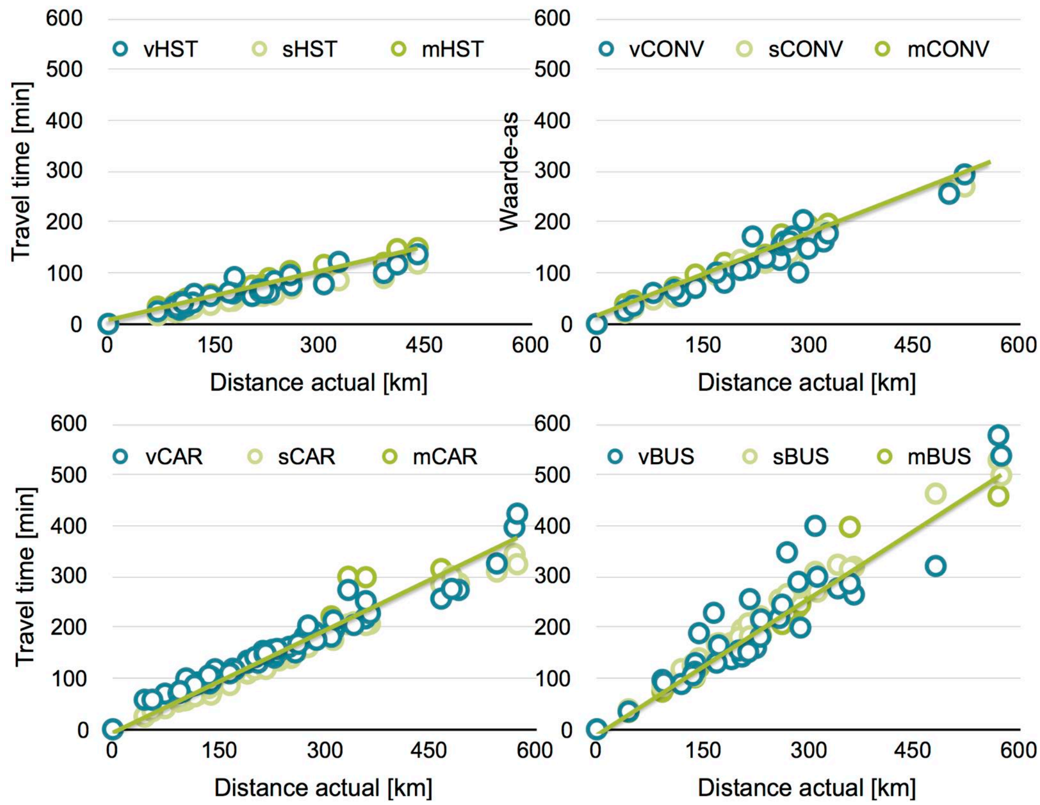


Figure 3.5 – Speed regression analysis. vXX (dark green) = observed travel time, sXX (light green) = Initial estimated travel time, mXX (green) = Modelled travel time. Angle denotes the speed. (Own calculations & research).

Air travel has a time disadvantage to other modes due to the way passenger are handled at airports compared to other modes (in Europe). This is modelled with an actual waiting time at the terminal dependant on the destination. If the internal market border of Schengen is not crossed, there are no passport controls involved, only security checks. Travelling outside Schengen, custom controls are added to the journey. In addition to the passenger waiting time at the terminal, the plane has also additional flight time. Gate to gate travelling involves board checks, taxiing and hold patterns without getting closer to the destination gate. A fixed time penalty for each flight is added.

Access to train station is reversed to airport access. People first have to get to the station from the surrounding city area. This is modelled with a distance based on the average city radius based on the area of the metropolitan area. City travel has its own detour factor, very low due to the many possibilities, however with a low speed.

Method for modal split

Based on the mode network and imposed link cost the shortest path between cities is determined. Shortest path is based on travel time, not on actual travelled distance. The shortest path is selected with weighted paths, being the travel time via the Dijkstra algorithm (Dijkstra, 1959). This will return the shortest path cost for each pair and mode in the network.

The different path costs for each OD-pair, including the explained city specific supplements for access and egress determine the choice set for the modes. Choice probability is determined with Random Regret Minimisation (Chorus et al., 2008), instead of the more common Random Utility Maximisation. This choice is based mainly on the fact that RRM also takes into account the performance of other alternatives to determine the regret avoided by choosing an alternative. In the trip calibration the estimation of the total capacity showed that RRM did have a better fit and explanation for the observed market shares compared to RUM, especially for the difficult smaller distances. The mathematical formulation is the following:

$$R_m = \sum_{n \neq m} \sum_{TT} \ln\left(1 + e^{[\gamma_{TT} \bullet (x_{nTT} - x_{mTT})]}\right) \quad ;\forall\, m \in \boldsymbol{M}$$

$\boldsymbol{M}$: set of modes

R_m: Regret value for mode m

γ_{TT}: Sensitivity for attribute TT

$x_{mTT} = TT_m$: Mode specific attribute value

In case that the error is distributed i.i.d. Extreme Value Type I, which is assumed to be the case, the probabilities follow Logit-probabilities:

$$P(m) = \frac{e^{-R_m}}{\sum_{TT} e^{-R_n}} \quad ;\forall\, m \in \boldsymbol{M}$$

Modal Split applied

For each OD-pair a maximum of 5 competing modes is calculated. It is hard to provide any conclusion on the bare data itself of the modal split. On itself the modal split is not as interesting as it is when combined into the route assignment bringing all steps together into a single link of passenger travelling. Nevertheless, it is possible to provide some aggregated or city specific insights into the modal split. Figure 3.6, on the opposite page, shows the modal split graph. This is completely as expected and does not reveal any surprises on an aggregate level and is in line with previous mode choice studies for long distance (Goeverden & van Arem, 2010).

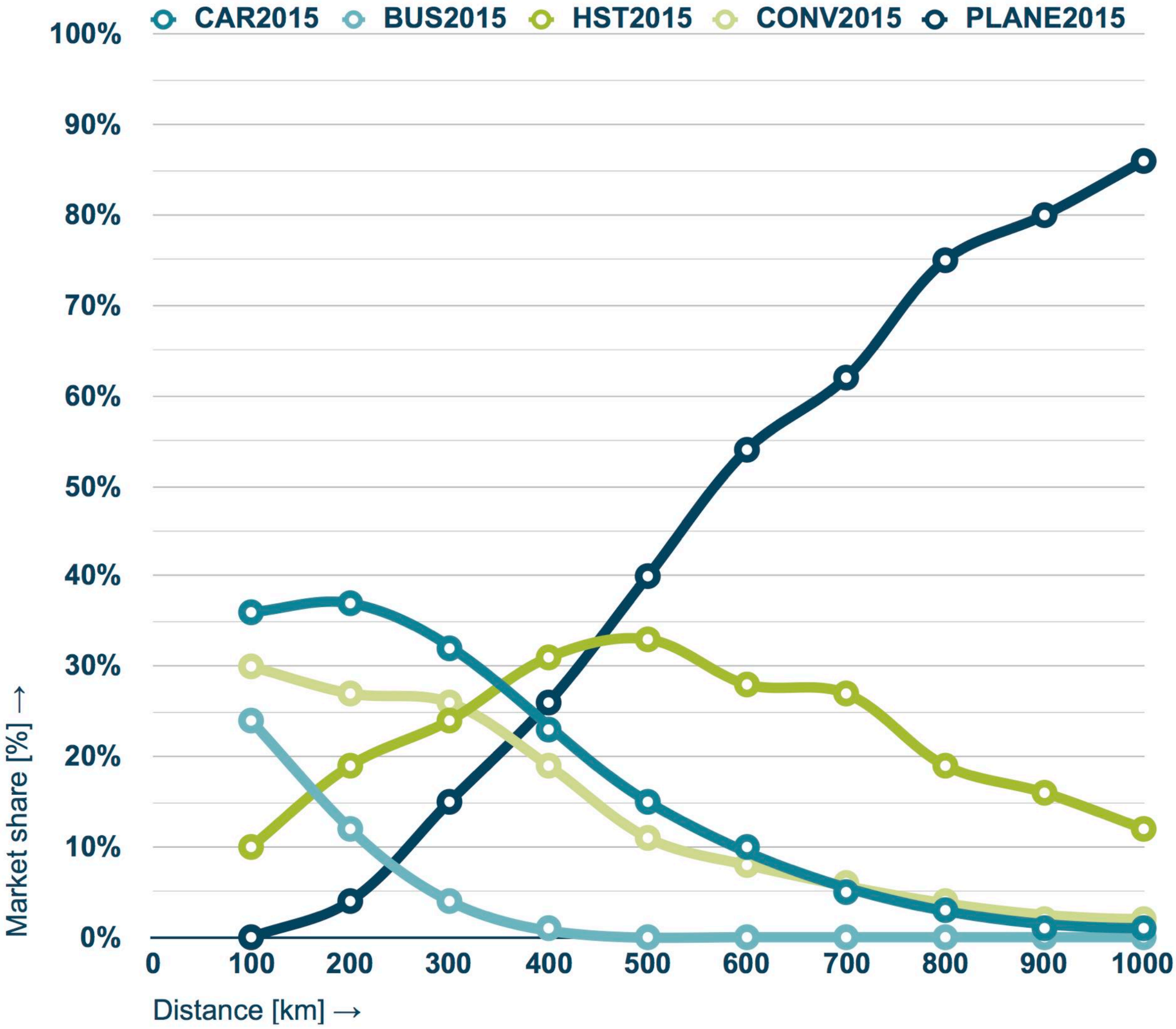


Figure 3.6 – Modal split graph 2015 per distance; (HST = High Speed Train, Conv = Conventional rail), (Own calculations & research)

It is apparent that train travel is very attractive up to 500km. even up to 1000km the train is able to provide significant modal split when Conventional and high speed services are combined. This is also in line with ongoing policy which has train travel as the preferred mode of transport up to 750km (Albalate, Bel, & Fageda, 2015).

Some connections are already provided more or less in an optimal way. Eurostar claims market shares (Wolmar, 2014) on the Paris/Brussels to London market of around 75% which is also the case in the model. When focussing on the interval between 400 and 500km, the goldilocks position of high speed trains, cities with good high speed connections score very well. Cities without an airport or low generation (so a lot of OD-pairs below the capacity threshold for viable air transport), score also very well. The penalty of having to travel to another airport first as well as sitting idle in the airport and plane is especially heavy on the relative short distance.

It is more the general connectivity that does count in this case because in the top 25 (Table 3.4) are also many cities which do not have direct access to the high speed network however are as a spider in the railroad web. The influence of an existing railway network is apparent for long-distance travel with an environmental aware capital like Copenhagen serving only 11% of the 400-500km by train (Figure 3.7), compared to 70% for Paris.

	City	Car	Bus	Train	Air
1	**Zaragoza**	12%	0%	85%	3%
2	**Aachen**	16%	0%	75%	10%
3	**Rouen**	8%	0%	74%	18%
4	**Gent**	18%	0%	74%	8%
5	**Iasi**	24%	0%	72%	4%
6	Paris	**4%**	**0%**	**70%**	**27%**
7	London	**5%**	**0%**	**70%**	**25%**
8	**Utrecht**	15%	0%	70%	15%
9	**Leeds**	5%	0%	70%	26%
10	**Rennes**	4%	0%	70%	27%
11	**Lille**	7%	0%	68%	24%
12	**Birmingham**	11%	0%	68%	21%
13	**Kiel**	23%	0%	63%	13%
14	**Brescia**	18%	0%	62%	21%
15	Amsterdam	**9%**	**0%**	**60%**	**31%**
16	**Koeln**	7%	0%	60%	33%
17	**Manchester**	10%	0%	60%	30%
18	**Mannheim**	13%	0%	60%	26%
19	**Grenoble**	12%	0%	58%	30%
20	**Antwerpen**	9%	0%	58%	34%
21	**Karlsruhe**	13%	0%	58%	29%
22	**Liege**	9%	0%	55%	36%
23	**Ruhrgebiet (Essen)**	8%	0%	54%	37%
24	**Rotterdam**	9%	0%	54%	37%
25	**Bologna**	9%	0%	53%	39%

Table 3.4 – Top 25 train modal split, distance class: 400-500km, (Own calculations)

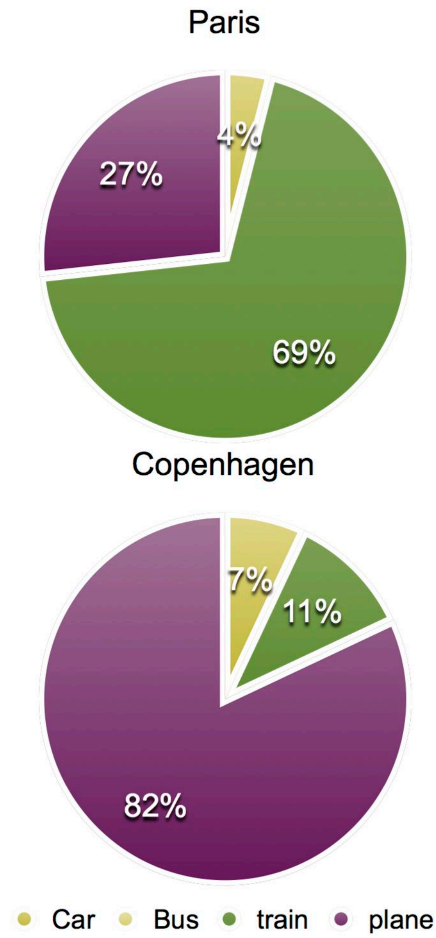


Figure 3.7 – Modal Split comparison, (Own calculations).

3.1.4. Route Assignment

The route assignment is the choice of route given a certain mode. The mode has been chosen in the previous step, providing the input on how many people would travel by a certain mode on the direct OD pairs. This traffic should be loaded onto the network to get an understanding on what routes are used. The network upon which the routes are chosen is not very fine grained, limiting the probability that alternative routes to the shortest path would result in high yields. The main method for route choice is as a result all-or-nothing assignment (AON). All traffic on a OD-pair and mode chooses the same path.

The path that will be chosen is the one with the least barriers or shortest travel time, also known as the shortest path. These paths have already been determined for all OD-pairs in the process of the previous step, the modal split, via the Dijkstra Algorithm. The algorithm stores all shortest path making it possible to export a link graph consisting of all possible routes using a particular link. The link load results from bundling multiple OD-flows over a single link in the network. This bundling is what provides train transport with an advantage over flying, which can only be strictly point to point. Additionally, it could be infeasible for a single OD to have trains running on a convenient base, but with the addition of flows from other pairs, the economic base would be sufficiently large.

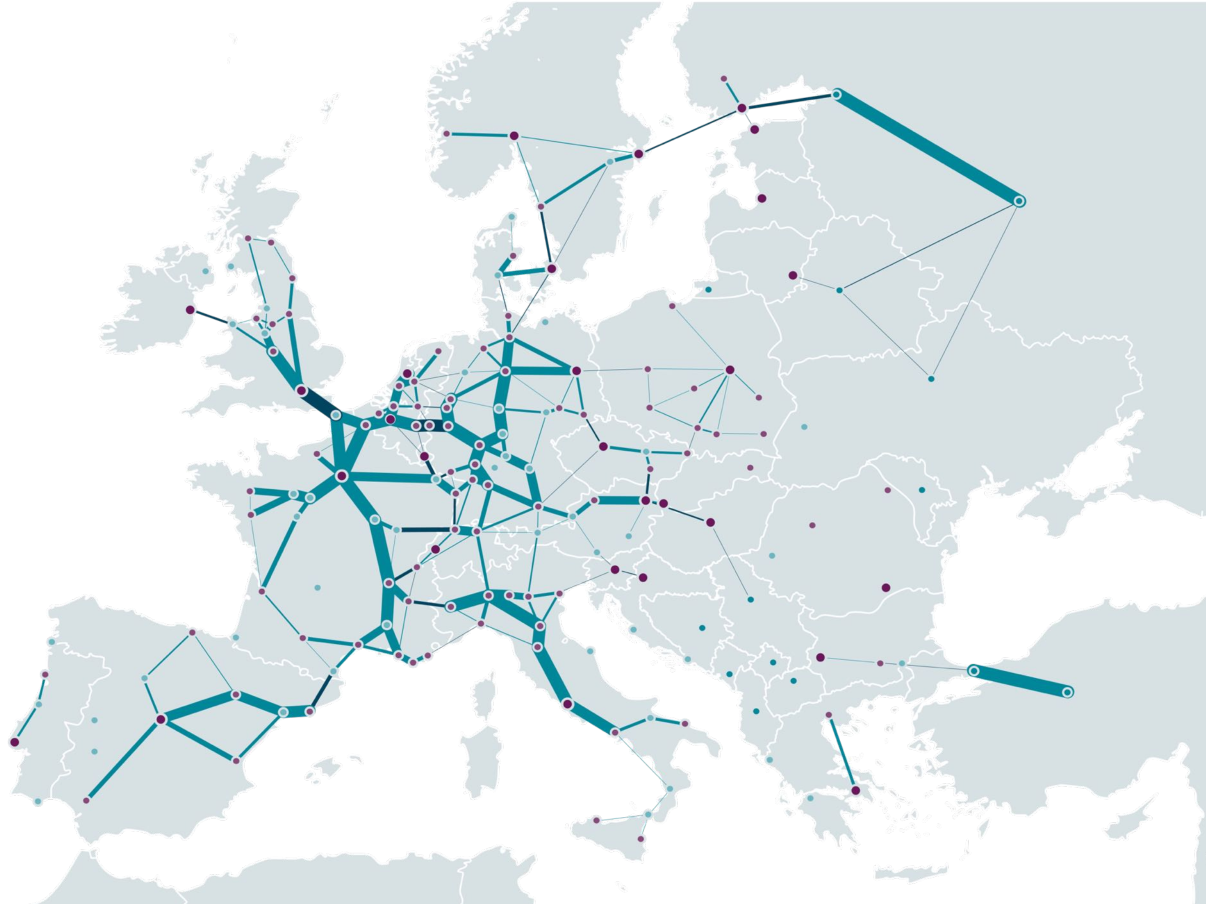


Figure 3.8 – Network assignment 2015, thickness of the link denotes the amount of traffic using a link, if amount is smaller than 250.000 trips annually the link is not shown, (Own calculations).

As a result of the limited space of paper and the relative high density off links a proper form for presenting the results is prepared and made available via: www.train2eu.org/research. The link map alone however, consists of all the possible routes from a single mode, for rail based modes 325 links and 15225 unique pairs (including the additional network cities). This results in almost 5 million data points without any additional information about OD loads and modal split distributions, neither link info nor travel time. In total five such networks are constructed, with the air network being the biggest because air travel is possible between any airport pair.

In Figure 3.8 is a map with the links loaded for HST and conventional combined, the darker edges are cross border links. Links with a load under 250.000 in a single direction are not included due to the insignificance for actual train operations, even if the perceived optimal could be realised. The busiest is between Paris and Lyon, 23 million potential passengers/year/direction, consistent with the claimed (Cox & Vranich, 2008), of 39 million passengers. The loads for each link are provided in Appendix E.

3.2. Modelling adoptions

The following list is a summary of all the key assumptions made in the modelling process. Most have already been described in the previous explanations of the different steps and methods. Similarly, the references for the statements have already been provided. The adoptions can be interpreted as strengths or weaknesses; they are stated as a disclaimer for the considerations that have been made. Furthermore, the adoptions are a preliminary list of discussion for the interpretation of the obtained results and recommendations on additional research challenges.

- Data is the main challenge in the research, especially reliable, consistent, openly accessible data. This necessitates some aggregations (metropolitan regions vs. larger urban zones) and calibration on estimation of total flows fitted by travel time. Additionally, this makes it difficult to provide statistical significant input for some model. This report nevertheless makes the trade-off in order to provide answers based on reliable open-access data resources.
- Complete elimination of geographical areas and population as well as all other attributes outside the 125 cities in the scope, with the exception for additional network (city nodes) and rest zones in generation and distribution. Especially for tourist travel, rural areas can account for a significant flow. Choice for elimination is based on keeping a manageable scope.
- Generation only based on GDP/capita, a typical production indicator and the elimination of a separate attraction indicator. Leaving the possibility for a skewed distribution for cities that are small in production (low inhabitant levels or low GDP/capita), but have a high attraction level. This does introduce a bias, however given the Urban Hub city set, the size and select set of cities this will be limited. The introduced error will be no greater than the goodness of fit error of 10%.
- GDP/Capita and average willingness to travel (*t*) as main indicators for trip generation on a per person base. Also using the found willingness to travel for the EU for other countries. Justified by adoption of willingness to travel to the ratio of GDP/capita.
- The willingness to travel (*t*) is defined for long-distance travel (>100km), however the city set does include some pairs with smaller in between distance, over which all the passengers are distributed. Choices in reality are never made over a specific sub-set.
- Network has been simplified, however all averages hold for the defined links. The adopted values also hold for Eastern Europe, according to the regression analysis. As a result of the selection of cities, all being of significant size/importance, links between these cities are well established with regard to infrastructure quality. Special links do also allow ferries and the access and egress features optimise realism for multimodal trips. This results in a R^2 of 98% on detour factors and for speed the goodness of fit is 85% for all the modes, taking into account the modelled network characteristics with access and egress of airports and stations. Airport accessibility is exceptional in being more diverse due to the wide range of possible placements of airports around cities.
- Travel time (door-to-door) is a good indicator for mode choice (Schäfer, 2007), although preference in modern transport models is to include more attributes, the size scope and goal of potential limits the possibilities to include other attributes. Additionally, travel time in combination with RRM performs well as explanatory mode choice.
- Mode specific barriers that relate to the operations of the mode are only taken into account for flying. This may seem as unfair competition in the model, however the airline market has already been disrupted on price with a complete commoditisation of the product as a result. The operation for the passenger however have not changed, flying still involves actual waiting. Railway and bus operations on medium and long-distances across Europe proof that waiting for a train (or bus) should not be necessary when properly implemented. The waiting time of flying is thus a result of the complete system or infrastructure and not of the individual operator.
- Modes are not always available, either the necessary infrastructure does not reach the city, like airports. Or the amount of people does not justify a way of transport by the particular mode.

- Modes should be significantly different to prevent generating nesting effects, especially with high speed trains running on conventional tracks. If the OD travel time for HST and conventional are equal, HST is disregarded. If not, conventional rail is only considered if the travel time is 1,5x or 120 minutes longer. If travel time is 3x as long as the HST conventional rail is disregarded. This ensures a proper way of defining mode distinction within the network.
- Price performance or underlying cost structures of modes is not taken into account. It is assumed that the price performance of each is equal to the expected level of service. In practice this would result given the travel times an equal price for all offered modes.

3.3. Future passenger-trip potential

The future potential in this report is meant as an outlook on what to expect in the future and what the possibilities are of the future. The outcome of the seating capacity potential and preliminary core network can be assessed and justified by what the future scenarios provide as guidance and opportunities. The future potential is discussed first with a general introduction of the data involved and the quantification of the previously outlined scenarios. Then the 4-step model is filled in for each scenario with on every step an assessment compared to the current situation of chapter 3.1.

3.3.1. Quantification of scenarios.

For 2030 the 4-step model is filled in once again. The steps, adoptions and methodological framework will be equal to the present day situation, however the input into the model will change according to scenarios developed in chapter 2.5. and summarized in Table 2.4. In combination with the Global Europe 2050 report, data is found through global consultancies or development organisations (OECD, IMF) and existing reports (Gros & Alcidi, 2013; Hawksworth J. T. Hoehn and A. Tiwari, 2009) to adjust the input data. Three themes are used to group the different scenario factors, economy travel and institutions.

Within the economic theme, the population scenarios are all based on fertility rates and migration scenarios which are independent of economic scenarios. Cases where population is important for economic predictions, always the most likely average scenario is used. For this report the same approach is used. Eurostat has made population estimations for all the metropolitan regions selected as Urban Hubs which will serve as new population in all future scenarios. All other data of the economic theme, GDP (per capita) and infrastructure will change for each country specifically. Some countries will react differently on the economic challenges or opportunities of the future than others. This has to do with the differences in maturity of the economies across Europe. Nevertheless, the general consensus will follow regardless of the scenario a path of increasing urbanisation.

Travel indicators can change across Europe because they are applicable to more city specific data. The willingness to travel diverges between -30% and +30%. The +30% is rather conservative, there are indications that the value of 12 trips annually is already becoming a standard. There is no indication or scientific research available that suggest that economic developments cause shifts in travel time sensitivity or mode preference. On a household and social group level there are limited indications that economic events with great impact on the personal life of people does trigger structural behaviour change nevertheless (Ulfarsson, Steinbrenner, Valsson, & Kim, 2015). This is however related to commuter traffic and deemed outside the scope of this research.

The final theme, institutions, is also applicable across Europe because these are the barrier factors perceived when travelling long-distance. There is no indication that the EU will be able to change the federalist barrier in certain countries, however the expectation is that the three scenarios provide a clear guidance on the development of the other barriers. Either Schengen, at least in perception is abolished in the Div-scenario. With returning border controls across the continent (eliminating the additional Schengen barrier as well). As result of reduced travel, language gaps become greater. Or on the other side of the spectrum, the integration with a further abolishment of borders and language barriers due to mutual understanding. Evidence does exist that (perceptual) trade barriers can deteriorate very quickly (Santana-Gallego et al., 2015). All three themes quantifications are summarized in Table 3.5.

Theme	Factor	Divergence	Status Quo	Integration
Economy	GDP	-	-/+	+ +
	Population	|	|	|
	Infrastructure	-/+	+	+ +
Travel	Average trips	-30% (t=6)	0% (t=9)	+30% (t=12)
	Time sensitivity	|	|	|
	Mode preference	|	|	|
Institutions	Country	6,05 (+2,02)	4,03 (-)	2,02
	Language	8,12 (+25%)	6,50 (-)	4,03
	Schengen	0 (-2,02)	2,02 (-)	2,02

Table 3.5 – General scenario quantification, (based on: European Commission, 2012a; own elaboration)

3.3.2. Future trip generation

The method for trip generation is kept exactly as for the current situation time frame. The input is adjusted according to the scenarios. No cities are added to selection neither subtracted and the properties of the cities, with regard to country, language, area do not change either. Population does see a country specific increase. The increase for all Urban Hubs is the result of the relative short time-span, most countries start having lower citizenship around 2050. Little to no year-over-year growth in GDP/capita results in minor 15-year growth in the divergence scenario and much higher average year-over-year growth in major 15-year increases for the integration scenario. Remarkable is the incredible growth expectations of eastern European countries. Although still conservative compared to the last 15 years, in which some have grown 250%. The willingness to travel does change for the divergence and integration scenario, however the mean GDP will change according to data set, and the assumption will hold that the average European will make a long distance trip *t* times a year.

In Table 3.6 an overview of the top 25 cities, most fond of travelling, ranked for 2015. The numbers in front of the generated trips is the ranking of the city in the respective scenario. In Figure 3.9 the same 25 however rendered as a graph, London and Paris are left out of the graph, because they would distort the scale. Between 2015 and 2030 there are some big changes, upcoming economic powerhouses will lapse past giants. In all scenarios the biggest growers are the same cities as a result of the spectacular mix of population and economic growth. Between the different scenarios, there is not much difference in relative generation. There is however a huge difference in actual performance. Only 5 cities will increase the amount of people willing to travel in the divergence scenario and on average 27% less trips will be made. For the Status Quo there is an overall increase of 10% with 90 cities growing and 58 more than average. In the integration scenario, despite the huge growth in mean GDP/capita (+25%), trips will increase with 47% and all cities will increase their trip generation.

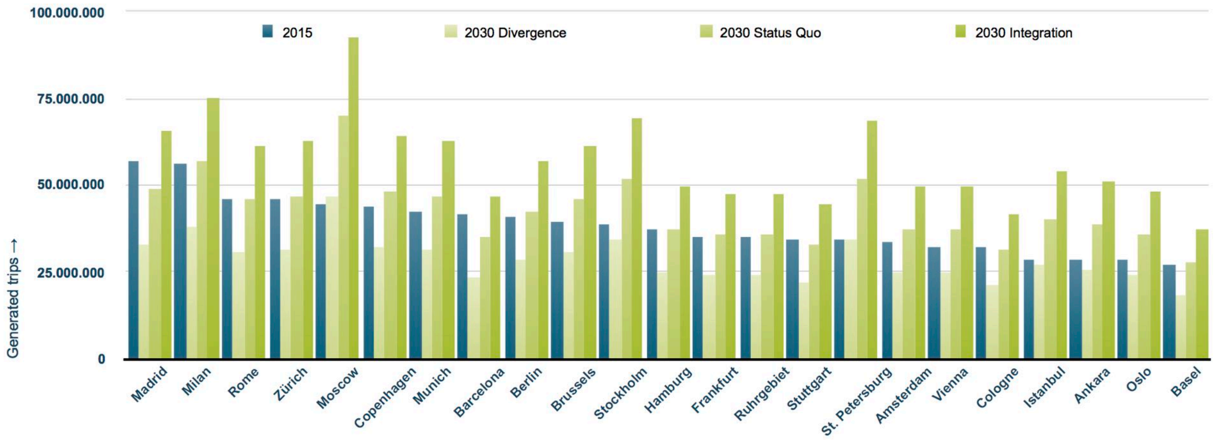


Figure 3.9 – Trip Generation, top 25. London and Paris left as a result of size distortion, (Own calculations).

		Trips 2015		Trips 2030 Divergence		Trips 2030 Status Quo		Trips 2030 Integration
		2.229.764.240		**1.638.285.969**		**2.458.338.384**		**3.276.204.504**
Paris	1	180.852.819	2	131.853.227	2	198.727.095	2	264.700.736
London	2	179.126.144	1	145.078.248	1	218.125.506	1	289.928.516
Madrid	3	56.891.307	7	32.706.230	7	49.290.859	7	65.650.547
Milano	4	55.928.588	4	37.725.928	4	56.777.804	4	75.533.099
Rome	5	46.093.815	12	30.476.029	12	45.866.651	12	61.017.688
Zurich	6	45.755.254	10	31.342.575	9	47.018.318	10	62.840.712
Moscow	7	44.504.789	3	46.765.494	3	70.082.258	3	92.888.793
Copenhagen	8	44.091.500	8	32.242.679	8	48.063.837	8	64.395.366
Munich	9	42.719.375	9	31.489.760	10	46.941.469	9	62.891.629
Barcelona	10	41.586.903	22	23.265.720	22	35.063.269	22	46.700.805
Berlin	11	41.249.451	13	28.687.030	13	42.763.467	13	57.293.991
Brussels	12	39.492.563	11	30.552.379	11	45.890.806	11	61.407.648
Stockholm	13	38.905.839	5	34.618.960	5	52.049.692	5	69.183.519
Hamburg	14	37.400.410	16	24.982.586	18	37.241.290	17	49.895.443
Frankfurt	15	35.104.997	20	23.903.433	20	35.632.607	20	47.740.149
Ruhrgebiet	16	35.104.997	21	23.903.433	21	35.632.607	21	47.740.149
Stuttgart	17	34.129.562	23	22.309.770	23	33.256.950	23	44.557.271
St. Petersburg	18	34.078.334	6	34.530.499	6	51.747.028	6	68.586.816
Amsterdam	19	33.377.930	18	24.866.215	16	37.477.965	16	49.919.942
Vienna	20	32.524.006	17	24.938.077	17	37.365.007	18	49.880.657
Koeln	21	32.202.385	24	21.045.761	24	31.372.705	24	42.032.782
Istanbul	22	28.861.204	14	27.140.249	14	40.581.533	14	54.030.041
Ankara	23	28.824.594	15	25.744.714	15	38.494.856	15	51.251.850
Oslo	24	28.433.855	19	24.180.344	19	36.045.395	19	48.293.198
Basel	25	27.033.119	27	18.574.446	27	27.864.310	27	37.241.083

Table 3.6 – Trip Generation, top 25, (Own calculations).

3.3.3. Future trip distribution

The trends of the trip generation are similar in the distribution, when less people are willing to travel or less trips are undertaken, less pairs will pass the set thresholds. Also the development between the scenarios is similar to the distribution. Except for the fact that domestic travel decreases and international travel becomes much more attractive. In the current situation 38% have a destination abroad, in the divergence scenario this is the lowest due to the high barriers. In the Integration scenario this increases to almost 50% of all trips.

For all scenarios the London-Paris and Paris-Brussel pairs have the highest amount of desired trips. For western European destinations a clear decrease in trips is recorded in the divergence scenario, this is not the case for metropolitan zones outside Europe. Partly explained by a limited need to adjust to the new stricter border situation. In the European top 50 (Appendix F) as was presented in Figure 3.3 (page 34) very limited changes, some city-pairs leapfrog, however very limited structural changes in desire or the willingness to go somewhere else. Figure 3.10 provides an illustration of the development of trips over 5 selected OD-pairs.

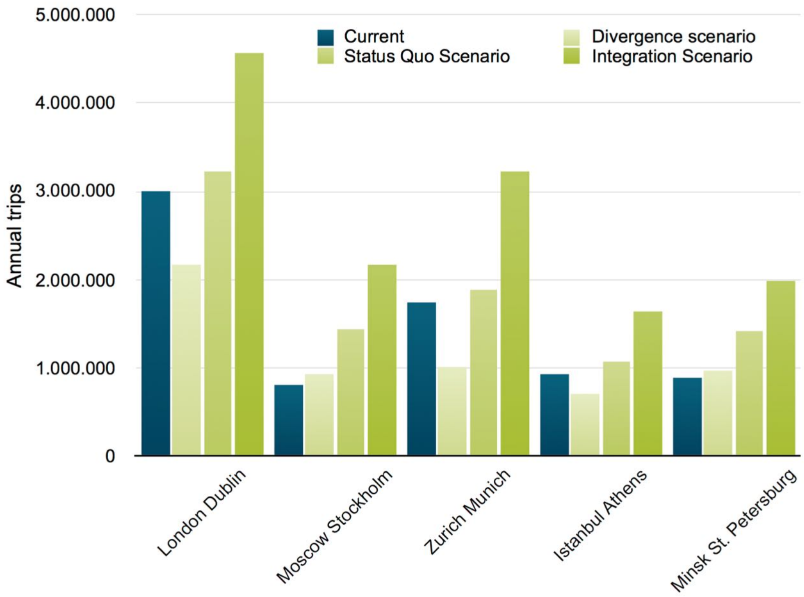


Figure 3.10 – Trip distribution comparison with scenarios, cities in Eastern Europe see grow in all scenarios, Western European cities see decline in divergence scenario, (Own calculations).

3.3.4. Future Modal Split

Modal split is based on door-to-door travel times calculated based on the available infrastructure. Network properties in itself stay the same, so no adjustments to detour factors and average travel speed. The network themselves however do develop. These developments are focussed on long standing policies, like the completion of the TEN-T core network by 2030 (European Parliament & Council of the European Union, 2013) with railway lines for passengers at a HST-standard. As a result, new links are modelled, 2 links in Div. scenario, 3 more links Quo and 5 more in Int. In modelling the future network, the current project situation is taken into account. For construction of a project, 15 year should in general be sufficient, it is however very unlikely that something gets built in this timeframe if no public plans exist yet. In addition, the scenarios are interpreted as political climate to move forward with large scale transport investments, sometimes perceived by the public as prestige projects. In a very difficult investment climate (Divergence) projects, even projects in construction will not be finished, in a positive climate (Integration) visionary projects will still be greenlighted. In Figure 3.11 the 4 network states over the different time frames are provided for the railway network.

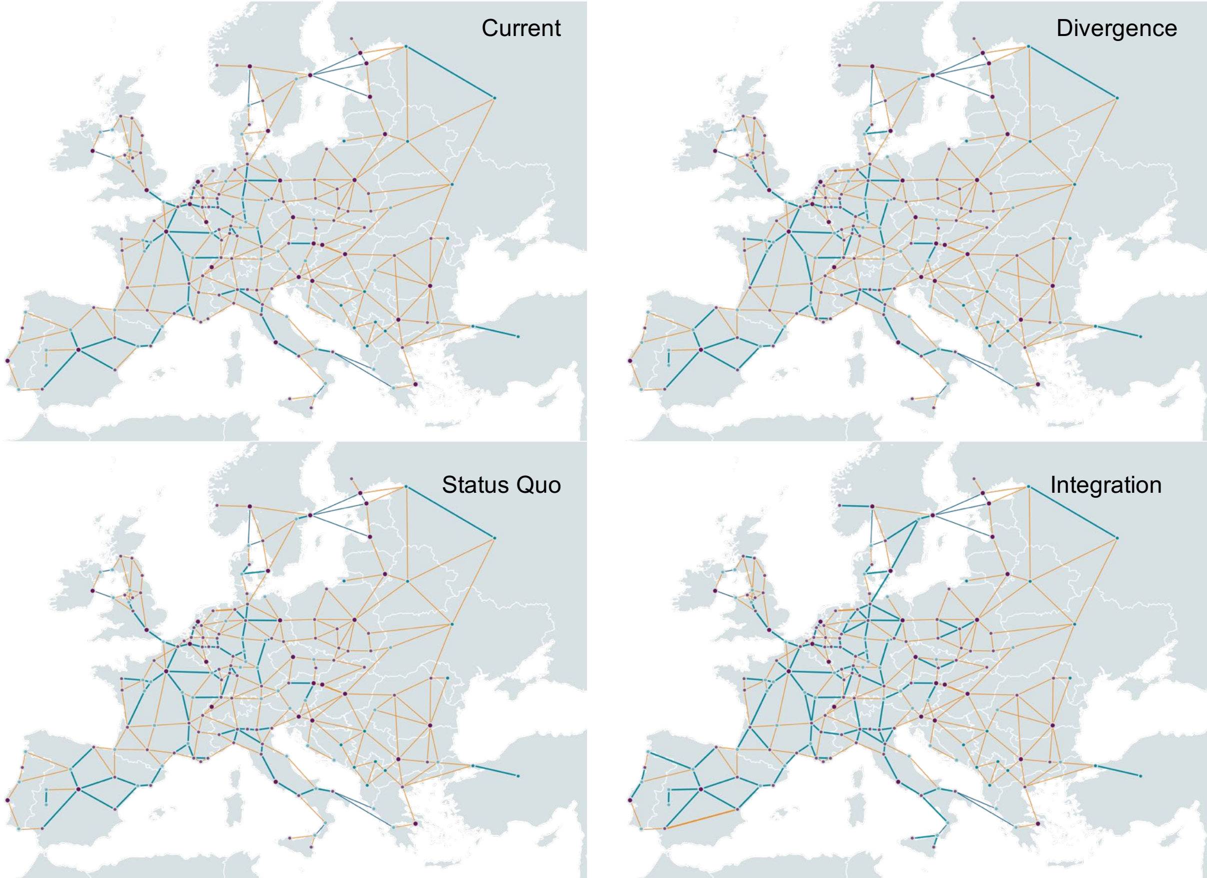


Figure 3.11 – Network of the different scenarios 2030, bold lines is HST, (Own elaboration).

As a result of the increased high speed network capability and the increased network effect of high speed, the train becomes incredibly competitive in market share. This is already apparent in the divergence scenario, where finally vital network pieces will be completed in the high speed rail network. In Figure 3.12 (next page) an overview of the different modal splits is provided, based on the percentage share of traffic choosing a mode. It is very clear that in the integration scenario, without additional investments in infrastructure, just finishing existing plans, an incredible modal shift can be realised. From 50% rail in 2015 to 68% in 2030 at the distance class 200-300km. However much more important is the shift around 1000km. Air traffic could be possibly as low as 65%, just by providing a complete network as competition instead of all kinds of bits and pieces.

In addition to the modal split in percentage shares, as common for providing the aggregated choices per mode, Figure 3.13 provides an overview of the modal split in trips, with the right figure being a zoomed-in and clarified version to show the changes in the 500-1000km range. Directly obvious is the incredible peak of traffic in the 300-400km range, with train taking the majority share this creates a peak at this range. Traditionally this has always been a very good and competitive market for train traffic, this could become even better with a market twice as big of 300 million annual trips in this range. For the future this market almost doubles in size, consistent with the overall market growth. It should be noted that although the model split of air traffic reduces by 20% absolute points (2015-2030Int), the absolute amount of potential passengers still has increased by almost 10million, due to the bigger market in this scenario.

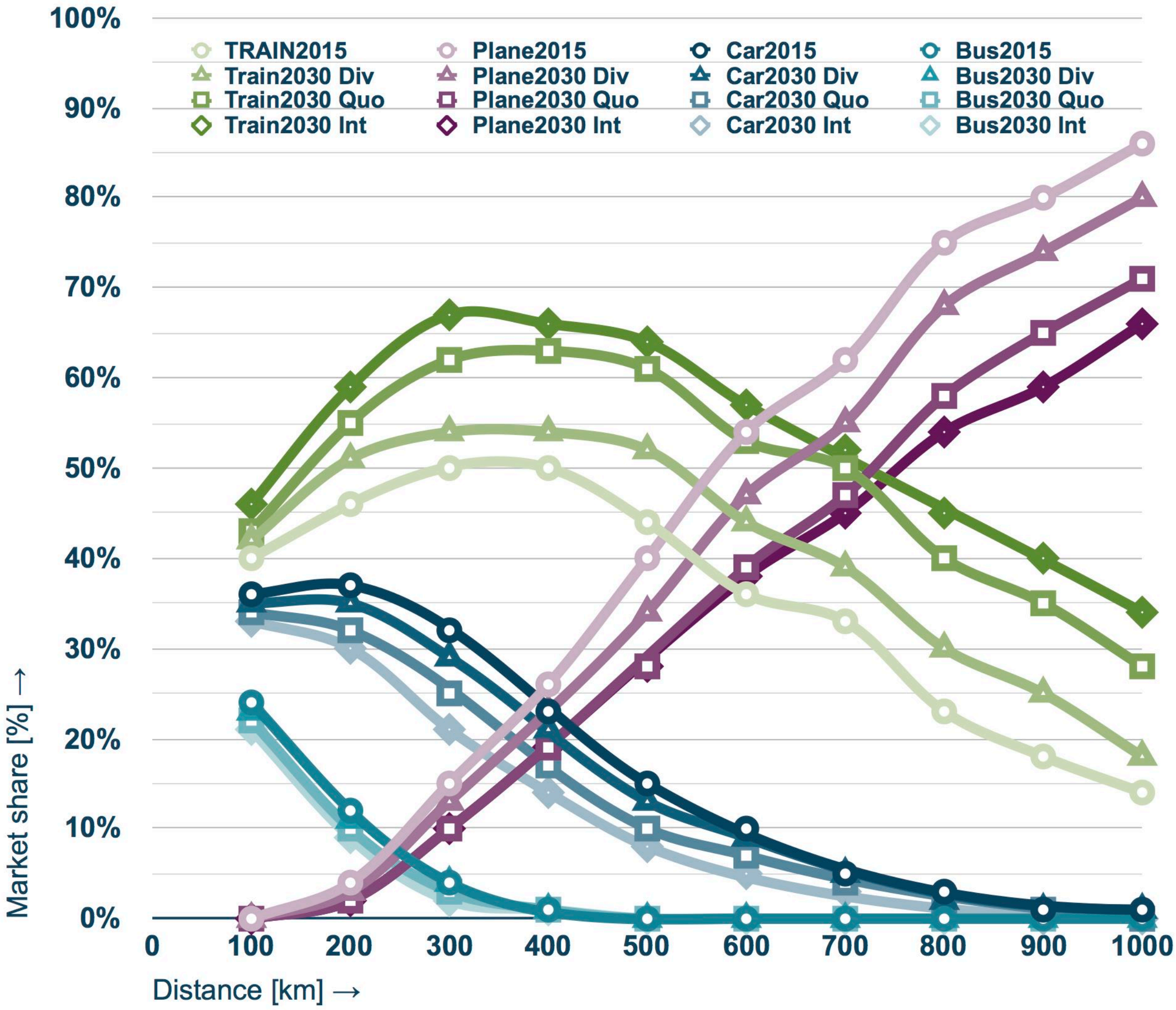


Figure 3.12 – Modal split (%share) per distance in different scenarios, (Own calculations). Scenarios: Div =Divergence, Quo = Status Quo, Int = Integration.

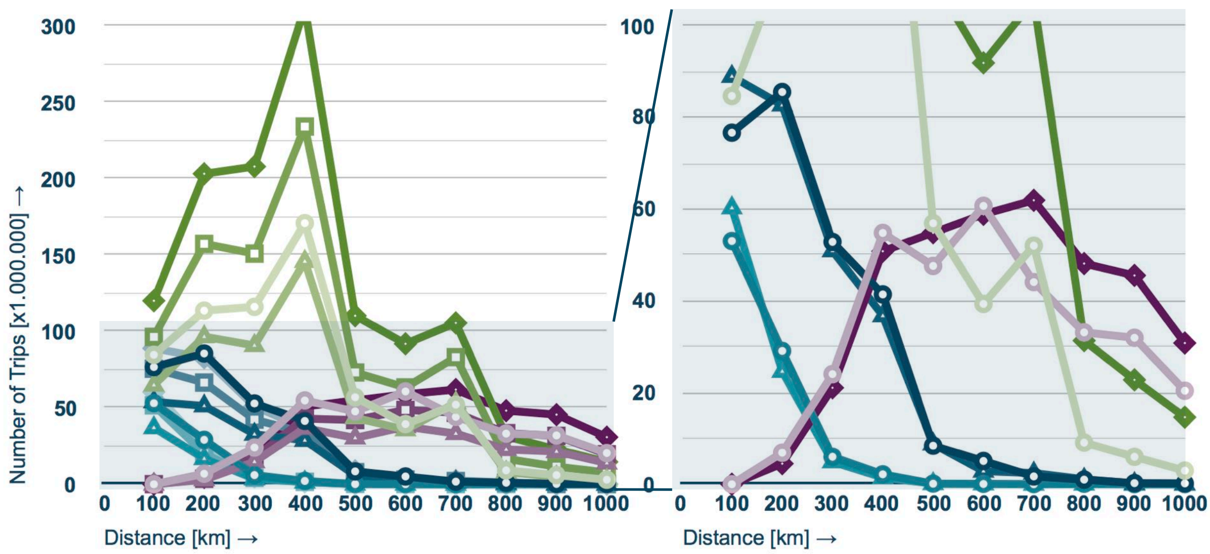


Figure 3.13 – Modal split (1.000.000 trips) per distance in different scenarios, (Own calculations). Colours and shapes corresponding to Figure 3.12. Left complete overview of all Scenarios and complete result range. Right, crop with only 2015 and 2030 integration scenario.

Based on this market share and shift from air to rail some environmental effects could be estimated. The amount of CO_2-emission that could be reduced is impressive especially given the fact that the scenario with the highest modal split for train is also with the most trips. Based on the emission factors of CE Delft, (CE Delft, Otten, ’t Hoen, & den Boer, 2015), and the model split up to 1000km, the shift from train to plane would cut CO_2-emmissions by 28 million tonnes each year. An additional shift can be observed from car to train, on some lower distance classes. Even given the fact that more trips are made and people in Europe have become more mobile, the reduction in CO_2-emmision is still realised. The increase in traffic is offset by non-uniform distribution in distances classes as presented in Figure 3.13. Reduction of pollution is not only limited to CO_2-emmission; also other pollutants (NO_X, PM10, noise, etc.) can be reduced. Additionally, the shift from train to plane also shifts the locations of the pollution, from high in the air to the ground, where the generation of electricity takes place.

One of the most remarkable findings of the modal split model is the insignificant performance of bus travel. Many TOCs are afraid that competition of the bus will break their business model. Based on this transport model, not taking into account ticket prices but merely travel times, this threat would not exist. Apparently people are willing to sit much in a bus to avoid a train.

3.4. Passenger-trip potential conclusion

This part of the report provides the answer to the following set of sub-question:

B What is the passenger-trip potential, demand, of the European railway market?

- a How many people will travel between destinations (trip distribution)?
- b What is the expected modal split between destinations (mode choice)?
- c How are the different destinations bundled in corridors (route choice)?
- d How will the amount, modal split and corridors change in the future (2030)?

In order to actually be able to answer the questions a model or framework was developed based on the traditional 4-step model. Generation was production based on GDP/capita and population. Distribution gravity based with additional barriers for international travel. The modal split was based on the sensitivity for in a Random Regret Minimization (RRM) framework to better capture the interdependence between mode performance and better adherence to reality on short distances and finally based on Dijkstra’s algorithm a link map build to assign people onto the developed simplified network.

The amount of people choosing to go somewhere is equal to the amount of travellers willing to travel and generated for the model as such. For the model including some external cities outside Europe a total of 2,23 billion trips each year. This represents the current, 2015, potential in passengers-trips. When distributed over the destinations about 38% is choosing an international destination without taking into account barriers perceived by mode alternatives, however taking into account real-life barriers like language, borders and passport controls. The modal split is dependent on the relative travel time performance of a mode to the destination. As distances grow larger, past 1000km, the performance of the plane is always superior, however between 100km and 750km a great (40-50%) market or modal split does exist for train travel. The extent to which rail travel is desirable for inhabitants of a city within the Urban Hub set is however related to the accessibility to high-speed rail, as a viable competitor on door-to-door travel time. In addition, due to the assessment of a complete network instead of separate lines, the network effect is taken into account and imbricated services could provide direct profitable connections on much longer distances.

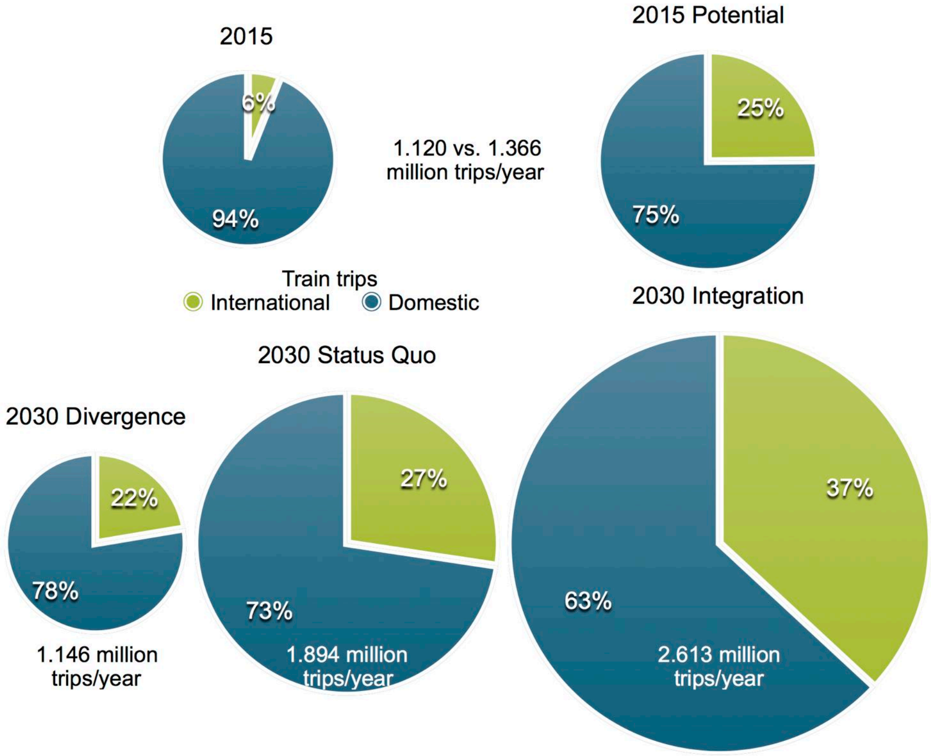


Figure 3.14 – Potential trip development, the market pies, (Own calculations).

In order to make an educated guess about the future (2030), three scenarios have been worked out based on European policy, a divergence or decline scenario, the status quo and an integration and growth scenario. The first will see a decrease in trips however an increase in market share for trains due to the limited new infrastructure available. The growth scenario will result in much more trips, because of a higher GDP/capita and a greater willingness to travel. Nevertheless, due to a more efficient and larger rail (HST) network the modal share of rail could increase to 68%, This would save 28 million tonnes of CO_2-emmissions on a yearly base only for the plane-train shift.

The final question would be: "What is the passenger-trip potential, demand, of the European railway market?" Within the model the answer would be 656 million passengers annually and an average market share of 43% for rail products as well as an average distance per trip of 322km (in total: 211,4 billion passengerkm). This only takes into account the selection of 125 Urban Hub cities. The population of this selection does consist of just 40% of the European population (EU and Schengen) however does make 48% of the total trips. By approximation a total of 1.366 million long-distance rail passengers in Europe, according to Amadeus only 1.120 million are served, having a potential bigger pie already in the current situation of 22% and an incredible potential to growth. In addition, the share of international travel is 25%, compared to the currently 6%, so most of the growth could be found in the international segments. The potential market development is represented in Figure 3.14 for the trips (passengers).

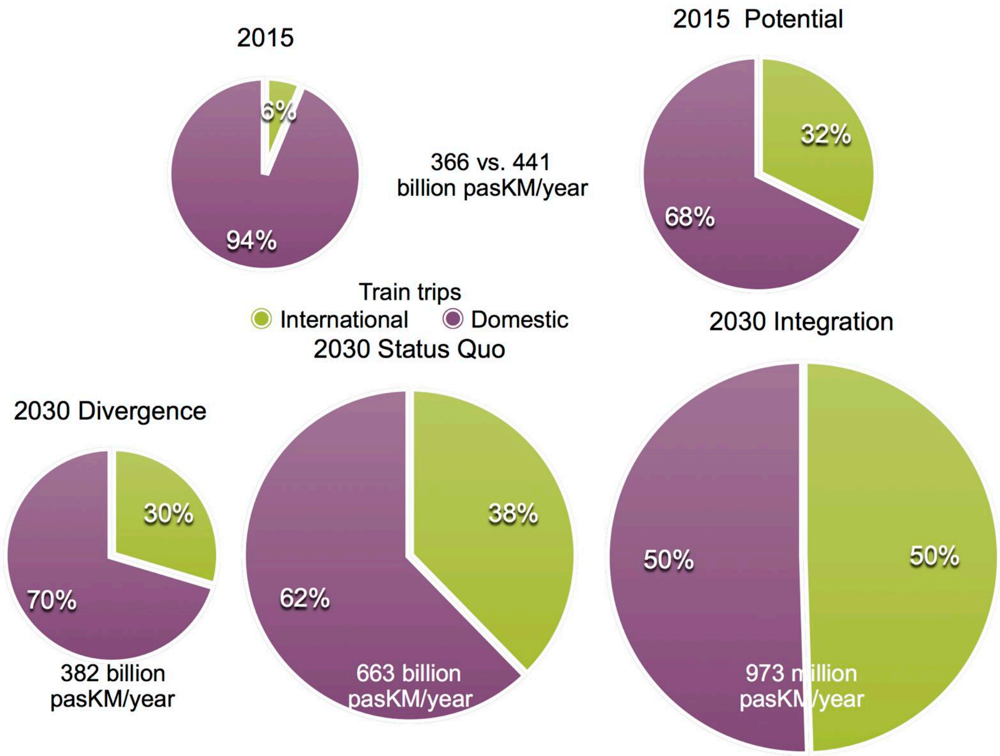


Figure 3.15 – Potential passengerkm development, the market pies, (Own calculations).

The passenger kilometres (paxkm or passengerkm) have a somewhat different development over the scenarios. The passenger kilometres denote the total amount of kilometres travelled by all passengers (trips) combined. Already in the actual current situation international trips have a higher average paxkm than domestic trips. The discrepancy will only grow in the potential of the model. This is represented in Figure 3.15 denoting the total paxkm development over the different scenarios. Currently the average long-distance trip is 327km for the current potential this would reduce slightly to 322 due to exclusion of rural domestic areas. International is 347 actual compared to 419 in the modelled potential. For 2030 in the integration scenario this could developed into an average of 372km for all trips with 500km for international trips. The general billing methods in the sector are based on travelled distance, this would provide great opportunities with respect to revenue development.

Given the relatively large potential in the current market, the question of validity could come up. Despite all the considerations, assumptions or adoptions, the potential amount of domestic train passengers is in the same order of magnitude as the as the actual recorded current statistics. As a result, the growth of 22% of the total market is observed in the international market. The current travel statistics on the aggregated level offered by the Amadeus report have only been used for comparison and not for calibrating, validating nor fine tuning the model. Still they show similar results on the domestic aggregated markets.

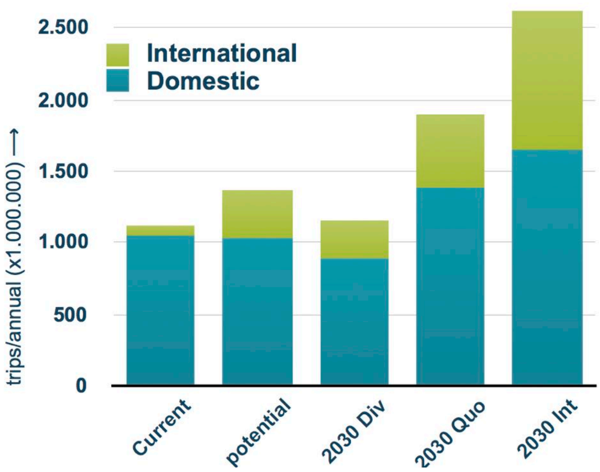
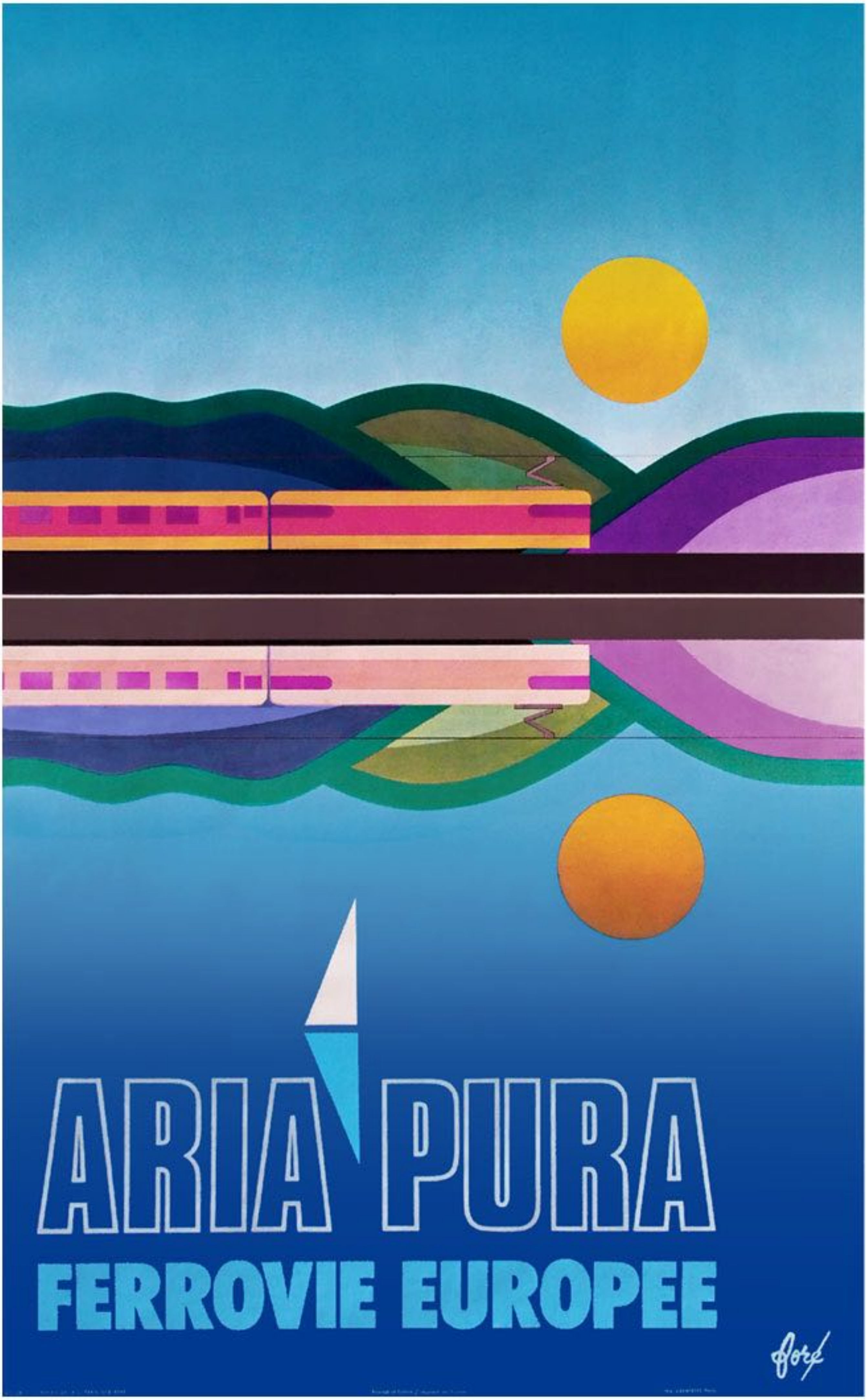


Figure 3.16 – Potential trip development, growth development international and domestic, (Own calculations).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4 Seating capacity potential

The seating capacity potential is the gap between the potential travelling passenger demand and the currently running services, or connections on the infrastructure network. The emphasis is on the trains running and not on the available infrastructure necessary in order to support new connections. Currently running connections do not only provide direct supply by supplying seating capacity, there are also other attributes which determine the level of service offered.

This chapter, seating capacity potential will provide answers to the third sub-question of the research question, represented in the list below. In Figure 4.1 the structure for this chapter is provided within the broader structure of the report.

C What is the seating capacity potential, supply, of the European railway market?
- a How can level of service be assessed
- b What is the level of services offered in the market (current)?
- c What is the level of services to meet potential demand (desired)?
- d What is the discrepancy between connections and passenger-trip potential?

The structure of the chapter itself will follow the report structure and questions closely. First the system of interest with regard to the services/connections is provided. Elaborating on this the level of service is determined in an assessment between the expectations stemming from the passenger-trip potential and the reality of connections. Based on this assessment the potential, or gaps between reality and desire are detected, which provide inputs for connection improvements. The latter will conclude the chapter and answer the question what the seating capacity potential is in the European railway market.

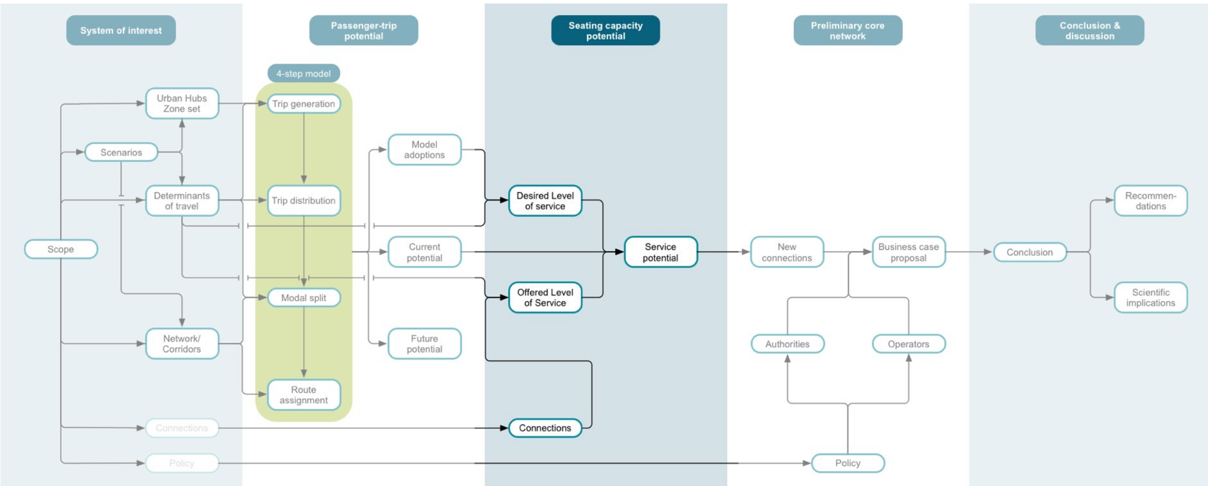

Figure 4.1 – Flow-chart of the report and position of the Seating capacity potential.

4.1. Current connections

Part of the system of interest are the connections offered on the train network. These are train services run over the existing railway network in Europe. In international context this can be the Eurostar services, connecting London with Paris and Brussels, for instance. The choice to adapt the nomenclature of connections to train services is to provide a clear distinction in this research between a train service connecting places with or without transfer and the service level. Service level something quite different than a service running. To prevent and limit the confusion as much as possible running trains are called connections in this report. The current connections are the actual products from which passengers currently can choose in order to make a trip in Europe. In order to draw any conclusion on the perception of travellers, being that the choices on the international market is to restricted compared to the demand (passenger-trip potential) first the existing supply of connections should be assessed.

In contradiction to the model that provides an assessment of both the domestic and international markets, the offered connections focus on the international, cross border services. This restriction, is the result of limitations in data provision by national TOCs of their schedules. The amount of domestic provided connections is in some countries completely obscure and differs every month. The international connections provide however clear intersections (borders) on which the amount of services can be assessed. In addition a survey has already been made commissioned by Train2EU (van Soelen, 2015) focussing on international connections, and can be used as a starting point to collect connection data.

This nevertheless still offers sufficient challenges in the gathering of information, due to the restrictive nature of information provision. Itinerary, route and transit planners offer consistent answers on point to point queries, however the provided information is very limited to the query. In order to make a proper assessment the (typical) composition of a connection (string of stops) and (typical) composition of a train (used carriages or units), is necessary as well. Information provision in the railway sector relies greatly on reporting all different exceptional individual scenarios instead of providing generalised aggregated information, e.g. (Thalys International & Nuelant, 2014), (ÖBB, 2014).

Figure 4.2 – Current offered daytime connections. HST (dark blue), IC+ (light blue), IC (green), (Own elaboration).

54Figure 4.2 and Figure 4.3 provide an overview of the current running services. The differences in lines indicates a difference in offered service level with regard to the speed performance and train compositions deployed on the connections. The extend of the night train network, and visualisation in a separate figure has to do with the independent nature of the connections and the long-distances possible during, relatively long, overnight services. It is however striking that the centre of gravity of the night network is much farther east, compared to the international day network. The complete list of connections is included in Appendix G: Connections.

The distinction in service levels based on speed performance and train compositions is fairly is partly based on description of services in reports (Parlementaire enquêtecommissie Fyra-rapport, 2015), regulations (European Commission, 1996), studies (Alpu, 2015), (Cascetta & Coppola, 2014), (Takeshita, Shimizu, & Kato, 2007) and history of railway operations. For long-distance connections the basic three levels are defined, InterCity (IC) and High Speed Trains (HST) with in between, IC+. The latter being upgraded or high standard quality IC connections (like EuroCity), or downgraded HST connections, not actually offering high speeds (like X2000, Cisalpino or Railjet). The night train class does not quite fit in these categories. Although no HST-night connections are running on the European network, they are in China (Travel China Guide, 2016), night trains are offered with multiple levels of services. In general it would be an upgraded IC, however across the board not always IC+. The EuroNight (EN) brand does exist and implies in corporate branding a similar standard as Eurocity, however non-such standards are agreed upon for using EN. The future of night trains in Europe is however questionable (Bündnis Bahn für Alle, 2017), as the biggest operator (Deutsche Bahn) is in the process of liquidating al their existing night connections.

Figure 4.3 – Current offered night connections, (Own elaboration).

4.2. Level of service

Connections can be assessed on the provided or delivered level of service. This is an abstract definition, based on the preferences, characteristics and determinants to travel of the passengers. The list of characteristics has already been determined in chapter 2.3.2. The distinction is made between the current, offered level of service of the identified connections and the desired level of service resulting from the passenger-trip potential on cross-border links. The assessment is made on the separate preferences or service level indicators to be combined later in the end of this chapter.

4.2.1. General approach

For the general approach it should be noted that the initial assessment is on the international link level in the developed scenario of 2015, boldly highlighted in Figure 4.4. As a result of the nature of the network, with a strong focus on long-distance international (rail) travel, it is no surprise that the amount of international links is relatively high when assessing the links themselves.

All the connections of chapter 4.1 have been listed with origin and destinations, as well as where necessary the intermediate stops. Based on these stops along the route, the Dijkstra algorithm and network assignment of chapter 3.1.3 will assess the links that are used by a connection in their journey. This method takes into account that more than a single connection offers capacity on an individual link.

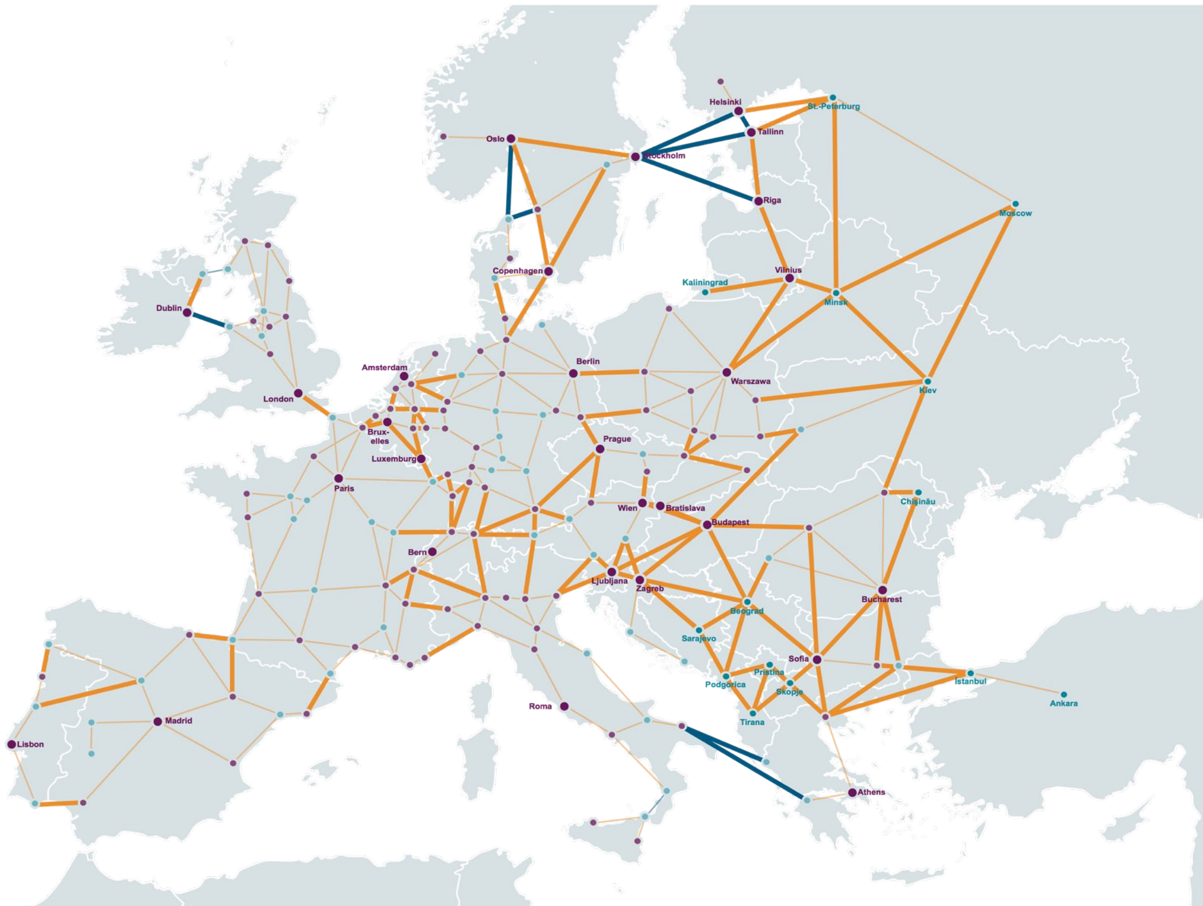

Figure 4.4 – Modelled railway network 2015; bold links are cross-border, blue are ferry-links, (Own elaboration).

4.2.2. Seating capacity

The first and possibly the most straight forward service characteristics, is the offered seats on a link by the different connections. The seating capacity is the possibility of people actually being able to travel regardless of the desire to travel. In addition, if no seating is available on a certain link the seating capacity potential could possibly with few simple steps be transformed into a viable business case, regardless of the service standards.

In order to obtain comparable capacities for all the offered connections, it is necessary to translate the observed service pattern and train type into seats in a uniform matter. What is observed from a connection is the frequency it operates, (daily, hourly or anything else), the (marketing) service level, e.g. IC, express, regional, TGV, Eurostar, etc and as already mentioned the route of the train as provided with the Dijkstra Shortest Path algorithm (DSA). These factors are put in the following formula to get the seating capacity offered on the links in the network.

$$S_{ij} = \sum_{l \in \boldsymbol{L}} S_t \bullet \Lambda_l \quad ;\forall\, i,j \in \boldsymbol{N}$$

$$\Lambda_l = \begin{cases} 1 & \text{if link } l \text{ is used} \\ 0 & \text{otherwise} \end{cases} \quad ;\forall\, l \in \boldsymbol{L}$$

$$S_t = f_n \bullet C_t \bullet 365 \quad ;\forall\, t \in \boldsymbol{T}$$

$$f_n = H_o \bullet f_a \quad ;\forall\, t \in \boldsymbol{T}$$

$\boldsymbol{B}$: set of cities
$\boldsymbol{L}$: set of links
$\boldsymbol{T}$: set of train connections
S_{ij}: Seating offered on link between i and j
S_t: Seating offered by train t

Λ_l: link-value for DSA
f_n: Norm frequency (notional value)
f_a: Actual frequency (observed value)
C_t: Notional capacity of train t
H_o: Daily operating hours of system

One of the fundamental assumptions is that every seat offered by the connection is regarded as being available to a passenger. The results are very conservative and absolute maximum values because in general the perception of a crowdedness of a train is based on many more factors than only available seating (Hirsch & Thompson, 2011). Additionally, the offered capacity of train material can vary as a result of the nature of the trains. For example, a connection is run with as TGV-set, TOCs do not provide data about the consists regularly running. In some cases public databases and open source information has collected such information based on empirical, observed evidence of the past, e.g. (SOMDA & van der Leek, 2016). Both the perception error of crowdedness and the uncertainty of running material is solved by providing a bandwidth of offered capacity in addition to the estimated capacity.

The notional frequency is necessary in order have a level playing field with regard to the operating hours between daily operating services and hourly operating services. The model is based on daily frequencies because these are most reported for long-distance international connections, however some services are offered, publicized and marketed as hourly running services, which should be translated to daily connections by the train. The operational hours are not only necessary for the assessment of frequency, but also for average waiting time and deferred travel time, both part of other service characteristics. The airline industry regularly uses a 12-hour operating day (Belobaba, Odoni, & Barnhart, 2009), which is too short for train operations. An international operating day (departing trains) from 6:00 to 20:00 is fairly common across Europe, resulting in a 14-hour operating day for the complete system. The used values for the factors is the formula are represented in Table 4.1. Ferry transport is included to complete the rail network as special amenity, like already noted for the development of the network itself. The provided capacity is the amount of passengers on the ferry in total, not only coming from (connecting) train services.

Traintype	Lower	Upper	C_t	Typ. Yield
Eurostar	750	900	**825**	0,975
TGV	361	1018	**690**	0,75
Thalys	361	754	**558**	0,75
ICE	391	920	**656**	0,75
X2000	318	636	**477**	0,5
nighttrain	350	350	**350**	0,5
Intercity	350	800	**575**	0,4
EuroCity	350	800	**575**	0,4
RailJet	400	400	**400**	0,5
Ferry	800	1875	**1338**	0,75
Regio	125	250	**188**	0,3

Table 4.1 – Ct and boundary values, (based on: TOC-information; own elaboration).

In Figure 4.5, the top 10 (out of 112) international fixed rail links based on unserved (mean) seating capacity is represented. Figure 4.6 shows the amount of unserved trips annually. The upper and lower bound denote the error margin due to uncertainty in used trainsets on the link. On the Lille-Brussels link the uncertainty is 4,5 million seats annually due to the fact that either TGV-Reseau and single Thalys trainsets can be used (361 seats) or coupled Thalys-sets and TGV duplex (754-1018 seats). In total 46 links are underserved with a total of 31 million trips in the current situation, based on seating capacity and the limited set of cities in the model.

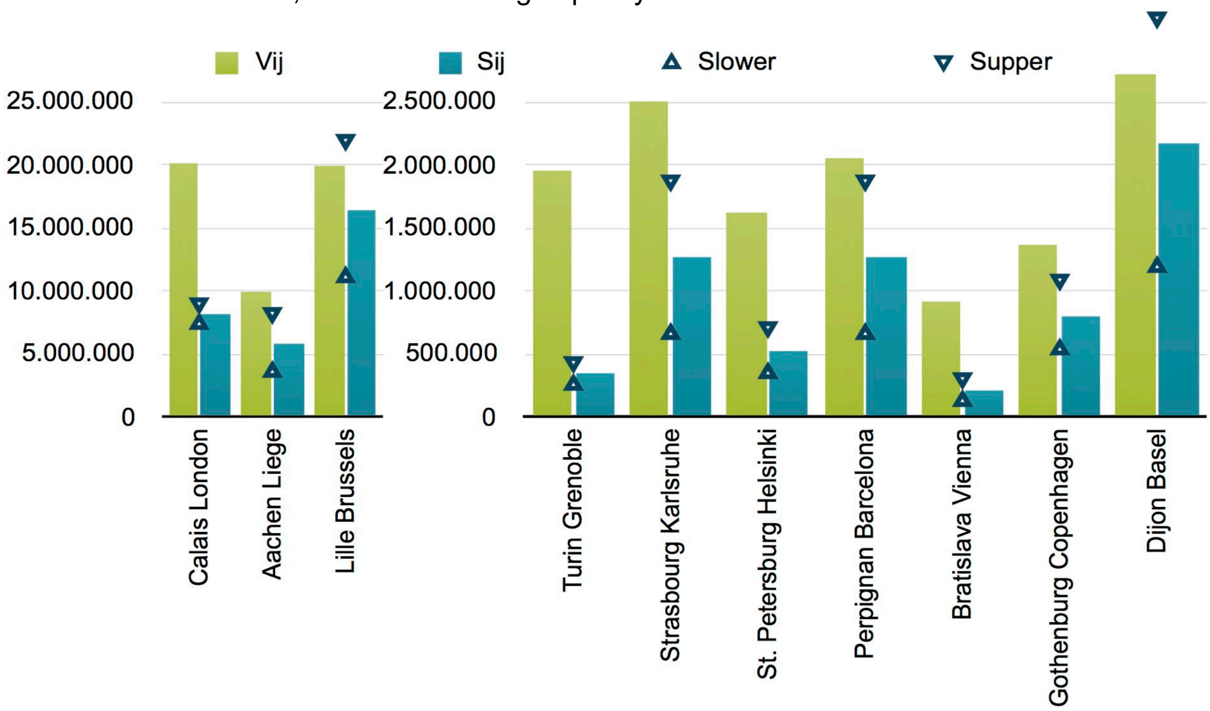

Figure 4.5 – Potential on offered seating capacity, difference V_{ij} ~ S_{ij} is potential; V_{ij} = potential trip demand, S_{ij} = Seat supply, S_{lower} = lower boundary on seat supply, S_{upper} = upper boundary on seat supply. (Own calculations).

On the other hand, based on all offered seats on international connections 66 links are over served (33,5 million seats) in comparison to the expected demand of the model. First of all, the model itself only generated and assigns 48% of the total expected trips across Europe to the network as a result of the limited set of cities. Adapting modelled link traffic to total expected traffic, including the non-modelled demand is impossible without an incredible amount of unfounded assumptions. Additionally, many seats are included which are actually offered for other purposes than long-distance travel. The assessment based on offered service level will be performed in 4.2.5. Seats with a different purpose are offered for short-distance, regional traffic which is in entirety not taken into account in the model. As a result, seats are taken into consideration for unaccounted traffic, providing a skewed initial outcome.

Nevertheless, some links (Vienna – Budapest or Belfast –Dublin), indicate that also when only dedicated long-distance connections are included in the connections, much more seats are offered compared to the potential. This can be explained by government stimulation of a mode (subsidies) or (private) fare competition, making train travel much more attractive on the route than the achieved travel time would suggest.

Purely based on the offered seating capacity, with almost all internationally running services included regardless the target market (short/long-distance), there is only limited indication of structural underserving the international rail market. A limited amount of offered seats on international links would suggest a direct potential that could be capture. This connection can only be made for a very limited set of links and connections. The thing that is made clear by the assessment on offered seating capacity exclusively, is the mismatch in offered capacity and desire to travel across the European continent. This would point towards an incomplete market without perfect competition. Either caused by the lack of information for all stakeholders involved or with high barriers to enter to offer connections elsewhere from a TOCs perspective.

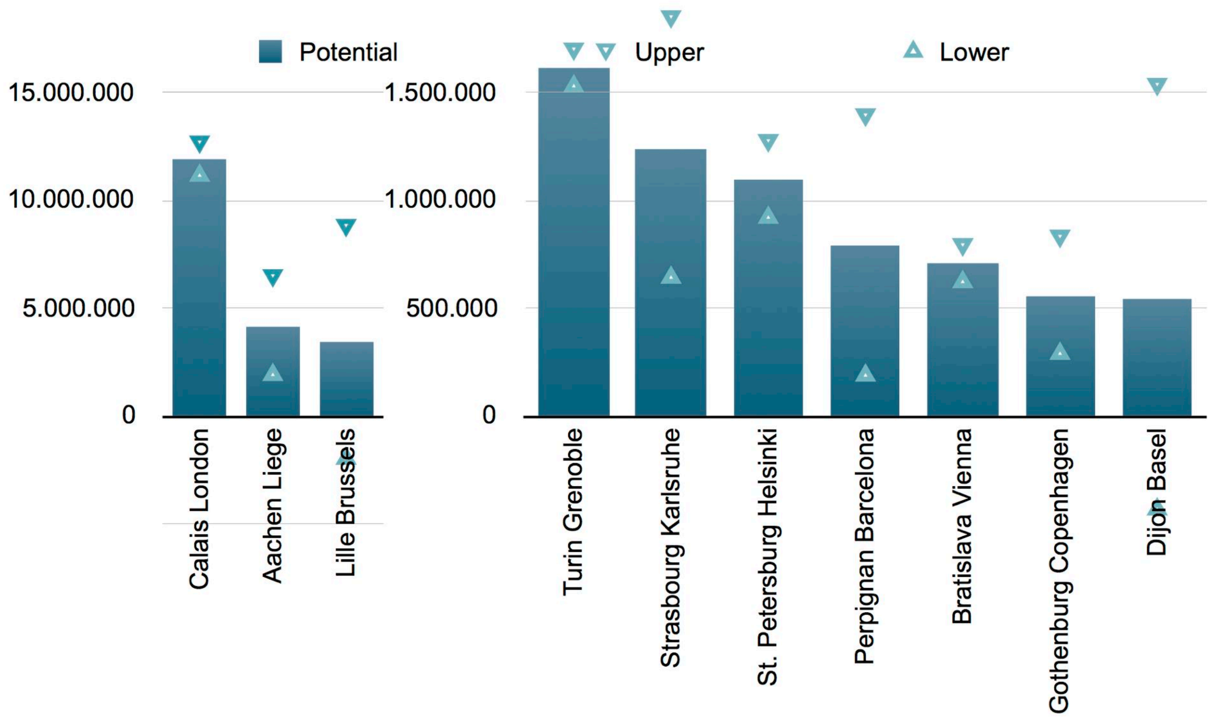

Figure 4.6 – Unserved potential on offered seating capacity from running connections with upper and lower boundaries, (Own calculations).

4.2.3. Frequency

All the included connections are also assessed on frequency. The general census in literature is that frequency of (train) connections for long-distance travel is unimportant (van Goeverden et al., 2015), correlated with in vehicle time (Román et al., 2014), (Birago, 2014) and makes limited difference for the choice of passengers (Brietzke, 2015). The reality of airline industry however suggest a contrary importance of frequency, (King, 2007), (Belobaba et al., 2009). Frequency is not captured in the average waiting time, most commonly applied to penalize lower frequency (Ortúzar & Willumsen, 2011). For airlines, frequency is assessed with the displacement in the preferred travel schedule, to estimate market share. This concept translate the inconvenience perceived of adjusting to the scheduled operations of (public) transport.

In case the preferences of travellers are uniformly distributed, as well as the distribution of train departure across the operating hours, the displacement in schedule is half the maximum displacement. The displacement time is calculated with the following formula:

$$TT_t = \frac{H_o/f_l}{2} \quad ;\forall\ t \in \boldsymbol{T}\ ;\forall\ l \in \boldsymbol{L}$$

$$TT_{dis} = \frac{TT_t}{2} \quad ;\forall\ t \in \boldsymbol{T}\ ;\forall\ l \in \boldsymbol{L}$$

$\boldsymbol{T}$: set of train connections
$\boldsymbol{L}$: set of links
TT_t: Transfer time, max. time between t
TT_{dis}: Displacement time
f_l: Norm frequency on link
H_o: Daily operating hours of system

The displacement time is evaluated based on the travel time that could be expected of the connection. This provides the displacement ratio. A ratio of up to 50% (1 (3) hour displacement in case of a 2 (6) hour journey), is regarded as acceptable to still offer a valid and attractive service level. Additionally, the train frequencies are distributed over the network according to the DSA-method. Every link supports multiple connections running on it. For example, the Thalys connection Amsterdam-Lille does offer a twice daily connection, given a 105 minute displacement (90% of the travel time). However due to all other services running between Amsterdam and Lille, the max displacement on this trajectory is 7,5 minutes. Headways (time between consecutive connections) of up to 15 minutes are deemed as continuous by travellers (Oort, 2011), (Vuchic, 2005). Adjustments of schedules of maximum 15 minutes are not deemed disadvantageous for getting a service.

Of the affected passengers, 36% is presented with a connection that does result in a greater than desired displacement of schedule. On link level this is as much as 86% of the international links, 11 links do not even offer a connection at all. Although given that displacement is the concept of people wanting to travel at a different time, this can be translated into underserved passengers. The actual displacement compare to the desired displacement can provide the ratio to which potential trips are served. If this ratio is applied to the offered seats on the links, the balance of offered seats changes dramatically with a total of 78 links underserved for 42 million trips. The displacement time distribution to the network links and affected passengers is represented in Figure 4.7 on the opposite page.

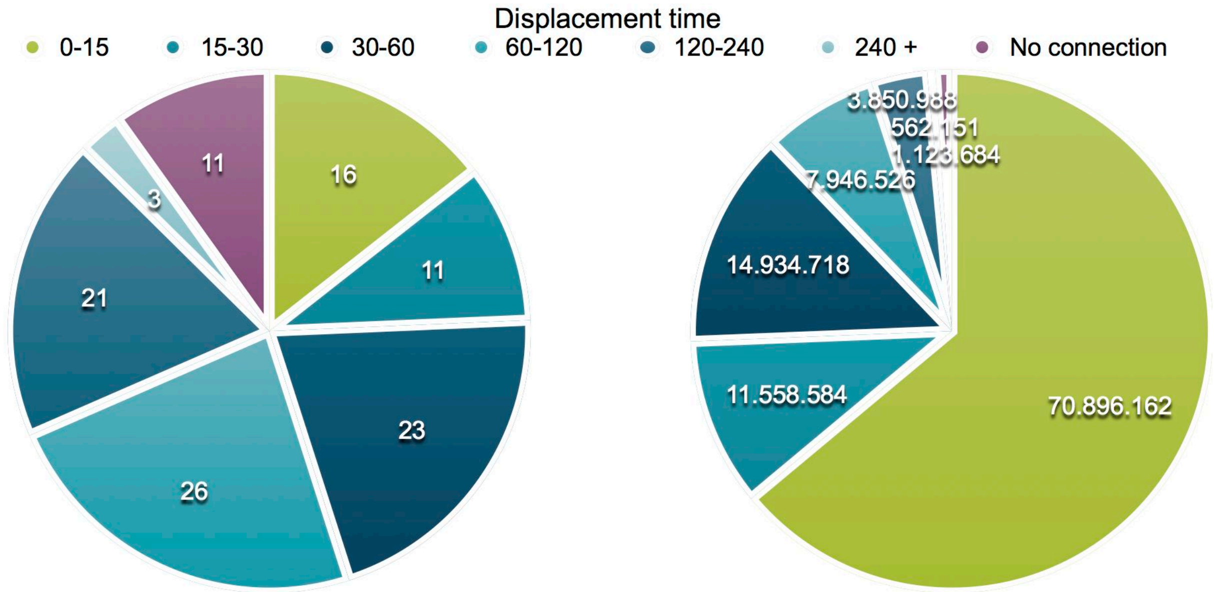

Figure 4.7 – Displacement time distribution on int. links (left) and by affected trips (right), (Own calculations).

4.2.4. Transfers

Transfers in the overall network are almost limitless and the amount of provided connections, especially domestic connections, does guarantee the accessibility of all locations via rail. With the limited scope of the research, the transfers as service characteristics is not as much assessed on the origin to destination relations, rather more on a link level. Like with seating capacity and frequency, the focus is on the performance of connections on the international links, as defined in the modelled network. Most domestic networks guarantee transfer free connections between major domestic destination, especially those included in the Urban Hub city selection of this report.

Transfers in an ongoing journey between origin and destination result in two disadvantageous factors in the trip. The transfer itself, from one train to another, across platform, station or complete station complexes as well as finding the connection and securing a spot in the respective train (Birago, 2014), (Oort, 2011). The second factor is the delay in travel time (Ortúzar & Willumsen, 2011), (Brietzke, 2015), as a result of the transfer, the trip is stopped at a station and only after the connection has been made, the trip can be continued. Both factors can be reduced to a minimum when offering cross-platform transfers and connecting services. Although the transfer from one train to another still has to be made, there is only very limited searching, walking and waiting involved. This way operationally difficulties can be reduced for offering direct connections to every destination but still a high level of connectivity can be ensured.

Both factors can be modelled in the choice of passengers and trips, with additionally time penalties. A fixed penalty for the transfer and the average waiting time for the connection, where the fixed penalty could be replaced by different time sensitivity for the waiting time. Given the developed network and scope of the trips in this research, transfers on the included network links are not necessary and highly undesired by passengers. Especially when this is not limited to a single easy transfer, rather multiple transfers with long waiting time or difficult connections.

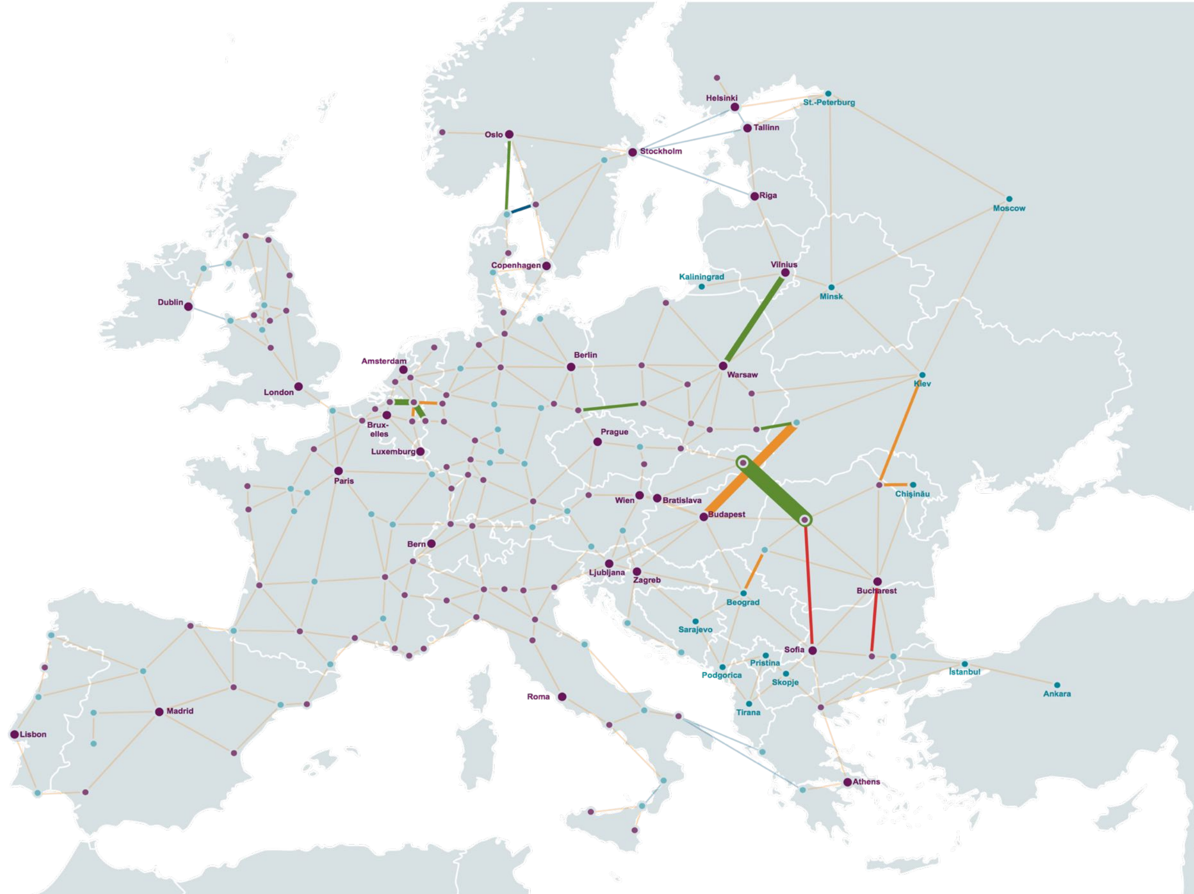

Figure 4.8 – International links with transfers; green = optimised transfers, orange = average waiting time, red extreme wait for transfer, (Own elaboration).

A total of 16 (out of 111) links need a transfer on the international stretch, 5 links need more than a single transfer. Location and number of transferred is represented in Figure 4.8. Remarkable is the central location of Eindhoven as a spider in a transfer web, indicating the relatively cumbersome connectivity with foreign destination from here, with regard to direct connections. All transfers are right at the border stations, given insight in the service provision of the TOCs. The quality of transfer is measured with the performance of a travel time adjustment for average waiting time, as result of unconnected schedules. The expected modelled travel time is adjusted for the transfers on the route. If the new ratio is around 0%, there is no optimisation of schedules. Values far below 0 indicate optimisation, values far greater than 0% indicate that even the average waiting time is optimistic to estimate the waiting time between connections. The results are also visualised in Figure 4.8 denoted by the colours.

4.2.5. Service level

The offered service level of a connection is less tangible compared to the other characteristics. Most of the time, the service level is reflected in the train sets and coaches running the connections. The connection can also be offered under a brand for the relative offered speed, additional amenities on the train or provided connectivity. The categorisation to service level in this part of the report is an attempt to lift the services from their marketing infused descriptions and put them into more uniformly applicable categories. As already described in section 4.1, five train categories have been defined. InterCity (IC) and High Speed Trains (HST) within between, IC+, for the long-distance services. For the shorter connection patterns the regional (express) service and separately the night trains. On a connection/link level the additional special category of ferry connections is defined to capture transfer traffic without a fixed rail link or continuous operating connection (like Hamburg-Copenhagen).

Both HST and IC+ are aiming at providing a service level of high quality on long-distances with matching performance in speed and interoperability. Long-distance travel does require somewhat different characteristics to seating quality, pitch and width compared to short-distance local and regional travel. This is guaranteed with all HST and IC+ connections. Within the IC+ category all EuroCity connections are included, providing a fixed high quality service and additional amenities like food and beverage sales on the train. Overall services on these connections match the services found on airlines, HST in general more resembling legacy carriers and the IC+ skewed towards low cost carrier service levels with regard to provision of auxiliary food and beverages. In order to compete with airlines, the service level should at least be equal or better.

Intercity connections resemble national, domestic intercity services of many countries. Although service levels with regard to seating quality has become on par with EC levels, other aspects of the service have not. Like the sale of auxiliary food and beverages which on (very) long journeys is desired. Priority of speed over serviced stops (stopping pattern) is in general more skewed toward stops which is also observed in the travel time performance, section 4.2.6. Discoverability of international running InterCitys is lower compared to the other products because it involves mainly linking two domestic connections across the border. This practice is actually the easiest way of providing an international connection from an operational point of view. Overall the InterCity category does offer the minimum level of service for long-distance (international) travel.

Regional services are focussed on short-distance connectivity to larger urban areas. As a result, stopping patterns include (almost) all stops along the line which greatly affects the travel time performance. In general, regional services are only used for short periods of travel, not necessitating high levels of comfort for seats and amenities. Although regional trains do offer a vital connection on several international links, 11 out of 111, the provided level of service is very limited and not well suited for long-distance passengers. With regard to discoverability, they rarely included advertised international connections, only just happening to do so.

Night trains and ferries, within the scope, offer varies level of service, however all very specifically catered towards long-distance travel. This makes them with regard to level of service very well suited for long-distances. Night trains provide berth in exchange for travel overnight, somewhat in contradiction with the traditional way of modelling transport and also contradicting the current practice of planning journeys. The appeal of night trains is so specific that it is incompatible with the assumptions made about travel choices in this research.

4.2.6. Travel time performance

Compatibility of infrastructure, differences in capacity allocation and misalignment of basic hour schedules result in infamous delays at border stations. Many of these delays have already been taken care of as a result of European directives and regulations (Council of the European Communities, 1991; European Commission, 1996; European Parliament & Council of the European Union, 2013). Nevertheless, the perception of many passengers is still that the connections running on the international network do not offer the travel time performance as could be expected of domestic infrastructure.

In order to filter the connections, that do offer a direct link between origin and destinations, however are not competitive in travel time, an assessment of the travel time is made. This assessment focusses on the infrastructure estimations of the developed model for passenger-trip potential and the reality observed. In contrary to the other determinants already assessed, the travel time performance is assessed on a connection level, instead of on the international link level. An international connection running domestically in an uncompetitive manner, will not result in a competitive or desirable connection for the international part of the connection. Many examples exist across Europe, at least in perception or in research e.g. (Parlementaire enquêtecommissie Fyra-rapport, 2015). With the ongoing focus of the European Commission of interoperability (European Commission, 2013a) of infrastructure networks, there should be no technical differences in operated a connection across borders. The travel time performance should as a result be similar to that of domestic connections.

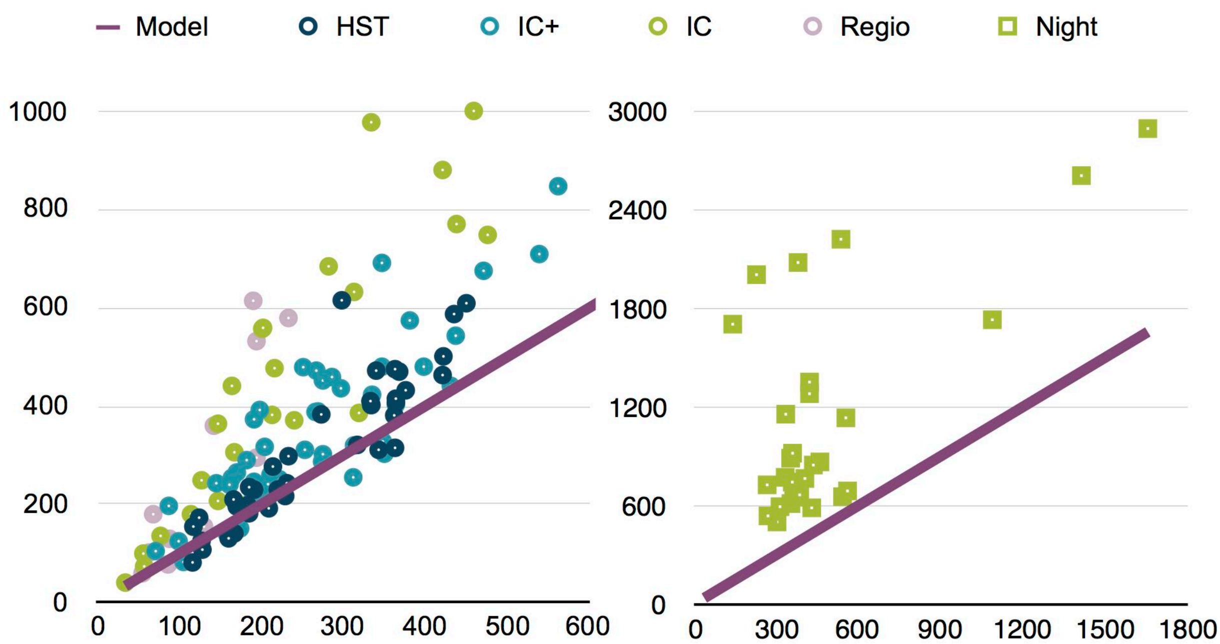

Figure 4.9 – Travel time performance of different service level categories. Observations close to the line have travel time performance close to infrastructure capabilities, (Own elaboration).

The model as developed for the network travel times had a goodness of fit to explain the travel time of rail of 85%. Overall high speed trains perform very well, with the modelled times explaining 71% of the travel time. Out of the 39 HST-connections, 10 even outperform the model, providing a (much) better connection than anticipated. The IC+ service level performance with 55% adherence to the expectations worse, however 7 connections still outperform the expectation. Both HST and IC+ rely heavily on marketing the speed performance of the service. As a result of the high quality of the service, the priority in ensuring a conflict free travel path with minimum wait times is higher, so both perform pretty well on travel time overall. HST connections that run for large parts on traditional railway infrastructure, however operated with HST trainsets perform particularly substandard.

For IC services (25 in total) an adherence of 45% is observed, providing evidence to the lower priority in travel time optimisation of the services. In planning the train paths of the connections, they are not of the highest priority and stops become sometimes long to provide conflict free paths for other connections first. Regional services, as a result of their frequent stopping pattern, already remarked for level of service, can be fitted for 22% of the travel time. Both IC and Regional connections perform overall to limited to really be attractive to international long distance travellers as a viable alternative to other modes. It is obvious that night services have a very poor fit with regard to travel time performance. Most logical explanation is that services run across the night and travel time is more determined by the necessary hours of sleep, than getting somewhere quickly. Night services are as a result, competing in a different market, on time of day choice and the necessity of an extra night in a hotel at the destination.

Overall the travel time performance of connections can be estimated in affected offered seats, based on the travel time sensitivity in the mode. The effective offered amount of seats would be reduced with 37 million annually, almost 32%. Resulting in 46 million unserved trips on 83 international links. This reflects greatly the importance of a competitive travel time, also on long distances. Although travel time sensitivity of people is lower compared to short distance trips, a very long travel time, especially compared to expectations and alternatives renders an offered connection obsolete or redundant.

4.2.7. Additional service indicators

On top of the five mentioned specific service/connection characteristics, several others can be of importance in order to choose train over another transport mode. Research (Goeverden & van Arem, 2010), (Giannini, 2012) and (Brietzke, 2015), has shown that three characteristics of connections are especially important. These are reservations, ticketing, both directly related to the booking process and finally timetable information and transparency. All three affect the available information on which the decision for a mode is made. Unfortunately given the limited scope and the incredible lack of transparency of TOCs on certain connections, or lack of clear regulation these indicators cannot be quantified for all connections. To provide a fair and complete as possible comparison they are taken out and separately mentioned here.

Reservation

The reservation of train tickets is greatly the result of the need for yield management, the attempt to spread load factors across running trains and reduce the impact of peak demand on the system. Often the narrative around mandatory reservations points to the airline industry where reservations are mandatory as well. The big difference however is that in the airline industry, planes are not freely accessible, where trains are accessible for regional and domestic connections. This creates a strange bias for an implied similar product, multiple levels of planning are necessary. Additionally, although reservations are mandatory on planes in order to get a seat, when seats are still available before the closure of check-in procedures, the seats can still be booked. That is not the case currently with many high speed trains (e.g. Thalys services Amsterdam-Rotterdam)

Ticketing

Ticketing includes the tickets themselves (the proof of seat) and the process of getting this proof of seat. The purchase of international train tickets is fairly cumbersome. Trains to directly neighbouring countries are still relatively easy to find and purchase tickets for, however trains further away across Europe can be an incredible challenge. The time to book a plane ticket across the world 6 months ahead can be performed in minutes, purchasing international train tickets for direct trains can take much longer, even without any special circumstances as travelling with aid-assistance. As far as this practice was acceptable in times gone by, due to the information innovation of present time, customers no longer accept the cumbersome process and opt for alternatives.

Tickets themselves can be cumbersome as well, for example non-matching ticketing systems across countries, like the Dutch OV-chipkaart and systems of the surrounding countries. This not only creates interface problems and validity questions with both travellers as well as operating personal. It also creates situations that one has to hold multiple tickets for the same journey, let alone the fact that separate tickets are necessary for out- and inward journeys. Making the airline analogy, in general the passport or ID-document is sufficient across the system, especially in the internal Schengen market.

Timetable information/transparancy

The choice of taking a train as alternative transport mode relies on the fact that a traveller is aware of the existence of the train service. Not only knowing a train exists, more important the ease of finding and navigating the timetables. Timetable information published is not accessible, not findable, inconsistent or contradictory. If timetables are openly published it is very hard to get the complete view of possibilities and structure, like a general pattern.

Soft factors in travel barriers

In addition to the previously mentioned hard barriers, actually preventing people to travel when not overcome, several soft barriers do exist as well. Most of these barriers are not directly related to trip in the main mode of choice, however are part of the complete door-to-door trip and are partly responsible for the last-mile problem. Additionally most of the barriers are not only applicable train transport, but also for other non-private transport. Examples of these soft barriers can be the availability of information about, as well as the availability of egress transport in the destination city. This barrier can be so important that even the destination choice is adjusted. A more train related soft factor would be the auxiliary services and comfort offered by train travel, which are positive factors. Quantification of these soft factors and barriers is very difficult and data integrity and effect is more based on the individual cities than on applicable to a complete connection or the overall network. As a result, the soft barriers are left outside the scope of the research, however to provide a seamless travel experience these are inevitable factors that should be solved.

4.3. Combining LOS to seating capacity potential

All the different level of service characteristics in the previous part provide an insight in the reaction of travellers and the trips that will be made by train as the alternative mode. The separate indicators have to be combined together with the desired level of service from the passenger-trip potential in order to get the answer of the question, where seating capacity potential does exist. First the desired level of service is established given the outcome of the model from the passenger-trip potential. Based on the already used effect on offered seating capacity the seating capacity potential is determined, matching the amount of potential trips and the effectively offered seats by current connections.

4.3.1. Desired level of service

The desired level of service would offer the service level to which the traveller has to make as little adjustments as possible with regard to their expectations, perceptions or determinants of travel. The threshold values for the different determinants in the assessment of the current level of service already reflect what would be a desired performance of connections. With respect to the defined preferences this would result in a connection offered under the conditions as listed in Table 4.2. Although the additional service indicators are not quantifiable, they do have a desired level from the passenger-trip potential.

Traintype	Desire	Realistic desire	Indicator
Frequency	Continuous	Minimal displacement time	$TT_{dis} \leq 15min$
Transfers	None	Minimal disruption	$TT_{adj} << TT_t$
Travel time performance	Direct p2p service	Full infrastructure capability	$TT \approx TT_{mod}$
Service level	HST	Long-distance service	HST, IC+, IC
Add. Reservations	None	None	-
Add. Ticketing	No physical ticket	Single ticket	-
Add. Timetable information	Fully available	Accessible planner	-
Add. Timetable transparancy	Clock-face schedule	Clock-face approx.	-
Seating capacity	Unlimited	Minimal potential demand	$V_{ij} = S_{ij}$

Table 4.2 – Desired level of service indicators, (Own elaboration).

The desired level of service is based on the assumptions and erased (operational) limitations of the passenger-trip potential model. Almost all barriers, perceived or encountered are eliminated as far as practically possible and within the vision of interoperability of the European Commission. The most important assumptions in the passenger-trip potential are the additional service indicator values. In order to be able to choose the train as a viable alternative a traveller needs to know a connection is offered (timetable), the travel time and operating hours (timetable) and how to get a valid ticket (ticketing and reservation).

If at least all this information is available, the other indicators can be assessed by the passenger. For frequency the displacement in desired schedule should be as limited as possible, though no greater than 15 minutes. Direct connections are preferred, nevertheless if a transfer is offered with minimum waiting time and cross-platform the burden becomes way less. Similarly, to travel time performance, direct service without stops to the destination would be desired, however limited stopping patterns making full use of the infrastructure capabilities and no unnecessary waiting times will provide a desirable level of service. Finally, for seating capacity, standing for long-distances is not an option, so seats should be available. The potential amount of trips is equal to the link load as determined for the passenger-trip potential.

4.3.2. Combining LOS indicators

In order to get an overall estimation on what the seating capacity potential could be, the effects of the different indicators should be quantified. A kind of monetization, of converting the qualitative and widely varying indicator units into a single comprehensible unit. Actual monetisation depends also on cost factors and the value of an indicator. This is regarded out of the scope of the research and only a conversion of factors into the generalised and understandable unit of effectively offered seating capacity is made.

The seating capacity of the offered connections is the most relatable with the amount of trips that potentially will be made, this makes it a suitable conversion unit. Most service indicators provide already an indication on the single effect of the indicator on the seating capacity. The combined effect of the indicators will be less than the sum of the single effects because some undesirable indicator values belong the same connection. Figure 4.10 shows the overall outcome and difference compared to Figure 4.5. In generally the connection towards London, either from Brussels or Paris is perceived as a connection that leaves little desire. Assessment of the service indicators supports this, all actual offered seats are available seats from the point of view of the potential passenger of the service.

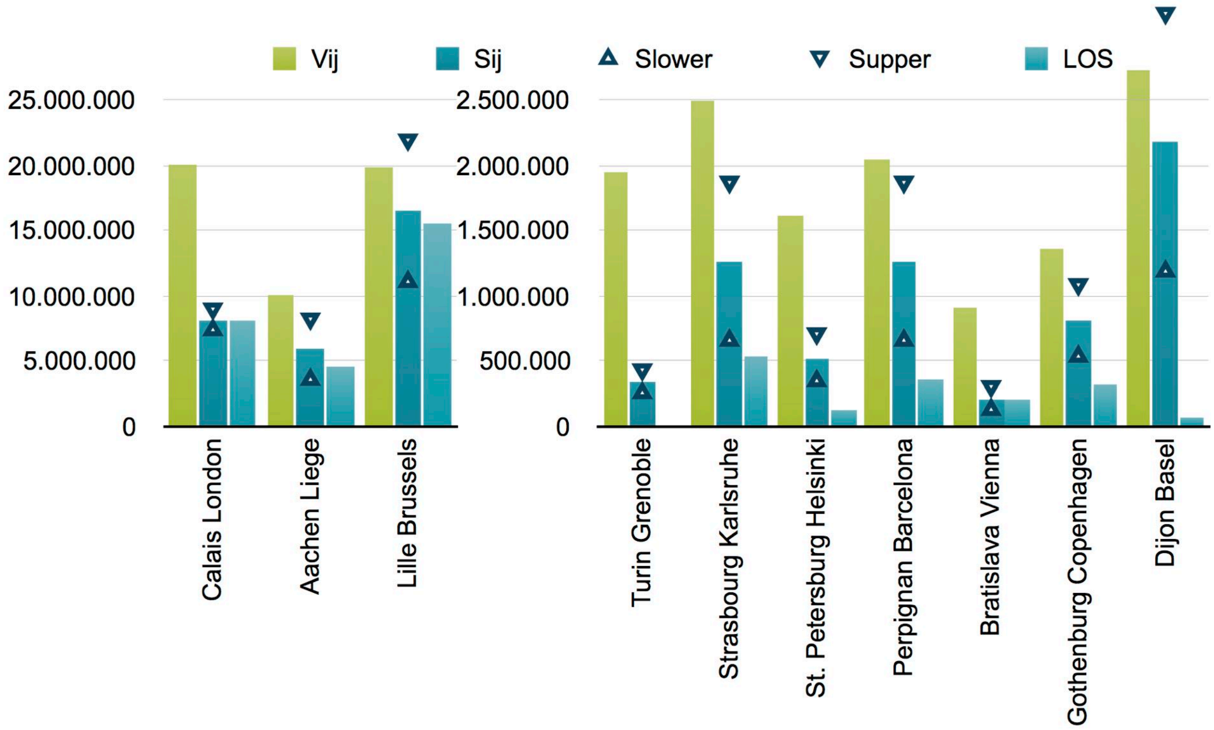

Figure 4.10 – Level of service (LOS) indicators converted to offered seats (LOS-bar), V_{ij} ~ LOS is seating capacity potential; V_{ij} = potential trip demand, S_{ij} = Seat supply, S_{lower} = lower boundary on seat supply, S_{upper} = upper boundary on seat supply, LOS = effective seat supply resulting from offered level of service. (Own calculations).

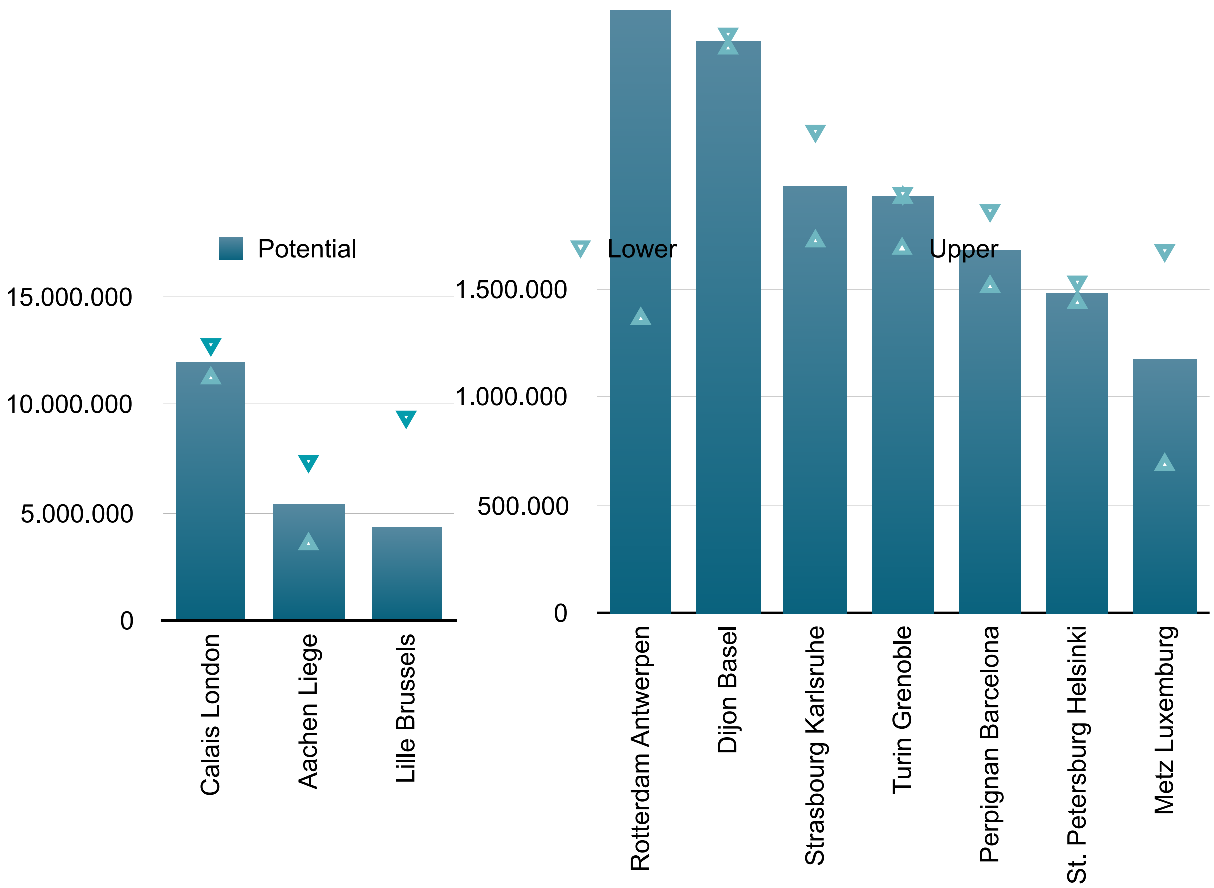

Figure 4.11 – Unserved passenger-trip potential, (Own calculations).

4.3.3. Unserved passenger-trip potential

As a result of the converted seat offering, there is a transition in positions among the top 10 with the most potential passengers unserved. The complete top 10 is provided in Figure 4.11, together with the amount of unserved potential passengers and the range.

In total 98 links are underserved compared to only 45 based on actual offered seats. This leaves 58,6 million passengers unserved on international links, almost 60% of the total potential demand on international links, all on an annual base. For comparison, the international airport of Frankfurt, 3rd busiest in Europe, served 59 million passengers in 2014. A total of almost 50% of the actual offered seats are not effectively offered as a result of shortcomings in the other level of service indicators that are quantifiable within the scope of this report. Still some links are overserved compared to the potential expectations. This is the result of very effective marketing and provision of services. The Vienna – Budapest link consistently scores higher in the indicator assessments than could be expected of a link of its size and infrastructure.

4.4. Conclusion seating capacity potential

This part of the report provides the answer to the following set of sub-question:

- C What is the seating capacity potential, supply, of the European railway market?
  - a How can level of service be assessed?
  - b What is the level of services offered in the market (current)?
  - c What is the level of services to meet potential demand (desired)?
  - d What is the discrepancy between connections and passenger-trip potential?

Answering the main question, needs the answers of the sub questions. These consecutively provide a framework on which the seating capacity potential, supply, can be assessed and quantified with respect to the previously modelled passenger-trip potential. The level of service is assessed based on service characteristics most commonly used as preferences or determinants of travel in other research projects. As a result of the scope of the research and the very restrictive information provision of TOCs, not all used characteristics in literature could be used for assessment of current connections. The information used is all available through open-source/-access databases. The exact characteristics are the most common determinants of choice or travel with regard to modes, or services: frequency, transfers, travel time performance, service level and restrictive use cases (e.g. reservations).

The current level of service offered to the market by the connections depends on the indicator that is assessed. With regard to the offered amount of seats, 46 links are underserved for a total of 31 million trips. All other links (111 in total) are overserved according to the actual estimation of the offered seats. This would indicate a structural saturation of the market with the amount of offered seats. Additionally, this contradicts all the expectations based on the perception of limited international connections. Further assessment of the connections on the other indicators, frequency, transfers, travel time performance and service level suggest that the current level of service has a relatively high standard. Many services run only once a day on irregular schedules providing very limited connectivity to the potential passenger. The level of service is a result of the assumptions for the potential travel demand. Transfers should not occur on defined links and links on origin destination relations should occur as burden free as possible, cross-platform and connected. Overall long-distance travellers do expect long-distance services on their journey, on some links only or partial regional services are offered which lack the service expected for long-distances. With regard to frequencies, lessons from the airline industry indicate that a minimum displacement of schedule time is desired. However, average displacements of 15 minutes are acceptable without really causing inconvenience for long distance travel choice, this is still a headway of an hour. Off-course a seat should be offered to fulfil the desired level of service.

Current connections only offer 58,7 million seats annually on the 111 international fixed rail links in the model. The potential demand is 110,9 million annually on the same international links, leaving an aggregated total of 52,2 million passenger trips unserved. However, some links have a greater number of journeys offered than the potential, taking this factor out a total of 58,6 million passenger trips are unserved (60% of the total potential passenger-trips). Main links of interest are those with an annual unserved demand of one million trips or higher, given the network potential, links of 500.000 unserved trips can be of interest given the current economics of railway operations. The highest annual unserved demand is on the links, Calais (Lille) – London, Aachen – Liege and Brussels – Lille. Given this, it comes as no surprise that so many TOCs try to enter the open access market of the channel tunnel.


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5 Preliminary core network

Passenger-trip potential, in the context of this research, is the potential of trips and demand on the systems. The seating capacity potential is the mismatch between current offered seating capacity and the effectively offered capacity by the connections and passenger-trip demand. The objective of this chapter is to translate to seating capacity potential into more tangible assets, operational trains and services. Although there will be no assessment of business cases in itself and a complete proposal of operations is outside the scope of this research. The aim is to propose a preliminary passengers core connections network for a viable business case based on the modelled potential and assessed seating capacity potential.

This chapter will provide answers to the fourth sub-question of the research question, represented in the list below. In Figure 5.1 the structure for this chapter is provided within the broader structure of the report.

- D What is the preliminary core network for the European railway market?
  - a What is the policy-framework for offering international railway services, on an authority and TOC level?
  - b Where are the current and future bottlenecks (market)?
  - c How would a core network relate to the existing operational reality (hierarchy)?
  - d Why are TOCs so reluctant to fulfil the apparent potential (opportunity)?
  - e How can this network be realised or made viable?

The objective of this chapter is to make the transition from the model and assessment of the current situation to implementation into the current market. The structure of this chapter is supportive to this objective. First the current policy outlines and objectives are provided, both on an authority and operating perspective. The second step is the conversion of the seating capacity potential on individual links to operational potential connections. The combination between the policies and the proposed connections provides the input for proposals of business cases. The business cases are only pointed out by this research and not evaluated and assessed themselves. These three steps will answer the questions as posted before and outline the preliminary core network for the European railway passenger market.

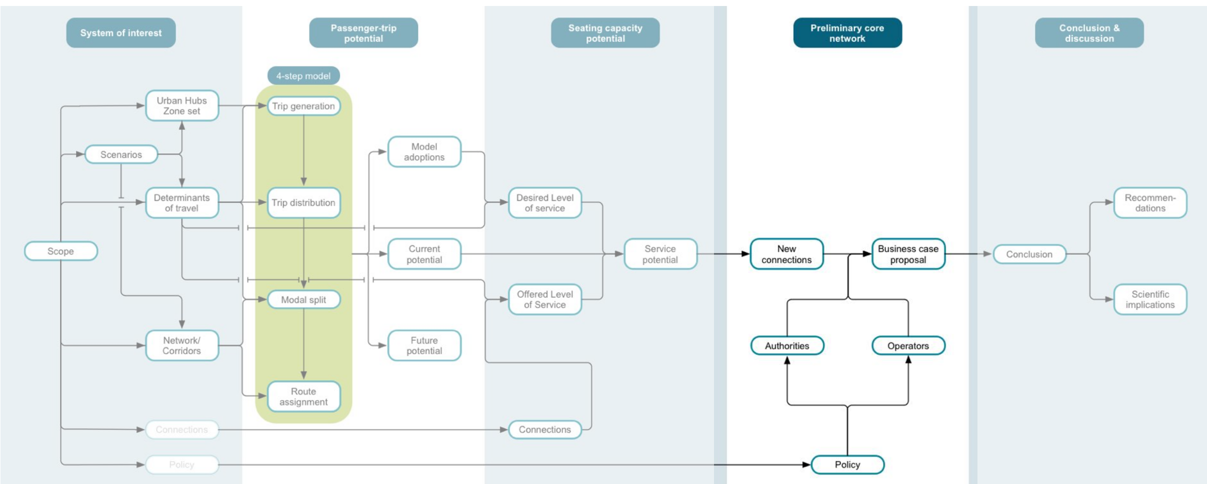

Figure 5.1 – Flow-chart of the report and position of the preliminary core network.

5.1. Policy

Almost all policy on train and railway operations is the result of European cooperation. In order to provide a comprehensible understanding of the different terms in this part, a small explanation is provided on the differences on EU legislation. EU legislation defined in the Treaty on the Functioning of the European Union (European Commission, 2012b), as well as prior legal entities, defines three types of legislation which all differently affect national legislation of member states. The most restrictive form of legislation, are the so called regulations. Regulations do have a general application in the member states of the union. The regulation is binding in its entirety and when adopted, directly applicable for member states and the citizens of the EU. Directives are a form of legislation which are only binding after the member states, for which it is applicable, transposes them into national legislation. As a result, the implications of a directive differ from state to state, however the directive does provide directions on how the implementations should be done into the national legislation. Furthermore, a directive is more focussed on the objectives themselves, and less on the way that the objectives are achieved. The third legislative option are the decisions, also completely binding, or in case a specific legal entity or state is addressed only applicable to them. Decisions in general are the result of juridical procedure at the European Court of Justice. Main point is the direct implications of a regulation as EU applicable law and more indirect objective driven application of directives within the EU legislative framework.

The European community has a long standing wish of providing integrated seamless transport across the borders of the community. This already started in 1991, before the Schengen treaty came into effect with the “First Railway Directive” in the 91/440/EC directive (Council of the European Communities, 1991). This was followed by amendments on the first directive resulting in the first railway package. Additionally, followed by the second and third package and currently the fourth railway package is in negotiations, between the European institutions and the member states. Each package consists of a set of regulations, directives and amendments on already existing legislation. All have the aim to accommodate interoperability and support the formation of free market economics on railway infrastructure, with only a minor role for the member states, after the example of the unification of the market in the airline industry. Some of the legislative tools apply to the authorities and some are more applicable to the TOCs. For each a short summary is provided on the main policy implications.

5.1.1. Authority

With regard to the authorities, the railway policies of the EU have resulted in the creation of separate infrastructure manager. Responsibilities for maintenance of the infrastructure are allocated here as well as the non-discriminatory allocation of capacity on the network (European Commission, 2001). The structure of a separate infrastructure manager creates a market in which the transport service providers are able to operate on a level playing field, at least in meaning of the legislation. A similar structure is in place for roads and airports, where the management of the infrastructure services is separated from the provision of transport. Additionally, licenses for operating companies, driver’s and trains should be recognised across Europe, eliminating the need for separate licensing procedures across the Union.

Not only the railway packages affect the member state authorities in their policy on railway, also the TEN-T regulation (European Parliament & Council of the European Union, 2013). This sets goals of the requirements on upgrading existing and construction of new infrastructure in order to create a core network in 2030. This also obliges member states to ensure interoperability across the continent, for example by unifying safety and communication systems (ERTMS), platform heights and electrification. This ultimately results in the creation of a single European Rail Space, this is however a unification in the railway traffic management and not the single economic market, like the European air market as established in the 1990's. Almost all policies are aimed at the provision of infrastructure and support of interoperability so the free market can provide the interoperated connections. Although the establishment of the European Railway Agency has brought a unification of passenger rights, the provision of passenger or service infrastructure (information, timetables, ticketing) is very limited included in the policies aimed at and applicable to the authorities (Rail Forum Europe, 2016).

5.1.2. Train operating company (TOC)

The first railway directive resulted in (partial) privatisation of state owned railway companies and separating them into train operating companies and separate infrastructure managers. For the train operating companies this EU policy should mean a level playing field on the access to infrastructure, with capacity allocation in a non-discriminatory manor by an independent operated manager. In combination with other EU policies, tendering procedures are established for public service provision, in order to compete for the market instead of in the market directly for the passengers. Additionally, the requirement to create an interoperable network does result in less complicated train configurations and eliminating interfaces between different operating, safety and electrification systems.

The second railway package already included provisions to allow open access operations for freight transport (European Commission, 2013a). Liberalisation was however slow across Europe, (European Commission, DGTREN, Wheat, & Nash, 2006). As a result the third railway package has foreseen in further separating the vertically integrated TOCs and more provisions on the non-discriminatory manner of scarce capacity allocation (European Commission, 2007). Overall the policies introduced and proposed by the EU provide, in potential, great promises and opportunities to the train operating companies: a level playing field of competition in the rail market itself. However, the difference in pace and the implementation itself across member states, still provides barriers.

The fourth railway package aims at further opening up the passenger market, more specifically Directive 2012/34/EU (European Union, 2012). One of the main concern is the right of cabotage, (providing domestic service pick-up and set-down passengers as foreign operator) across Europe without additional restriction. Member states are allowed to enforce exceptions on this provision (Section 4 Article 11). For instance, when departure and arrival destinations are both covered by existing service contracts and the execution of the open-access rights would "compromise the economic equilibrium of public service contract". Effectively every tendered franchise is a barrier of true open-access operation. Except when either the economic equilibrium can be restored or compensated, or no pick-up and drop-off is exercised in the same country. Restoration of the equilibrium or compensation can be established with cooperation with the existing contracted railway undertaking. Unfortunately, enforcement of member states of Section 5, cross border agreements is lacking. Neither cooperation and the establishments of cross-border agreements is properly handled, e.g. NL-BE (Parlementaire enquêtecommissie Fyra-rapport, 2015). The aim of the commission is to properly establish a single European market. It is assumed that the policies as proposed by the commission are applicable and binding to all states and all links in the network. This does open up the possibility of running cross-border connections, the simplest, by linking existing domestic connections.

5.2. Capturing seating capacity potential

The seating capacity potential indicated individual links with a potential to service travellers in a different or more appealing way. In order to capture this seating capacity potential as described, the connection should be made between the individual international links assessed and wider relations that are desirable. In order to propose connections that are the most viable and best fit the desires of potential travellers, first the existing relations between city pairs is assessed. Additionally, the interconnectivity between modes is reviewed. This means the way rail could replace air entirely on certain stretches in order to capture an even bigger market than based on potential could be expected. Finally, a set of new connections are proposed, as well as hierarchical place of this network, in order to capture the seating capacity potential.

5.2.1. Existing and future relations

Some international relations already exist and city pairs can be formed based on existing transport data as well as the trip distribution data of the passenger-trip potential. These city pairs can provide an indication for possible corridors of relations. Combining these existing relations from air traffic, the TEN-T core network and network assignment and the seating capacity potential of international links, this can be transformed into new connections.

Air Corridors

The most tangible current relations can be seen in frequent air-pairs. In the past the transfer from frequent air connections towards (high speed) rail has been very successful in order to accomplish a modal shift towards rail traffic (Nash, 2010), (Román et al., 2014). Based on the data of 2015 of Eurostat (avia_par), the busiest corridors in Europe are mapped in Figure 5.2.

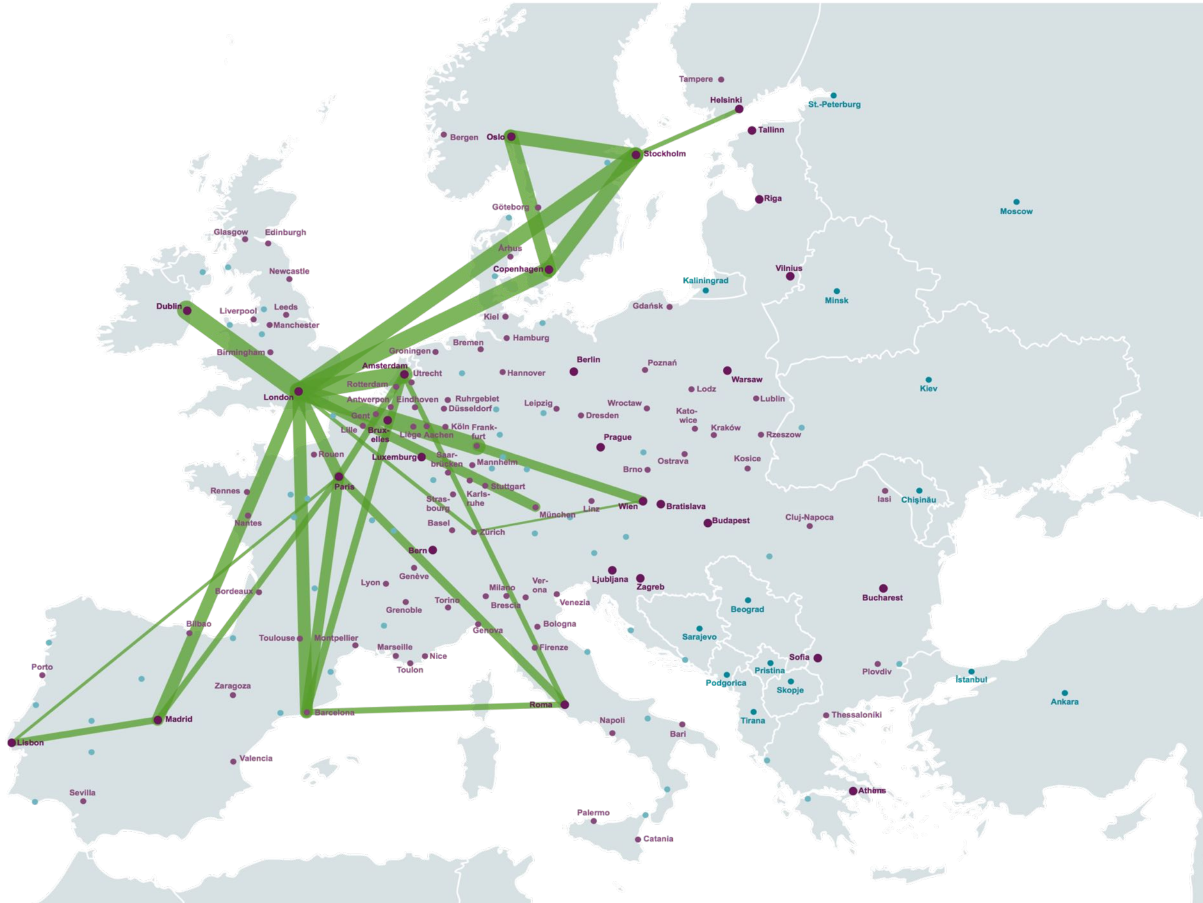

Figure 5.2 – Top 25 air corridors, thickness based on ranking, (based on: Eurostat, avia_par).

In 2015 the busiest European relation was Dublin-London (2,7 million passengers), followed by Amsterdam-London (2,6 million) and Frankfurt London (1,8 million). The first relation does not provide the opportunity for convenient conversion towards rail, due to the ferry crossing across the Irish sea. A through train on ferry could be possible though, just like current operations from Hamburg to Copenhagen. Nevertheless, such an arrangement would never be really competitive. Both the Amsterdam and Frankfurt connections could be provided via the channel tunnel and high speed networks that almost run from city centre to city centre. This would make competition very competitive with air transport. It is no surprise that multiple TOCs have already shown great interest in running these services. The least busy route in the list is Zurich-Vienna, serving 0,9 million passengers in 2015.

The Scandinavian triangle seems somewhat out of place with the rest of the top 25 air corridors. The existence of the triangle itself can be explained by both the geological feature of the Scandinavian peninsula in combination with the sparsely populated areas between the capitals. This makes provision of infrastructure on the routes expensive and difficult without the benefit of serving many people along the route. Additionally, the Scandinavian countries share a single flag carrier (Scandinavian Airlines System, SAS) since 1951 with the main intercontinental hub in Copenhagen and other major hubs in Stockholm and Oslo. From an airline point of view this arrangement creates effectively a single domestic market and routes are arranged accordingly with a lot of traffic between hubs. Nevertheless, the connections towards London from Stockholm and Copenhagen finish of the top 5. The connection towards Amsterdam is the fourth busiest connection from Copenhagen, however just outside the top. Remarkable is the focus on Western Europe with even the largest relation towards Eastern Europe (Warsaw-Frankfurt) carrying only 30% of the traffic of the busiest corridor.

Assessment of the map from a distance reveals some corridors of origin destination pairs across Europe. Three corridors could be distinguished and linked together into routes. This would be 2 East-West corridors, the first Dublin-London-Amsterdam-Copengahen-Oslo/Stockholm. The second East-West corridor would be Dublin-London-Frankfurt-Munich-Vienna. The North-South corridor could be defined as Amsterdam-Paris-Barcelona-Madrid-Lisbon. Defining these corridors provides insight in possible connections of international train services.

TEN-T

The Trans European Network – Transport (TEN-T) is the vision of a core network work for the European continent (EU) in 2030, similar to the Interstate network in the USA (European Parliament & Council of the European Union, 2013). The main difference is that the TEN-T network is applicable on all four modes: road, rail, water and air. By 2030, this network offers a consistent level of service with regard to speed, capacity and interoperability across the EU. The legislation around TEN-T is a directive, providing direct implication on the member states to develop the network as envisioned by the EU.

In order to concentrate effort, the European Commission has introduced 9 corridors in the network. These corridors are based on economic interconnectivity, existing travel and freight flows as well as historical relations. Additionally, the corridors are linking projects that need to be completed in order to establish a proper core network. In Figure 5.3 the defined corridors are portrayed, each in the colour as in use by communication of the EU and associates like TENtec.

Figure 5.3 – TEN-T corridors, (Based on: European Parliament & Council of the European Union, 2013).

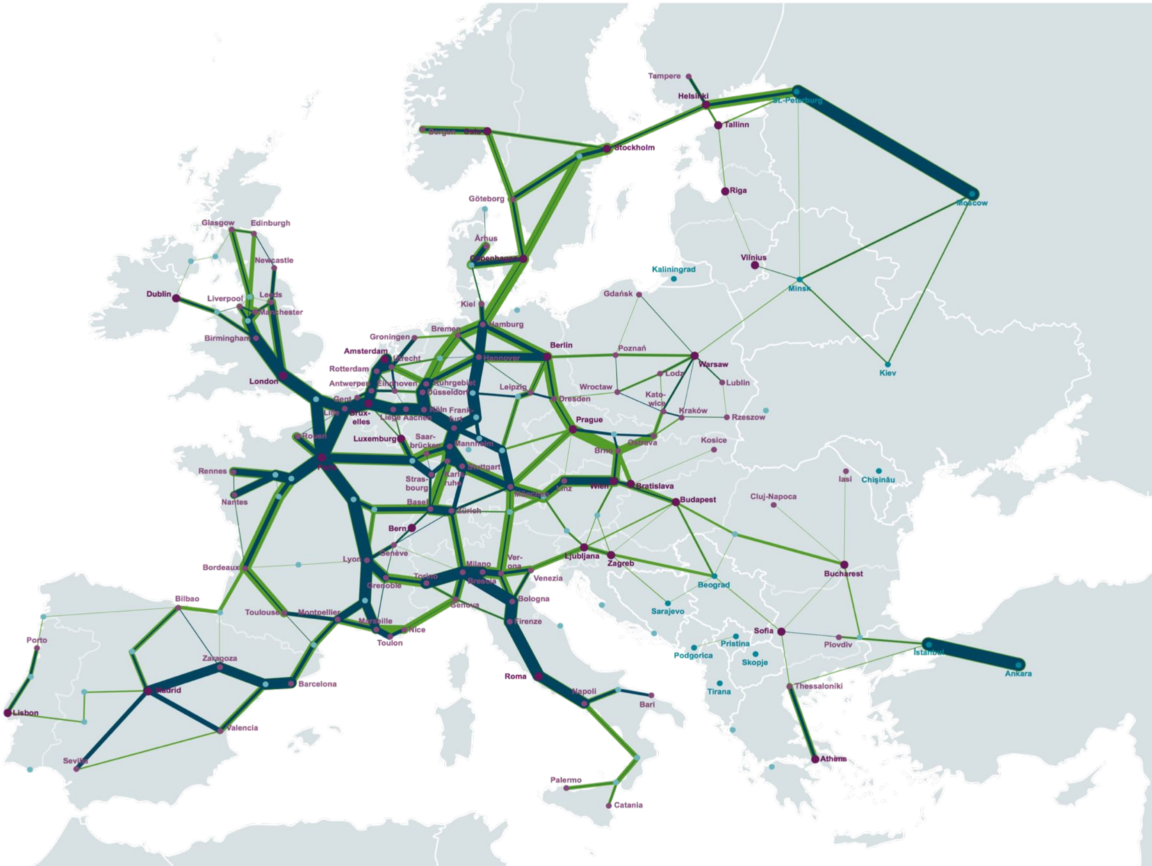

Figure 5.4 – Network assignment 2015 (blue) & 2030 (green), thickness of the links denotes the amount of traffic using a link, if amount is smaller than 250.000 trips annually the links is not shown, (Own calculations).

Network assignment.

In addition to the infrastructure corridors defined by the European Union and existing corridors in the air network, it is of importance to look at the network structure when all potential demand is loaded onto the modelled network. For the passenger-trip potential, the demand has been assigned to the network based on Dijkstra Shortest path algorithm. This is visualised in Figure 5.4, in blue the current potential and in green the potential of the growth scenario (integration) for 2030. Thickness of the line represents the amount of people travelling on a link. Scale for both time frames is the same, links with less than 250.000 potential travellers each year are completely left out.

The assignment in the current situation of the model does bear a lot of resemblance with the corridors observed from the airline network. Main difference are the high demand links in Germany and Italy, however, these are all domestic, so left out of the air corridor assessment. Development towards 2030, especially in the integration scenario reveals an overall increase across the network, although the corridors with already great demand reveal limited growth compared to other links. The link towards the identified Scandinavian triangle is established as well in the network assignment of 2030. The East West corridors stretch much further east, as a result of the growth and infrastructure development in this region. As a result of the close resemblance of the network to the TEN-T network, no real additional corridors can be defined. However, to make connections future prove prolongation and development towards Eastern Europe should be taken into account.

5.2.2. Interconnectivity and network effect

Much research is available on the interaction between new high speed rail infrastructure and the airline market on parallel corridors. Sometimes the point of view is from an investment effectiveness angle (Adler, Pels, & Nash, 2010) and providing additional insight in the benefits incurred by investments in rail infrastructure. Sometimes the question is posted what the effect is of the increased supply of airline routes on the competition and substitution effect between the two modes (Dobruszkes, 2011). Almost always the assessment of both (high speed) rail and the airline industry is done from this point of view, the view of competition and substitution. However, being competitive on certain aspects of the market does not mean that this competition can be observed across the complete market. Some recent research explores the possibilities of complementary supply to the overall transport market (Finger, Bert, & Kupfer, 2014) and (Albalate et al., 2015).

A network effect, the value of the product for a single user is dependent on the amount of user (Shapiro & Varian, 1999). In the case of transport, the users would be the entrance points into the network. Adding more entrance points to the network, would create a higher value for all points in the network. It could be argued that by making transfers between (high speed) rail and airports as seamless as possible both networks become supplementary and creating an incredible added value to both networks (Albalate et al., 2015). Some case studies have been performed on the Japanese market (Takebayashi, 2014). Both domestic rail and air services are very strong, however on the international market rail is non-existent, due to the island location of Japan. As a result, the argument is that high speed rail can complement international/intercontinental long-distance air traffic. This is profitable for airlines and cities because of the addition of entrance points directly in the city centres opposed to distanced locations (Takebayashi, 2015).

Conversion to the European situation has been attempted (Takebayashi, 2016). There is no island geography, however long-distance intercontinental traffic (in which rail has no role), could still complement European rail connections and create interconnectivity. For the Japan it seems that connecting airline hubs and HSR is advantageous, airline operations should however already be lean. Takebayashi suggests that overall profitability decreases of both airline and HSR if no connections at hubs are made. So connecting HST and airports could not only provide societal benefits due to replacement of flights by rail, also network effects and complementary service could benefit the operators.

In Europe interconnectivity could be created at the major airline hubs. Although most major airports are connected with their respective service cities by heavy rail/mass rapid transit, most are not connected directly to the main line infrastructure. Some of the largest airports in Europe (e.g. LHR-London Heathrow, MUC-Munich, MAD-Madrid Barajas) are not served by main-line connections, let alone international services). In Table 5.1, a summary is provided of hub-airports and airports with a long-distance railway connection.

Rank	City	Airport	Major Hub	Rail
1	London	Heathrow Airport	X	
2	Paris	Charles de Gaulle Airport	X	X
3	Istanbul	Istanbul Atatürk Airport	X	
4	Frankfurt	Frankfurt Airport	X	X
5	Amsterdam	Amsterdam Airport Schiphol	X	X
6	Madrid	Adolfo Suárez Madrid–Barajas Airport	X	
7	Munich	Munich Airport	X	
8	Rome	Leonardo da Vinci–Fiumicino Airport	X	X
10	Barcelona	Barcelona El Prat Airport	X	
11	Moscow	Sheremetyevo International Airport	X	
13	Paris	Paris-Orly Airport	X	
16	Copenhagen	Copenhagen Airport	X	X
17	Zürich	Zürich Airport	X	X
18	Dublin	Dublin Airport	X	X
19	Oslo	Oslo Airport, Gardermoen	X	X
21	Brussels	Brussels Airport		X
22	Stockholm	Stockholm-Arlanda Airport	X	X
23	Manchester	Manchester Airport		X
24	Vienna	Vienna International Airport	X	X
26	Düsseldorf	Düsseldorf Airport		X
28	Lisbon	Lisbon Portela Airport	X	
29	Milan	Malpensa Airport	X	X
31	Helsinki	Helsinki Airport	X	
33	Geneva	Geneva International Airport		X
40	Prague	Václav Havel Airport Prague	X	
42	Warsaw	Frederic Chopin Airport	X	
46	Stuttgart	Stuttgart Airport		X
48	Cologne	Cologne Bonn Airport		X
50	Birmingham	Birmingham Airport		X
56	Lyon	Lyon-Saint Exupéry Airport		X
57	Berlin	Berlin Schönefeld Airport		X

Table 5.1 – Major airport hubs and airports with main-line rail connection, (based on: respective airport authority).

5.2.3. Proposal of new connections

Connections are more than lines or a string of links between origins and destination, as already explained in chapter 4.1. Connections are a set of stringed links and level of service indicators. First the set of indicators is provided determining the new level of service for international operated long-distance trains. Next the string of links for the new connections is provided.

Service indicators for new connections

So for the other service indicators the connections all share the same minimum level of service. With regard to service level the minimum is IC+, however preferably HST, especially when infrastructure is available. Seating capacity is ensured on the international links and capacity on the domestic links can be provided by auxiliary domestic connections. Furthermore, the additional service indicators are all respected. Timetables are easy accessible, with free provision of timetable info to google, apple, and all other transit platforms. The competitive advantage is not the timetable information itself, as some legacy TOC still adhere to (Rail Forum Europe, 2016), but the transport services offered. Pricing information is equally accessible as it is for airlines or better (skyscanner, google flights), by integration into global ticketing system, to prevent a monopoly. Reservations can be made; however last-minute sales should be possible. Transfers within the connection are none existing and transfer between connections, are optimised to minimal waiting time and maximum convenience (cross-platform interchange). Finally, the international frequency should adhere to the minimal assumed average schedule displacement time of 15 minutes. This results in a frequency of once every hour or a headway of 60 minutes during the operating day. Given this set of indicators this would result in an offered seating capacity of each connection of 1,7 million seats annually, according to the same methodology as the seating capacity potential assessment. This does assume that every seat offered would be sold and load factors of 100%.

String of links in new connections

The TEN-T corridors and the observed air corridors both go across multiple Urban Hubs. However, some large Urban Hubs do not have convenient infrastructure for through running service. Most traffic even from an international perspective has as destination in these hubs. As a result, it is better for the limited amount of people to arrange convenient transfers, than invest large amounts of money to ensure trough running service. The largest cities in the city set do have such restrictions, Paris and London. History has resulted in multiple major rail termini, non-connected or with large detours around the urban cores of restricted infrastructure. Creating a situation where the operational choice is either serving the core city or providing a through service with just a stop in the suburbs. Assessment of the passenger-trip potential shows that only 11% of the all assigned trips over links to London, have a destination past the city, for Paris this is 12%. Just looking at international trips the number is somewhat higher, 16 and 21% respectively. To compare, a city that seems equally well connected based on link loads, Frankfurt these values are much higher, 67% and 80 % internationally. The conclusion that for some cities, the necessity to run through is existing, however has a lower priority.

Based on all the previous considerations, a set of 12 European connections have been established. This set is an objective solution of running European services without the considerations of national politics, a combination of demand, supply and relations. The overview of the created network is provided in Figure 5.5. Off-course this network has to be supplemented with national running services. Additionally, current successful connections like Eurostar, Thalys, international ICE or EC are not affected by this additional provision of trains.

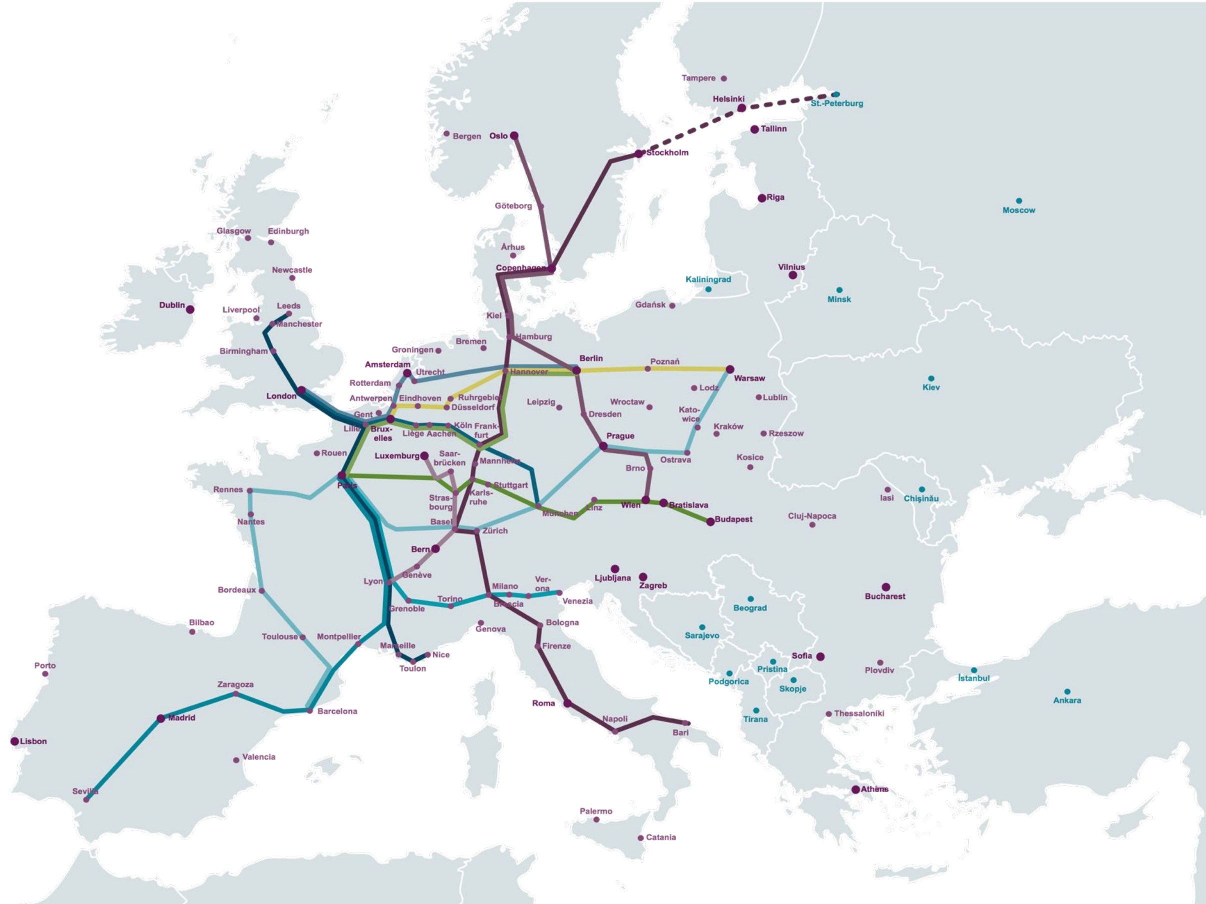

Figure 5.5 – 12 New European Connections, (Own elaboration).

New core connections network assessment

The 12 new connections that are proposed do form a new network in Europe. One of the main desires of passenger interest groups are the direct connections between main European destinations. Of the top 50 cities in Europe based on the amount of trips by train, only three are not connected with this network. Additionally, the network tries to avoid unnecessary transfers between the main capitals or focus cities, that are within the goldilocks-position of train travel 300-700km. As a result, direct connections exist between London, Amsterdam, Paris, Brussels, Frankfurt and Berlin, (Amsterdam-Frankfurt is not in the connections proposed, as it already exist). For operability a length until 1000km is desirable for long-distance trains, however vulnerability the time table is much more dependent on the priority of the trains within each country.

Some of the connections are more direct with regard to the chosen route on the source-target relation. Dependant on the importance of the direct relation between the source and target the directness is more important. Several connections are a string of desirable OD-pairs, for example London-Berlin joins the London-Amsterdam route to the Amsterdam-Berlin route. The most extreme is the route Barcelona-Warsaw linking multiple desirable sections to each other. Some of the routes are chosen on the service level, most are initiated as high speed routes if really increasing the competiveness. However, the Brussel-Warsaw connection is an IC+ service, using conventional links, hence the route deviating from the quickest travel time instead opting for a route linking unserved links and the shortest path in distance. Overall the presented connections form a competitive network.

	From	To	Via	Length	Detour	Level
1	London	Berlin	Amsterdam	+	-	HST
2	London	Munich	Frankfurt	+	++	HST
3	Paris	Berlin	Frankfurt	+	++	HST
4	Paris	Sevilla	Madrid	-/+	++	HST
5	Paris	Venice	Milan	+	++	HST
6	Paris	Budapest	Munich	-/+	+	HST
7	Stockholm	Bari	Frankfurt/Milan	--	-/+	HST
8	Oslo	Vienna	Berlin/Prague	-	-	IC+
9	Leeds	Nice	Birmingham/Lyon	-/+	+	HST
10	Bruxelles	Warsaw	Berlin	+	-	IC+
11	Luxembourg	Lyon	Basel	++	+	HST
12	Barcelona	Warsaw	Bordeaux/Rennes/ Basel/Prague	--	--	IC+

Table 5.2 – 12 New European Connections characteristics, (Own elaboration).

The proposed passengers core connections network, with 12 new connections, offering an hourly service across Europe at the desired level of service can be quantified with several key figures. In the current potential, none of the external included cities generates sufficient traffic to be included into the network, providing a high service level without additional requirements as a result of crossing the Schengen border. The main characteristics and qualitative assessment of the network is summarized in Table 5.2.

The proposed network connects in total 72 of 125 cities, have a city coverage of 57,5%. With regard to the amount of passengers served by the network, this is much higher. The model determined the potential for passenger trips via rail on 656 million without extrapolating for the complete population. Only 25% of these trips are international trips, 163 million annually. The core network would serve 133 million annual international trips, 82% of the total international market generated by the Urban Hub city set. With regard to all modelled trips, including domestic trips, the core network serves 74% (485 million annual trips). This lower service rate when all city pairs are included is the result that the core network is developed based on international seating capacity potential. This resulted in the exclusion of very high demand domestic relations. For example, Dusseldorf-cologne or Bordeaux-Paris are not a part of the core network, because the demand on these routes is almost exclusively related to domestic trips.

Furthermore, the network is well connected, reducing the necessity for transfers to a minimum. The most important OD-pairs, capitals in north-western Europe, have direct connections between one another. Almost every other OD-pair within the network can be reached with a maximum of a single transfer. Additionally, the transfer points between individual connections have a logical geographical location. Eliminating the need to make a detour in order to reduce the amount of transfers needed. The aim of the network is provided high speed connections. As a result, 80% of the modelled high-speed links are used by the network and over 95% of the modelled high speed network length, ensuring a competitive travel time compared to other available modes. Given the current lay-out, the network should also be able to deal with large scale failures as a result of strikes. Strikes of railway personnel, either on the operating level or infrastructure management level, currently greatly affects international travel. With the core connections a logical and clear alternative is offered, limiting the detours and impact of such network failures.

5.2.4. Network hierarchy

The network of new connections would interfere with the already existing network structures of the national TOCs. Such interference would result in new operational challenges on national and subsequent levels, where the aim of this core connections network is to eliminate as many barriers as possible. Additionally, creating barriers by interference of existing operations would result in resistance and hesitance of the incumbent operators in order to support the passenger core connections as proposed. In order to overcome these issues a proposal on the hierarchy of different networks is provided, based on the literature available on hierarchy in public transport networks.

Literature on network hierarchy

Hierarchy of infrastructure networks has been assessed multiple times on many different levels, however most often in the context of road networks (Bovy, Schoemaker, & van Binsbergen, 1994; Schönhartig & Pischner, 1983).There have been several research efforts to adapt the findings for road network hierarchy towards public transport networks or even multimodal network development, (van Nes, 2002). Nevertheless, the multimodal network development is mainly limited to development of urban public transport networks in the hierarchy of regional and national existing networks. For urban public transport, this is used to determine a set of characteristics of the public transport network. The main characteristic would be the timetables (Nielsen & Lange, 2007), with resemblance to the fish grate model, (Ministerie van I&M, 2011; NHTV, 2012). The latter is used in the Netherlands to plan urban and regional public transport in hierarchy to the stricter conditions of the existing railway infrastructure. However, it can also be used to determine complete reworks of networks in case of the introduction of new modes, (Saliara, 2014). Or the assessment of existing network strength and weaknesses and the optimisation opportunity this will provide in an urban setting, (Dodson, Mees, Stone, & Burke, 2011). Network hierarchical planning on a higher, long-distance level has very little literature available and is most often only touched briefly in visionary network ideas of future new-modes (Musk, 2013; Th.J.H. Schoemaker, Egeter, & van Goeverden, 1993).

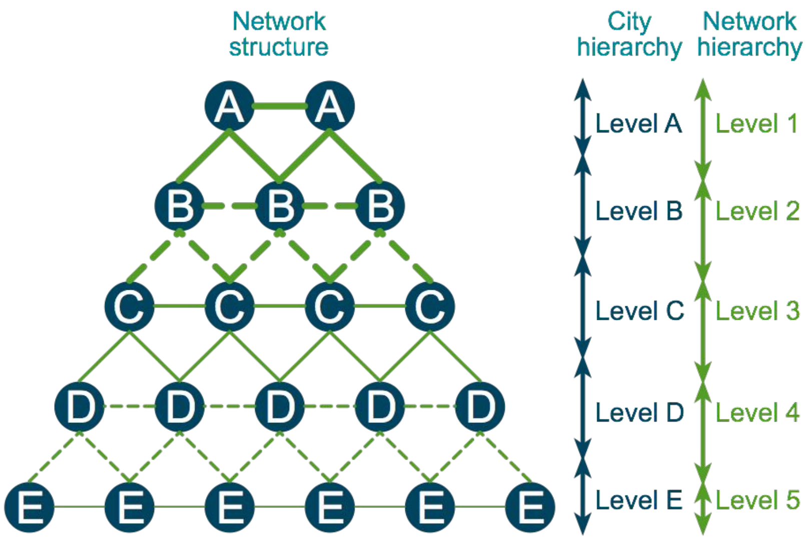

Figure 5.6 – Network structure and hierarchy, based on: (Schönhartig & Pischner, 1983), adopted by: (van Nes, 2002)

Despite this lack of high hierarchical implementation of public transport network structures, both existing work and history are able to provide indications on how the core connections would interact with the existing networks. The network structure, as shown in Figure 5.6 has multiple levels , as does the hierarchy of cities, (van Nes, 2002). In the assessment made by, Van Nes, five levels of cities in an inter-city context could be distinguished based on literature study. These are local, regional, interregional, national and international, with respectively villages, towns, cities, agglomerations and metropolitan areas as representatives. Each level could should be served by its own infrastructure network and own service hierarchy network. Currently train operations and TOCs concentrate on the regional to national level (network levels 2-4 in Figure 5.6), with providing different service level, stopping patterns and timetables on the distinctive levels. Depending on the country, most TOCs operate a two or three train system. The Netherlands for example uses a two train system, consisting of Sprinters (local/regional) and InterCity's (interregional/national), in Germany however a, de-facto, four train-system is existing with Regional, Regional Express (interregional), InterCity's (national) and InterCity Express, ICE, on a higher national level. The choice to have only a two-tiered system for serving four city levels has to do with capacity allocation. Having multiple operating speeds and stopping patterns, greatly reduces the capacity of the overall network, (Goverde, 2015; Pachl, 2014).

Proposed hierarchy level

The Urban Hub city set consists of the most important cities in the centre of metropolitan areas across the European continent. Although not all cities or areas are strictly of the metropolitan large scale urban agglomerate level that is represented in the international city level, most adhere because of their international importance. Proving a network between this level of cities automatically could be classified as a level 1 network. The characteristics of proposed connections can live up to the expected characteristics of a level 1 network on the metropolitan level. These are high-speeds, limited detours, limited amount of stops (entry-point density every 100-300km). Being a level 1 network also implies that the preliminary passenger core connections would be placed hierarchical on top of the existing operational networks of the TOCs.

As remarked having additional service pattern using the same infrastructure would reduce infrastructure capacity, which is a scarce resource in dense urban areas around the Urban Hubs. Nevertheless, the core connections are in essence high speed trains, which would use dedicated infrastructure, high speed lines, which are build and designed to serve metropolitan areas on a national scale initially. The usage of dedicated infrastructure for the network type provides many benefits, the most important that there is limited impact on capacity for existing services. With the development of the high speed network across Europe, the future scenarios already show the benefit of linking networks and the created network effects, this can be further enhanced by a new top-layer of truly European operating train connections.

The hierarchical approach should also take effect into the way capacity is allocated by the infrastructure managers of the member states. Although this should be done on a non-discriminatory base, infrastructure managers have established rules on the priority of service levels in capacity allocation and resolving disturbances. For the Netherlands this has resulted in a framework where international trains have the lowest priority of all passenger trains. Disturbances as an effect have the greatest impact on international trains which aggregate delays of multiple countries along their routes, not a practice belonging to the highest level.

5.3. Proposal of Business cases

The large cross European connections have been identified, in addition to these several shorter connections can be added to link up with the core system. Although the connections are based and formulated with existing relations and seating capacity potential at the foundation, this is not yet a complete business case. In total an unserved demand of 52 million people does exist according to the model, which has been constructed to give the best representable guess of what a utopian railway market would look like without the barriers created by current policies, authorities and operators. The proposed connections are an aid in tapping into this possible and reachable future. Only after the business case is positive, train sets can be ordered and passengers speeded around Europe.

5.3.1. Risk and competition

The provision of railway operation under public service contracts has limited the possibility of open access operations of railways to a great extent, as pointed out in the policy section. Much research has been done on optimising the governance of public service contracts for public transport operations (Veeneman & Nelson, 2010). Nevertheless, one of the common questions operators are presented with when having ideas of running services outside the scope of the contract is who will pay for them (Rail Forum Europe, 2016). In some cases, services will pay for themselves, as a profit can be made. In many cases however, as also pointed out by this research, the potential demand on international links is fairly limited, especially compared to the demand on the domestic stretches.

For domestic links across multiple service contracts in general an overarching authority can be found who will take up the responsibility of creating additional service contracts. On international level the executive power of the overarching authorities is currently too limited to take up a similar role. Almost all authorities are divided exactly along the country borders, from municipal, regional, national to infrastructure managers and infrastructure technologies creating so many interfaces that operations themselves become difficult and risky. Let alone who will take care of representing the social interest and responsibility for providing the service. In practice taking this responsibility means paying for the losses incurred by the provision of the connection. Additionally, the competition on the domestic stretches of the ‘regular operators’ does reduce the attractiveness for open access international operation except when a real competitive advantage could be offered like high speed connections or crossing the channel tunnel. As a result, the focus for possible business cases should be on links that can support themselves with limited need for public service provisions or other kinds of management/operational subsidies.

5.3.2. Growth expectations

Growth expectations are almost completely link towards the risk and the competition encountered in the market. In the growth scenario that has been made for the 2030 forecast, a tremendous growth for the future rail traffic demand does exist. However, if the European Union and the economy will see the decline as predicted in the divergence scenario, the size of the tapped in market will still be bigger than the current situation. In past years and with the optimism of the European Commission and Train2EU it would be expected that most of the growth and integration could materialise in the next 15 years. With the Eurosceptic sentiment among large parts of the European population, the integration part becomes much more uncertain. According to many models and future scenarios this will greatly affect the economic growth and stability as well, making the divergence scenario far from unthinkable. The first indications that the predicted effects of such a scenario are right can be observed in the economic effects of the recent referendum in the United Kingdom to leave the European Union, BRexit, (Giles, 2016).

Nevertheless, the growth can only be materialised in case that all the service indicators will be accomplished. Although not completely included in modelling the seating capacity potential, the additional service indicators are incredibly important for customers. If travellers are unaware of operating trains, they will never proceed into a booking ticket. For some trains customers do know that trains do exist, however stop trying to book when timetables or reservations slots are unable to be found.

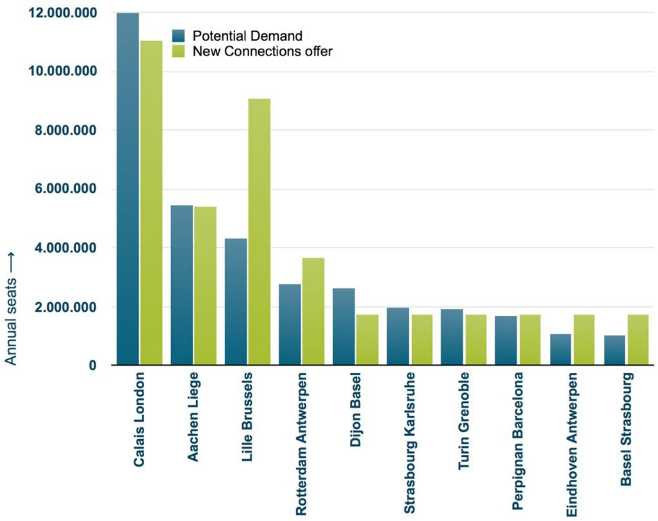

Figure 5.7 – Served potential demand by new connections, (Own elaboration).

Sufficient room is however available in the market, even with the addition of the new connections. As shown in Figure 5.7, the offered seats based on a single train each hour, as well as adjustment for larger trains in the channel tunnel due to safety requirements, at a 100% load factor, the seating capacity potential is not completely fulfilled. In addition to the new connections, shorter additional services can be provided by multiple operators. The seating capacity potential is based on existing running connections, only the undesirable connections should be replaced.

5.3.3. Opportunity gap of incumbents

One of the most pressing questions, already existing before this research, is the reasoning on why TOCs are so reluctant on providing the international connections. The initial perception was a limited market. However, this research has shown differently. Leaving, the question why the incumbents TOCs are unwilling to capture the opportunity gap of potential as presented.

Unfortunately, the complete reasoning for this reluctance is obscure and would necessitate a much larger research outside the scope of this report. Nevertheless, meetings with the current service providers have given some insight in their rationale and motivations. Most commonly it is their lack of awareness for additional possibilities because they operate from a point of view where they claim to know the passengers and their desires (Rail Forum Europe, 2016). Furthermore, the international divisions of the TOCs are much more focussed on the key performance indicators of their public service contracts. International services are not managed under such contracts and as a result have no obligations, only market forces.

This nevertheless is not an explanation why none of the existing incumbent operators, nor a new start-up operator is willing to break the status quo on international railway operations. In similar fashion of the market development of the airline industry with the introduction of low cost carriers. Probably this lack of initiative is the result of the high barriers of entry to the industry and market, with great start-up investments necessary. Additionally the legislative and governance framework is unclear in the consequences for the individual member-states with only a very long-term vision provided by the legislative authority.

5.3.4. Business cases

Really diving into the business cases and assessing the profitability or overall viability of the connections is outside the scope of this report. It will necessitate the dissection of each and every component of the proposed connection into monetized values. One of the important things that have to be kept in mind is that the connections have to offer a minimum level of service. This would guarantee, according to the model, the potential demand. However, in order to get to a viable business case some parts can be adjusted, like stopping pattern, timetabling and scheduling (Espinosa-Aranda, García-Ródenas, Ramírez-Flores, López-García, & Angulo, 2015). In order to have proper passenger expectations the changed indicators should be assessed once more, because no matter how they change, they will affect the passenger potential.

The main business cases that deserve further investigation out of the 10 new connections are the connections through the channel tunnel. Although some of this demand will be served in near future, (Railway Gazette, 2016), the corridors represent so much potential demand that even given the new services to Amsterdam (2 daily trains instead of the proposed 14), sufficient potential should be left. Furthermore, interest does already exist with different operators, Eurostar and DB, and trainsets able for the interoperability on most parts of the route are already in possession of these operators. Furthermore, the overall connection Brussel – NL – Berlin – Prague is of interest because of its limited reliance on HST infrastructure and the somewhat extraordinary route with regard to history.

Although the new routes try to take as much advantage as possible of creating complementary network values for the proposed services, competition with the airlines will still exist. Often the general comparison with the airline industry is made as well. For the current operating train connections, most have a very low frequency (once a day). In the airline industry the trade-off between single size capacity and frequency is won by frequency and as shown in Figure 5.8, even a A380 can offer double the frequency for the same capacity offering, though reducing wait and displacement times. Additionally, the trend is smaller planes with higher frequencies.

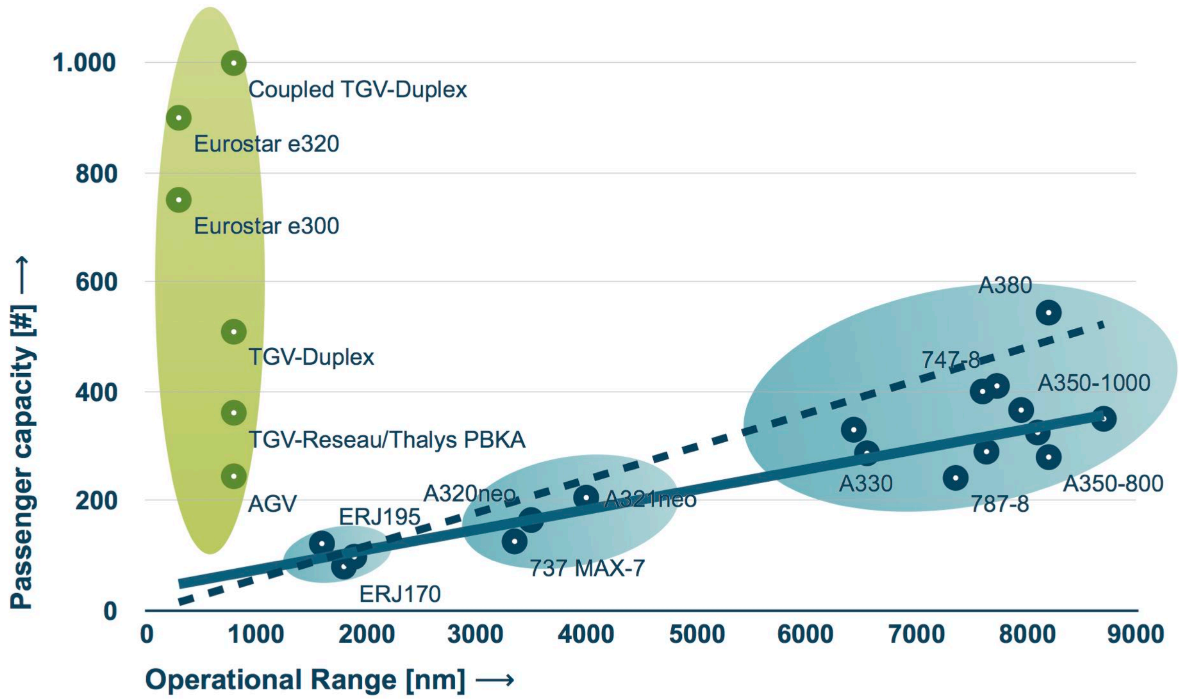

Figure 5.8 – Operational range vs. passenger capacity planes and high speed trains, (based on: TOC-information, manufacturers; own elaboration).

5.4. Conclusion preliminary core network

To wrap up the analysis of the European passenger railway market, the preliminary core network has been determined. The preliminary core network focussed on the discrepancy between the unserved links and the possibilities of offering new services, indicating spots and possibilities for new business opportunities as well as for which connections a proper business case could be constructed. In order to determine the preliminary core network a set of research questions was drafted. This chapter provides the answers to the following questions.

- D What is the preliminary core network for the European railway market?
    - a What is the policy-framework for offering international railway services, on an authority and TOC level?
    - b Where are the current and future bottlenecks (market)?
    - c How would a core network relate to the existing operational reality (hierarchy)?
    - d Why are TOCs so reluctant to fulfil the apparent potential (opportunity)?
    - e How can this network be realised or made viable?

The policies within the market of providing railway passenger traffic are mainly determined by European legislation. The legislation has multiple layers, consisting of directives which are directly binding and applicable to all member states and regulations which provide objectives that should be met by the member states. The way the member states will satisfy the objectives is up to the states themselves. With regard to railway policy, legislation is provided in packages consisting of a mix of directives, regulations and amendments to existing legislation. Since the first railway directive, all policies of the EU have the aim to create a level playing field on the railway market. This has resulted in privatisation and the separation of state-owned railway undertakings into infrastructure managers and train operating companies. The infrastructure managers will take care of the non-discriminatory distribution of capacity and other provision for safe operations. In the spirit of the legislation all TOCs should be able to make use of the services of infrastructure managers in order to provide open access operations across Europe. However, as a result of the way public transport is regulated, most operations are part of public service contracts which provide the possibility of limiting the access to the market and under strict conditions. Current policy on offering international railway services make real open access operation cumbersome, difficult, risky, uncertain and, as a result, unviable.

Current and future bottlenecks have already been identified more or less in the seating capacity potential as being the international links in the network. Nevertheless, this should be extended towards the proposal into new connections on the network. The current and future relations have been assessed. This assessment has been made on the currently existing air corridors as strict point to point relations. This resulted in three corridors, two East-West, and one North South. Additionally, the TEN-T transport core network for 2030 as proposed by the European commissioned, also provided 9 corridors in order to focus investment efforts. These corridors have been proposed on the base of historic and trade relations. Both the air corridors as well as the TEN-T network are existing corridors. The network assignment of the passenger-trip potential model does reveal the potential demand and were it will travel. Both in the current potential situation and in the future, providing the best educated guess on future network demands. Furthermore, the importance of incorporation of airport hubs as possible network extension has been established. A convenient and seamless transfer could provide additional value to the HSR and intercontinental plane networks that the modes could become complementary and generate overall a higher profit. Based on these assessments 10 new

European connections are proposed. The new connections should adhere to the minimal desirable level of service in order to materialise the unserved demand as identified as the seating capacity potential.

The preliminary core network would be placed in the defined hierarchy of cities. This hierarchy defines five levels of city importance and a similar set of network importance between the different city levels. The Urban Hub city set is of the highest hierarchical level for cities, the metropolitan level. Although not all cities adhere to the metropolitan definitions, they are de-facto as a result of their international importance. The core connections would form a network between the metropolitan areas, making it a level 1 network. The characteristics of proposed connections can live up to the expected characteristics of a level 1 network on the metropolitan level. These are high-speeds, limited detours, limited amount of stops. Although an additional network level could result in reduced infrastructure capacity, because of alternating usage patterns, this is insignificant. The core connections would be mainly high speed trains operated on dedicated networks, resulting in limited impact to the existing infrastructure capacities and operations of TOCs. The hierarchy should additionally be taken into account for infrastructure managers, in the allocation of capacity and solving disturbances.

Complete research into the actual motivation of the TOCs and market reluctance unfortunately is outside the scope of this research, it is however possible to make a breadth assessment on the subject. Reluctance of the TOCs in order to capture the apparent potential found in this research is stemming from an intrinsic motivation that they are aware and fulfilling the customer expectations completely. This creates a point of view in which they are unaware of the possible existing potential. It nevertheless does not provide an explanation why there are no other entrants to the market to break the status quo and capture the potential. The market on which train operating companies act is however much more complex and regulated on a national scale given the public service contracts. This creates high barriers of entry with great start-up investments and risks with regard to business continuity.

The passenger-trip potential and seating capacity potential within the preliminary core network can only be captured if the assumptions as created for the model are incorporated into the real world. To accomplish this a proposal is provided for the business cases of the new connections. The most interesting would be the connections towards London. Although new connections will start operating soon, according to the model a lot of potential is still let untapped. Nevertheless, a great deal of risk is involved in the business cases, both the operational reality and governance framework is not always clear for international services. Additionally, the scenarios for future potential provide a range into which development can take place. In the past the growth scenario would be most likely, however in the current Eurosceptical climate it is hard to predict what the future for the European free movement area will be and what it will mean for travel without borders. Nevertheless, this would provide a first step in the realisation of the Passenger Core Connections network as passenger rail alternative to the Rail Freight Network and TEN-T infrastructure network.

This approach could unlock to complete potential of the European passenger railway market. The market consists of the passengers willing to travel with connections that are competitive on multiple levels, not only travel time, but also frequency, travel time performance, findability and transparency. It is no longer as much about the actual characteristics of the connections on themselves, but the complete provided user experience.


THALYS PLATFORM
WELCOME TO OUR WORLD
THALYS BAHNSTEIG
WILLKOMMEN BEI UNS
THALYS PERRON
VAN HARTE WELKOM
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6 Conclusion & discussion

Railways and trains have marked Europe; the vast network was a quick way to get around the continent. They have provided Europe with some of the brightest and some of the darkest pages in its history. Fuelling the revolution of industrialisation and trade across the continent in the 19^{th} century, becoming a war machine at the start of the 20^{th} century. Ironically also the armistice that ended hostilities of the First World War were signed in a railway carriage and moving displaced emperors across the continent. In the '50 and '60's they became once more the connection to the world, with a great and luxurious network of TEE-trains. In recent years travelling the world has never been so easy, travelling by train however has become much more cumbersome. So the perception lingered, that the international railway connections for passengers are insufficient. It is the sincere dream and hope of many that railways once more will revolutionise Europe and will introduce a new and sustainable future.

The final chapter will provide the answer to the research questions posted in the introduction. In order to do so, the sub-questions that have been answered by the previous chapters will be first summarized. Together this will form the conclusion part of the chapter. Based on this, the report and research will be assessed and discussed in the scientific implications. As final part to the chapter recommendations will be provided on further steps towards Erasing borders!

6.1. Conclusion

This report does answer the questions: "Where and how in Europe does, currently and in 2030, the biggest potential of international train passenger travel exist, based on passenger-trip potential (demand) and seating capacity potential (supply)?" In order to do so, this report and research has been built upon a framework of modelling techniques and assessment methods. First the answers to all the sub-questions will be provided, which will result in the answer for the main question and main conclusion.

6.1.1. Sub-conclusions

The report has been divided into four parts, the system of interest, the passenger-trip potential, seating capacity potential and preliminary core network. Each part based upon the work and outcomes of the previous part and adding their own tools and point of view to the research.

A What is the system of interest for this research?

The first part is to define the system of interest, providing the scope of the research and exploring the existing structures within this scope. The focus of the performance of the rail market finds its source in competition with air travel. As a result, the first boundaries are marked as international long-distance travel in Europe, long-distance being anything further than 100km. Regional connections and local traffic is omitted from the research and methods. The answer to the underlying questions, determine to details within the system of interest.

A.a What level of aggregation is necessary to provide a clear and detailed outcome?

The aggregation level for geographic scope has been defined as the Schengen area, including the UK and Ireland, and leaving out island states without rail connection, Iceland, Cyprus and Malta. Additionally, 14 external cities in neighbouring countries are included as external connections. As a result of all the different definitions of cities or the vast quantities of the city datasets a new definition is introduced. The ensures that the most important cities are included as well as being able to collect statistical data on them. To denote a city within the set, the definition, Urban Hub is created. Based on population, metropolitan GDP and high education level, this created a set of 125 cities. The complete selection is provided in Figure 6.1.

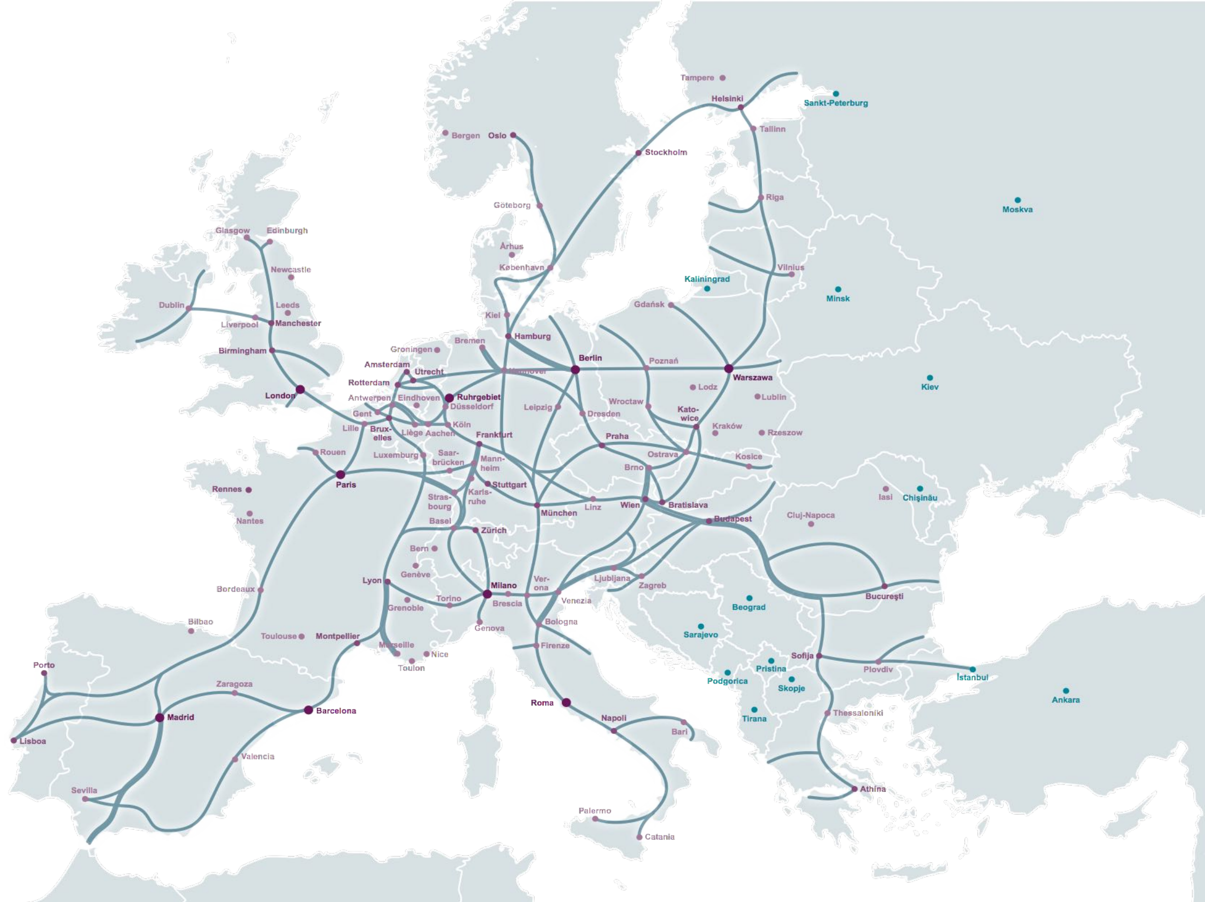

Figure 6.1 – City selection: Urban Hubs (purple dots) and external cities (green dots), (own elaboration). TEN-T network (lines) for illustration of EU corridor infrastructure. (Based on: European Parliament & Council of the European Union, 2013)

A.b What are the preferences and characteristics of travellers to make a choice with regard to destination, mode and service?

The preferences and characteristics of travellers to make a choice for destination, mode and service are actually the determinants of travel. Every choice in the process that is made is based on these determinants. The amount of long-distance studies is very limited and the definition of long-distance differs according to the purpose of the study. Characteristics can be divided in to three group: trip, passenger and city characteristics. The trip characteristics include preferences or sensitivity for travel time, travel costs (based on individual's value of time) and purpose. City characteristics are transformed into attraction and production values, a representation of the relative size an economic power of a city. Passenger preferences are the economic prosperity of the individual or household, the age, gender and employment characteristics. Modal split preferences are mainly based on trip characteristics and the relative performance to other modes, also for long distances. The importance of the relative performance is assessed by the sensitivity of passenger. The used determinants of travel are listed on the next page in Table 6.1; each column represents a part in the research.

Trip Generation	Trip Distribution	Mode choice	Service selection
GDP/Capita	Attraction	Travel time sensitivity	Travel time sensitivity
Population	Country		Travel time performance
	Language		Frequency
	Economic area		Transfers
	Distance (sensitivity)		Service quality
			Price performance

Table 6.1 – Preferences or determinants of travel used in the research for the different choices in the model.

A.c What scenarios can be used to provide an estimation for 2030?

Two time frames have been defined in the research. The first is the current (2015) potential situation. This is built upon the statistics data that is most recently available, generally the period 2011-2014 country dependant. This range is applicable and appropriate due to the fact that not all necessary data is available for every factor, city or country on a single time entry.

The second time frame is 2030. To deal with the uncertainties of the future, three scenarios are adopted from European policy assessments. A decline scenario (Divergence) with a diverging Europe and slowing economy, also resulting in people less willing to travel. The second scenario is the Status Quo, economic growth is limited and the EU will function as it does now. The third scenario is the most optimistic, with economic growth and further integration between countries (and so called Integration scenario). Perceptual borders will be eliminated further, increase in infrastructure investments and people are more willing to travel.

A.d How are the railway corridors in the European railway network defined?

As a result of the chosen modelling methodology and the scope it is not possible to use a complete model of the actual network. To overcome this limitation, the network is built upon connecting the cities with direct links. For proper representation, a total 50 additional network nodes are added on top of the 125 Urban Hubs.

The question has a wider interpretation: What is the infrastructure network in Europe that should be used for the model? In the research 3 different networks can be distinguished, road, rail and air. They support together 5 modes, car and bus on the road, high speed trains and conventional trains on rail and planes in the air network. To estimate the actual travel times, the great circle direct distance is multiplied by a detour factor and average mode speed. Additional network features are included to have a complete network. For both the road and rail network supplementary ferry services are available. In order to ensure proper representation of rail and air network access and egress, additional legs are needed to reach the infrastructure entry points. For the plane the airports are linked to their main city. Each city is assigned a maximum of one airport, always the biggest to prevent that a small but close airport has such a favourable travel time that it would be flooded with trips beyond capacity. Furthermore, waiting time is calculated for waiting at the terminal and idling on the tarmac.

A.e What connections (trainroutes/-services) are offered?

The current connections are the actual products from which passengers currently can choose in order to make a trip in Europe. The choice to adapt the nomenclature of train services to connections is to provide a clear distinction in this research between a train service connecting places with or without transfer and the service level. Assessment of the offered connections focusses on the international, cross border services, providing clear intersections (borders) on which the amount of services can be assessed. This limitation is necessary due to limitations in data provision by national TOCs. In total 175 connections are included, for all, the service level, frequency, travel time and brand are recorded. For service level an aggregate distinction into 5 categories is made, in an attempt to lift the services from their marketing infused descriptions and put them into more uniformly applicable categories. These being InterCity (IC) and High Speed Trains (HST) within between, IC+, for the long-distance services. For the shorter connection patterns the regional (express) service and separately the night trains. On a connection/link level the additional special category of ferries is defined to capture transfer traffic without a fixed rail link or continuous operating connection. (Elaborate description of this answer can be found in chapter 4 for readability and continuity instead of 2)

B What is the passenger-trip potential, demand, of the European railway market?

In order to actually be able to answer the questions a model or framework was developed based on the traditional 4-step model. Generation was based on production factors as GDP/capita and population, Distribution gravity based with additional barriers for international travel. The modal split was based on the sensitivity for doo-to-door travel time in a Random Regret Minimization framework to better capture the interdependence between performance of different modes and a better adherence to reality on short distances. Finally, based on Dijkstra's algorithm a link map build to assign people onto the developed simplified network.

The answer provided by the model would be 656 million passengers/annual and an average modal split of 43% for rail products. Only taking the 125 Urban Hubs into account. The population of this selection does consist of just 40% of the European population (EU and Schengen) however does generate 48% of the total trips. By approximation a total of 1.366 million long-distance rail passengers in Europe, according to Amadeus only 1.120 million are served, having a potential bigger pie already in the current situation of 22% and an incredible potential to growth. The share of international travel is 25%, (currently 6%), most of the growth would be seen on the international segments. Figure 6.2 for he potential market development.

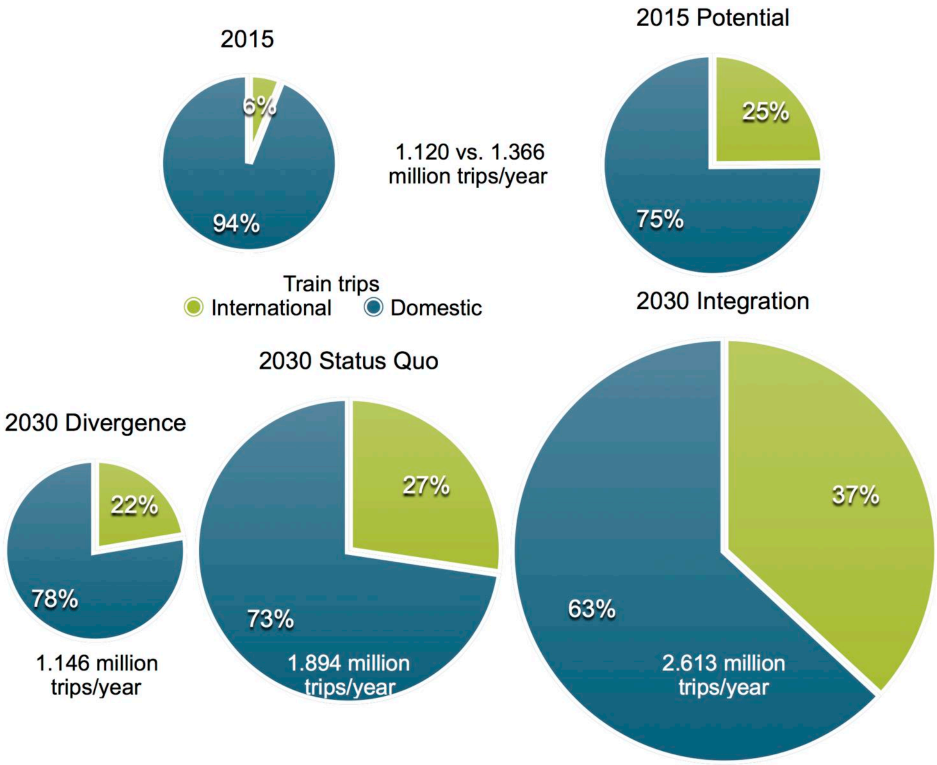

Figure 6.2 – Potential trip development, the market pies, (Own calculations).

B.a How many people will travel between destinations (trip distribution)?

The amount of people choosing to go somewhere is equal to the amount of travellers willing to travel and generated for the model as such. For the model, including some external cities a total of 2,23 billion passenger-trips each year. When distributed over the destinations about 38% is choosing an international destination. Destination choice does not take into account barriers perceived by mode alternatives, however includes real existing barriers like language, country borders, federal borders and passport controls outside the Schengen area.

B.b What is the expected modal split between destinations (mode choice)?

The modal split is dependent on the relative door-to-door travel time performance of a mode to the destination. As distances grow larger, past 1000km, the performance of the plane is always superior, however between 100km and 750km a great (40-50%) market does exist for train travel. In addition, due to the assessment of a complete network instead of separate lines also the network effect is taken into account and imbricated services could provide direct profitable services on much longer distances.

B.c How are the different destinations bundled in corridors (route choice)?

The route assignment is depicted in Figure 6.3. Links with a load under 250.000 are not included due to insignificance for actual train operations, even if the perceived optimal of the model could be realised. For 2015 (in blue) the busiest link is between Paris and Lyon, 46 million potential passengers/year/ direction, consistent with the claim of serving 39 million passengers annually. The green links are on the same scale for the 2030 Integration scenario.

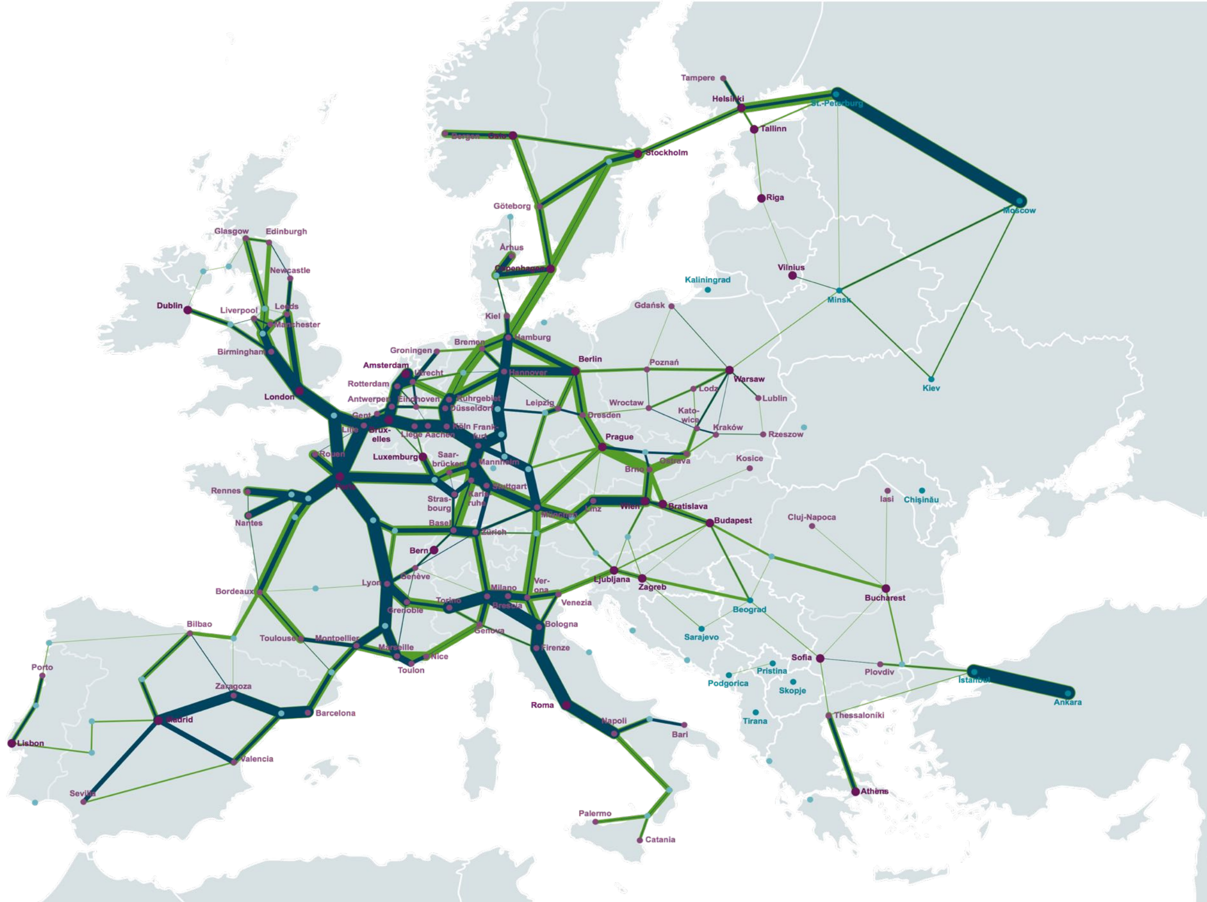

Figure 6.3 – Network assignment 2015 (blue) & 2030 (green), thickness of the links denotes the amount of traffic using a link, if amount is smaller than 250.000 trips annually the links is not shown, (Own calculations))

B.d How will the amount, modal split and corridors change in the future (2030)?

The divergence scenario will see a decrease in trips however an increase in market share for trains due to network effect of new infrastructure. The growth scenario will result in much more trips, because of a higher GDP/capita and a greater willingness to travel. Nevertheless, due to a more efficient and larger HST-network the modal share of rail could increase to 68%, saving 28 million tonnes of CO2-emmissions on a yearly base only for the plane-train shift.

C What is the seating capacity potential, supply, of the European railway market?

The underlying questions provide a framework on which the seating capacity potential, supply, can be assessed and quantified with respect to the previously modelled passenger-trip potential. The discrepancy between the potential amount of passenger-trips and effectively provided seats is 58,6 million, taken into account the level of service. Main links of interest are those with an annual unserved demand of one million trips or higher, links of 500.000 unserved trips can be of interest given the current economics of railway operations. The highest annual unserved demand is on the links, Calais (Lille) – London, Aachen – Liege and Brussels – Lille, despite the relatively high frequency and large capacity of the existing connections.

C.a How can level of service be assessed?

The level of service is assessed based on service characteristics most commonly used as preferences or determinants of travel in other research projects: frequency, transfers, travel time performance, service level and restrictive use cases (e.g. reservations). Additionally the actual offered capacity is included. This does provide information about the congestion or available seats on a link. All other service characteristics are converted into the generalised unit of effectively offered seats. This conversion provides a unified method for assessing the level of service.

C.b What is the level of services offered in the market (current)?

The current level of service offered to the market by the connections depends on the indicator that is assessed. Based on offered seats the market is structurally flooded with unnecessary seats, which contradicts the expectation and perception that international connections are only limited offered. Further assessment of the connections on, frequency, transfers, travel time performance and service level suggest that the level of service is much lower, because many seats are not effectively offered and level of service is (much) lower than desired.

C.c What is the level of services to meet potential demand (desired)?

The desired level of service is a conversion of the assumptions for the potential travel demand. Transfers should not occur on links and transfers on origin destination relations should occur as burden free as possible. Overall long-distance travellers do expect long-distance services on their journey, no (partial) regional services. For frequencies, lessons from the airline industry indicate that an average displacements schedule of 15 minutes are acceptable without really causing inconvenience for long distance travel choice, this is still a headway of an hour. Off-course a seat should be offered to fulfil the desired level of service.

C.d What is the discrepancy between connections and passenger-trip potential?

Current connections only offer 58,7 million seats annually on the 111 international fixed rail links in the model. The potential demand is 110,9 million annually on the same international links, leaving an aggregated total of 52,2 million passenger trips unserved. However, some links have a greater number of journeys offered than the potential, taking this factor out a total of 58,6 million passenger trips are unserved, more than 50% of the potential modelled trips.

D What is the preliminary core network for the European railway market?

The actual preliminary core network of the European railway market depends on the complete business case of new connections. The market consists of the passengers willing to travel with connections that are competitive on multiple levels, not only travel time, but also frequency, travel time performance, findability and transparency. It is no longer as much about the actual characteristics of the connections on themselves, but the complete provided user experience.

D.a What is the policy for offering international railway services, on an authority and TOC level?

The policies within the market of providing railway passenger traffic are mainly determined by European legislation. For railway policy, legislation is provided in packages consisting of a mix of directives, regulations and amendments to existing legislation. Since the first railway directive, all policy of the EU has the aim to create a level playing field on the railway market and increase interoperability across the Union. However, as a result of the way public transport (procurement) is regulated, most operations are part of public service contracts which provide the possibility of limiting the access to the market and under strict conditions. Current policy on offering international railway services on an authority and TOC level make real open access operation cumbersome, difficult, risky, uncertain and as a result unviable.

D.b Where are the current and future bottlenecks (market)?

To identify further bottlenecks for current and future situation, an assessment has been made on the current and future relations. These relations consist of the air corridors presently observed, TEN-T corridors and the network assignment from the travel demand, curenet and future. Furthermore, the importance of incorporation of airport hubs as possible network extension has been established. A convenient and seamless transfer could provide additional value to the HSR and intercontinental plane networks that the modes could become complementary and generate overall a higher profit. Based on these assessments 12 new European connections are proposed. The new connections should adhere to the minimal desirable level of service in order to materialise the unserved demand.

D.c How would a core network relate to the existing operational reality (hierarchy)?

The Urban Hub city set is of the highest hierarchical level for cities, the metropolitan level. The core connections would form a network between the metropolitan areas, making it a level 1 network. The characteristics of proposed connections can live up to the expected characteristics of this network level. These are high-speeds, limited detours, limited amount of stops. Additional network levels could result in reduced infrastructure capacity, due to alternating usage patterns. The core connections would be operated on dedicated networks (HST), resulting in limited impact to the existing infrastructure capacities. The hierarchy should also be taken into account by the infrastructure managers, especially for solving disturbances.

D.d Why are TOCs so reluctant to fulfil the apparent potential (opportunity)?

Complete research into the actual motivation of the TOCs and market reluctance unfortunately is outside the scope of this research. Nevertheless, the intrinsic motivation of the incumbent TOCs is that they already serve and know the passenger's desires. It nevertheless does not provide an explanation why there are no other entrants to the market to break the status quo. The market on which train operating companies act is however much more complex and regulated on a national scale given the public service contracts. This creates high barriers of entry with great start-up investments and risks with regard to business continuity.

D.e How can this network be realised or made viable?

The passenger-trip potential and seating capacity potential within the preliminary core network can only be captured if the assumptions as created for to model are incorporated into the real world. To accomplish this a proposal is provided for the business cases of the new connections. The most interesting would be the preliminary core connections towards London, given the proof of concept in operability and the tremendous remaining potential. This would provide a first step in the realisation of the Passenger Core Connections network as passenger rail alternative to the Rail Freight Network and TEN-T infrastructure network.

6.1.2. Main conclusion

With all the separate answers of the sub-questions summarized in one place consecutively, the answer to the main question leaves little surprise. Regardless, the answer to the main research question, "Where and how in Europe does, currently and in 2030, the biggest preliminary core network of international train passenger travel exist, based on passenger-trip potential (demand) and seating capacity potential (supply)?" can be provided. The short answer could be formulated as follows:

On the preliminary Passenger Core Connections, a set of 12 new connections the biggest passenger-trip potential exists, with regard to the offered seating capacity combined with the actual provided level of service. The connections are based on the current potential situation, however future scenarios have been taken into account and show an even greater potential. The first step in erasing borders!

Answering the main question in the end is the final goal of the research, and together with the sub-questions it does provide a very clear result of this study. Nevertheless, additional conclusion can be drawn from the individual components of the research which could be at least equally interesting. Most of these additional conclusions are the result of the methods used and were meant as means to an end, however seen in a broader context they are striking and provide useful information on both the interpretation of the main question as well as necessary future developments.

The initial perception and hypotheses that international train travel was missing connections and was indeed correct. Demand for international long-distance train travel is much higher than currently served by long-distance trains. One of the main resistant forces stemming from the train operating companies is the provision of information. The TOCs see timetable info as their own competitive advantage, giving up this, in single-interest, created protectionism would open up the market to about 240 million trips each year. Meaning the market could grow by almost 22%, creating a bigger customer base for all operators. It should however be noted that long-distance travel is a relative small percentage of the overall travel market. The share of international travel could increase to 25% if all potential demand is captured. However, compared to the total amount of international relations in the model, 93%, this is share of the market for international travel is relatively low.

Barriers for country-, language-, and free trade areas

The relative low percentage of international trips compared to domestic trips is the result of the perceived barriers for travellers not related to any mode of transport, but to the destinations themselves. Freight and trade-research did already suggest such barriers as a result of countries and languages, long-distance passenger research did not provide a consistent answer yet on the existence of these barriers in the decision making process of passengers. Modelling the data and fine-tuning the model with open source or freely available sources provides the insight that, country borders can physically be erased, they are still present in the minds of people. Even more striking, though somewhat expected due to anecdotes in the field was the fact that language has an even greater effect on destination choice. Off-course a language difference can become a communication barrier.

Overall network effect of high speed rail

Another remarkable conclusion that can be drawn from this research is the incredible network effect of interconnected high speed lines between the different scenarios of 2030. As the high speed network becomes bigger, and more and more connections are made between separate national island networks; suddenly the added value of multiple links creates incredible travel time saving for a complete set of destinations. Most infrastructure studies focus on the effects of new lines, or in rare cases the implementation of networks. This insight of network effects could possibly help TEN-T projects on cross border corridors to gain much better benefit balances than initially assumed.

Connection and service performance

On the supply, seating capacity potential site of the analysis it is remarkable that when applying service indicators in a reverse manner, compared to the traditional transport model, on existing connections, the turnout is so negative. Almost 40% of the provided seating capacity on the included connections is unattractive for the long-distance market based on the attributes in the model. Some distinctly long-distance trains do run, according to the model, for a handful of passengers each trip.

6.2. Scientific implications

Sometimes the objective of a research project is the development of a framework for assessment or modelling. In this research the aim was getting the best answer possible to the research question. Along the way a framework has emerged and developed, of modelling techniques and assessment methods, to provide insight on the potential of an existing (infrastructure/transport) network. This framework could be adopted on all sorts of transport or infrastructure networks that operate with, in assumption easy to eliminate or artificially created, barriers. This would make the framework much wider adoptable than only this single, fairly specific study. The framework further supports the ability to change modules. There is great reliance on the results from each module. Currently the implementation is such that the outcome from each module are in meaningful numbers, making them adoptable to conversion. The Gravity based distribution module could be changed for a different distribution method and still the rest of the process can be kept intact. Not only provides this an opportunity for new and more elaborate researches, it also provides possibilities to widen the scope of this research and deepen the results.

On top of these favourable side effects as implication there are some points that should be highlighted and need some caution when adopting the results and conclusions of this research. First a short discussion about the general research, followed by clear limitations in the study, approach and methodology. Most of the points have already been mentioned in the report itself, mainly chapter 3.2 the modelling adoptions of the travel demand gravity based 4-step model.

6.2.1. Discussion

The amount of long-distance models is extremely limited, especially for passenger traffic, as already remarked in the development of this model for the passenger-trip potential part. The models that exist are mostly not publicly accessible due to corporate interest. When models do exist, they stick with, and are aimed at, modelling the domestic travel patterns. Possible application country where these kind of models would fit into the scope of the domestic network would be the USA, however passenger railway market is to limited. Another candidate would be China, however consultation with contacts to the national planning office, responsible for planning the investments of the economic development plans, does indicate that no such methodology does exist in China. It is however unclear what the exact framework would be for the decision making process if not a similar potential long-distance network model is used. Freight models do have a broader scope with regard to distance however most often, the models are on a higher, aggregated level, e.g. country to country trade.

Data availability and data collection was one of the main points of concern for this research. Still only very limited comparison data is available about the actual current situations. No comparison can be made on the performance of the potential demand modal split and the actual current modal split, except for some previous performed long-distance preference researches. For rail traffic almost no data is (openly) available, this in very strong contrast to the airline industry. Although no individual airline information is provided by authorities, all airport data is publicly available. Fortunately, because this made constructing the model actually possible.

Network discussion

On top of the more overall data points, some discussion points affect the way that the networks in the model have been approximated. These are grouped together to provide some clarity and cohesiveness in the discussion.

In order to be able to approximate the network infrastructure capabilities, a (very) simple network was modelled. Although simple, all the used factors and average speeds hold for the defined links, also for Eastern Europe, according to the regression analysis. As a result of the selection of cities, all being of significant size/importance, links between these cities are well established with regard to infrastructure quality. Special links do also allow ferries and the access and egress features optimise realism for multimodal trips. This results in a R^2 of 98% on detour factors (except airport accessibility which is much more diverse due to the wide range of possible placements of airports around cities. For speed the goodness of fit is 85% for all the modes, taking into account the modelled network characteristics with access and egress of airports and stations. The modelling technique as a result introduces some errors into the calculated door-to-door travel times. As a result, they cannot strictly be used for individual trip planning. However, all OD door-to-door travel times for all modes are calculated with the same margin of error, creating a level playing field and eliminating the negative impact of the errors.

Another network related point of discussion is the availability of infrastructure. Modes are not always available in a city. Either the necessary infrastructure does not reach the city, like airports, or the amount of people does not justify a way of transport by the particular mode. This has been modelled with assigning other airport to the respective cities, with travel times towards the other airports equal to the travel time towards the other city and then to the airport.

Mode discussion
Additional to the network discussion point, a similar group can be made from modelling aspects around the mode choice. These affect modal split and the way modes themselves have been represented.

Mode choice is based on a single mode choice attribute. Travel time is a good indicator for mode choice, although preference in modern transport models is to include more attributes. The size, scope and goal of assessing the potential, limits the possibilities to include other attributes. Additionally, travel time in combination with RRM performs well as explanatory mode choice.

The inclusion of multiple modes on the same network, car and bus both using road as well as HST and conventional trains using the rail network, can create network (instead of mode) specific preferences. Modes should be significantly different to prevent generating nesting effects, especially with high speed trains running on conventional tracks. Penalties and threshold have been introduced into the model in order to ensure sufficient differences in travel time. If the OD travel time for HST and conventional are equal, HST is disregarded. If not, conventional rail is only considered if the travel time is 1,5x or 120 minutes longer. If travel time is 3x as long as the HST conventional rail is disregarded. This ensures a proper way of defining mode distinction within the network.

Barriers that are mode specific and relate to the operations of the mode are only taken into account for flying. This may seem as unfair competition in the model, however the airline market has already been disrupted on price with a complete commoditisation of the product as a result. The operation for the passenger however have not changed, flying still involves actual waiting. Railway and bus operations on medium and long-distances across Europe proof that waiting for a train (or bus) should not be necessary when properly implemented. The waiting time of flying is thus a result of the complete system or infrastructure and not of the individual operator. It could however be possible to make a similar study on what the potential for air traffic would be given that waiting time is incredibly reduced.

Seating capacity potential discussion
For the seating capacity potential some specific critical remarks can be made about the methods used. These are applicable on the interpretation of level of service and the quantification towards seating capacity potential, unserved seats.

The first point of discussion with regard to the seating capacity potential is the assumption that deviations in the level of service will result in effective reduction of the offered seats. This is done to be able to quantify the effect of the level of service offered in comparable amounts on the different links. This method however does take into account that for some indicators, not meeting the desirable or acceptable level of service does not result in a total elimination of the offered seats. The amount of seats within desirable level of service is kept as service.

Second discussion point is the complete lack of quantification of the additional service indicators. Studies have suggested that reservations for train services do reduce the willingness to travel by train, a similar relation is however not found for the airline industry where reservations are inevitable. Some connections do necessitate reservations for part of the journey or parts of the train creating barriers on obtaining cohesive data for the research. Additionally for reservations the correlation between effectively offered seats and necessity the reserve a seat is less eminent in literature, for ticketing and timetable information this relation is much more straight forward. If a connection cannot be found, it never can serve as an alternative. Effectively rendering all offered seats out. Overall this does affect the seating capacity potential in a negative way, the presented potential is in with additional indicators even higher.

The passenger-trip potential, could be extrapolated towards a number applicable and comparable to the complete existing market, due to the limitations in data this is not possible for the seating capacity potential. The stated figures of unserved passengers are based on the potential model, which only covers 40% of the population and 48% of the total European long-distance trips. Additionally, the seating capacity potential is very conservative because load-factors in the assessment and availability are assumed to be 100%, where in reality several successful long-distance trains operate with average load-factors of 30-50%. Both factors, limited presentation of overall trips and conservative load-factors to assess potential do result in a major underestimation of the actual real-life potential in seating capacity in the European railway market.

6.2.2. Limitations

Some parts and methods used imply limitations on the adoptability of the research. Although sometimes data could be generalised to make comparison with the current reality or actual situation possible. This should always be done with caution and taking into account the following limitations.

The scope of only long distance traffic (long-distance being defined as greater then 100km), eliminates all regional traffic. Small distance relations can be important to build the business case of the cross-border connection based on regional connectivity. This focus on long-distance also resulted in to the aggregation with the limited selection of cities in the Urban Hub set and the combination of some metropolitan regions (e.g. Rotterdam-The Hague). Including regional traffic and lower level cities would provide the possibility the create alternative routes. For example, the creation of the alternative link between Liege and Aachen via Maastricht and Heerlen. Both Dutch cities left out of the urban hub set, and the existence of the direct link would make this connection unfavourable from a long-distance point of view. However, from a regional perspective it does contribute tremendously to the regional development, resulting in the ministerial declaration on implementing this service and development of EUrekaRail. Depending on the way willingness to travel (*t*) is determined this could easily be adopted for new researches so also regional relations could be added.

The level of aggregation and limited selection of urban hubs does also affect rural areas. It creates the complete elimination of areas and population as well as all other attributes outside the 125 cities in the scope, except for additional network (city nodes) and rest zones in generation and distribution. Especially for tourist travel, rural areas account for a significant flow. This is related to the previous limitation of regional connectivity.

Trip generation is effectively only based on GDP/capita, a typical production indicator and the elimination of a separate attraction indicator. This does introduce a bias, however given the size and select set of the cities this will be limited. The introduced error will be no greater than the goodness of fit error of 10%. Not only is the bias introduced, it also eliminates other travel motives or the purpose of travel. Although the majority of the long-distance trips have a similar motif, leisure, a sizable amount comes from work or business related motifs. These rips tend to have other requirements. All this is already eliminated in the first step of the passenger-trip potential. Given the framework for assessing the potential, this could be added to the module nevertheless with sufficient data available on cross Europe travel motifs, which is currently lacking.

Additionally, GDP/Capita and average willingness to travel (*t*) are the main indicators for trip generation on an individual base. The willingness to travel is applicable for the EU according to the literature, it is also extrapolated to be applicable for other countries. This however, is justified by adoption to ratio of GDP. The willingness to travel (*t*) is further defined for long-distance travel (>100km), however the city set does include some pairs with smaller in between distance, over which all the passengers are distributed, this does create some bias that part of the long-distance generated passengers opts for a small distance destination. This is not counter-acted in the model because the conviction is that a similar process happens in reality, where people decide on short- or long-distance however when presented with the options switch between those arbitrary limited definitions.

Travel time sensitivity is equal for all modes. As a result of only taken into account travel time, and not ticket prices this is correct. However, when adding price information to the model people have different valuations for travel time and ticket price, this should be reflected in the research. For this research, price performance or underlying cost structures of modes is not taken into account. It is assumed that the price performance of each mode is equal to the expected level of service and travel time performance. Effectively there is no price differentiation by the modes to compensate for disadvantageous travel time performance.

6.3. Recommendations

In general, recommendations from a research report could be split into direct executable actions and further research. Executable actions would be the adoptability and implementation of the results into the company or product. However, in this case although business cases are pointed out, there is (not) yet a profitable railway operation to run based on this research only. As a result, only the recommendations for further research will be provided. For all the subsequent recommended research some research challenges are applicable which will be reviewed first. These research challenges have to do with several topics in and around this report on the way methodology, scope, time or topic has restricted the data availability.

On the different research fields, there is a distinction on who could coordinate the different topics, some would be best performed by Train2EU (or other NGO's with an interest in improving railway connections or sustainability in general). Some of the recommendations apply to Royal HaskoningDHV as an (engineering) consultancy as well as supporter of sustainable transport options. Furthermore, some are general research recommendations towards the EU or other governmental authorities.

6.3.1. Research challenges

The research challenges stem partially from the discussion topics and scientific implications of the report itself. They are fundamental to choices made in this research and will be also in reports and researches to come when they are not first removed or further dealt with. Research challenges are applicable to almost all the further proposed research fields and topics for all stakeholders. Three challenge fields have been defined, however can be summarized as building data bases on these particular topics which are openly available or under a CC-license which grant usage rights if contributions based on the data are made available as well.

Zonal data

Many choices in the research stem from limited data availability with regard to the selected zones. Main challenge for further research is the definition and scope of areas taken into account. Given the availability of data for EU areas via Eurostat with a relative consistent quality and definition of data the NUTS3 areas could be used as zones with a per zone assessment of the availability of modes and modal entry-points. The recommendation with regard to the zonal data is to provide a uniform available set of data, based on NUTS3, which is adoptable to the needs of the individual research.

Network data

Many efforts have been made to provide a single unambiguous available form of network data for research. One of the latest attempts was the TransTools, which stopped developing in 2009 and has not been adopted ever since. This has resulted in a very useful source of information based in outdated technology, unable to be run on modern more suitable systems for the required handling of large scale computations a long-distance transport model would require. Privately almost all network data is available via (semi-)open sources (e.g. Google/Apple Maps, Rome2Rio or TomTom). Most of them include network data like max. speeds and routes, nevertheless the network data itself is not publicly available for research. TransTools should either be updated or a different system should be developed to make use of the actual network instead of the modelled network used in this research.

Level of service attributes

Only a limited set of level of service attributes has been taken into account for this research. For further research it is necessary and the main challenge exist to gather more and more detailed information about the actual services offered for the currently offered connections. Challenge is in obtaining cohesive data from the different sources. This is a similar challenge faced by the passengers which try to make a choice of mode or route based on the characteristics or level of service offered by the operating companies. Resolving this barrier of information for research, would automatically be a valuable asset in the provision of information towards the end-user of the system, the passengers.

6.3.2. Recommendations to Train2EU

Train2EU as an association acting as NGO, would be very suitable to keep researching and looking for answers. This could be picked up with initiating a European research project. The Commission already showed interest in the possibilities of researching possibilities how existing infrastructure could be used more effectively instead of only providing enormous sums of money for new infrastructure within the TEN-T legislative structure. The following topics would be of interest:

Maybe the most pressing limitations and discussion point of this research, the elimination of price performance of the different alternatives. The reasoning behind it was that there is no clear or transparent information about the extent that ticket prices reflect (operating) costs. Some very minor explorations and expert discussion indicate that there is no clear comparison possible about the different costs incurred by each mode. As a result, one of the most fundamental research recommendations is about the cost structure of operations.

- The actual costs, societal costs and operational costs of different modes and the effect on (price) competition. This should not be limited to trains, but explicitly include the comparison with airline operation.

Explanations why train operating companies (TOCs) don't dive into the opportunity. The different stakeholders in the train market, all seem to know what the customers (passengers want), nevertheless apparently there is a bigger market. So why are private companies with an objective of maximising the bottom line not head over heels to grip this additional source of income.

- Study on the motivation of the privatised TOC sector to not grab seemingly easy markets.
- Study on creation of barriers by TOCs, authorities, infrastructure managers and other stakeholders in the market.

Societal effects of realising passenger-trip potential. The general assumption is that promoting rail travel over air is environmentally beneficial. In the current market and displacement pattern this is true. Very limited research has been performed what would be the actual effect of realising such a shift.

- Environmental gains of proposed large scale modal shift and added value of network effects.
- The effect of generation vs. substitutions in traffic movements due to better railway infrastructure and connections.

6.3.3. Recommendations to Royal HaskoningDHV

Royal HaskoningDHV as an engineering consultant, although very concerned with the objectives of Train2EU has broader objectives for themselves. These objectives are more towards the general development and applicability of research techniques for other projects and other fields of operation (or infrastructure). Overall Royal HaskoningDHV is interested in the commercialization of research results and techniques within the field of railway infrastructure and sustainable mobility.

Within the field of sustainable mobility multiple new and old networks are managed and improved. This research provides an initial framework for assessment of potential and the network effects. Further development of this framework could produce valuable insights in the missed opportunities of artificially protected networks or the added value as a result of network effects. As a tool this would provide added value for the clients of Royal HaskoningDHV beyond the initial scope without great additional efforts.

- Framework for the assessment of the potential of infrastructure or transport network structure could be developed further.

Possibilities of business case development for third party clients. Given the experience of the company with international (regional) connections, the business cases could be developed and marketed or commercialized.

- Built the complete business case for the 12 new connections, or the complete proposed core network.

In creating masterplans and development studies for cities and regions, the attractiveness of plays an important role. In general, this is based on existing information about the travel patterns. Further development of the long-distance model would take this attractiveness into account and give the company competitive advantage based on the inclusion of network effects in projects. Creating the opportunity to really enhance society together.

- Effect of multimodal transport networks to the accessibility and attractiveness of cities and regions on an international scale.

6.3.4. Recommendations in General

The general recommendation to and for everyone, especially institutions and stakeholders mentioned in this report, is an invitation to share and cooperate. Invitation to contribute to the research by providing data blocks on all levels in order to add to, evaluate or change the model input as it is. The ultimate goal would be the development of this framework and general model into a very detailed transport multimodal transport model including long-distance trips. The framework provided by this report could fuel many more researches, or research programs, possibly in the form of PhD-research, to promote European rail traffic.

- Further research on passenger segmentation and motifs
    - Motif to travel (willingness to travel)
    - Properties and importance of travel/trip attributes
    - Context of the journey/trip purposes
    - Space/time variables, last-mile problem at international relations. Not knowing how to get from the station to congress centre due to limited information provision local transport networks.

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List of data sources

Eurostat

All data retrieved between 02-2016 and 06-2016 from: http://ec.europa.eu/eurostat

Urban audit (urb)

- Cities and greater cities (urb_cgc)
    - Population on 1 January by age groups and sex - cities and greater cities (urb_cpop1)
    - Education - cities and greater cities (urb_ceduc)
    - Culture and tourism - cities and greater cities (urb_ctour)
    - Transport - cities and greater cities (urb_ctran)
- Functional urban areas (urb_luz)
    - Population on 1 January by age groups and sex - functional urban areas (urb_lpop1)
    - Education - functional urban areas (urb_leduc)

Metropolitan regions (met)

- Overview
    - Schematic overview: 'Defining urban areas in Europe'.
    - Complete list of metro-regions (based on the 2013 NUTS version and 2010 Geostat population grid).
    - Complete list of regional typologies and local information corresponding to NUTS 3.
- Demography statistics by metropolitan regions (met_demo)
    - Area of the regions by metropolitan regions (met_d3area)
    - Population density by metropolitan regions (met_d3dens)
    - Population on 1 January by broad age group, sex and metropolitan regions (met_pjanaggr3)
- Population projections by metropolitan regions (met_proj)
    - Main scenario - Population on 1st January by age, sex and metropolitan regions (met_proj_pms3)
- Economic accounts by metropolitan regions (ESA 2010) (met_eco10)
    - Gross domestic product (GDP) at current market prices by metropolitan regions (met_10r_3gdp)
    - Gross value added at basic prices by metropolitan regions (met_10r_3gva)

Regional statistics by NUTS classification (reg)

- Regional economic accounts (ESA 2010) (reg_eco10)
    - Gross domestic product (GDP) at current market prices by NUTS 2 regions (nama_10r_2gdp)
    - Gross domestic product (GDP) at current market prices by NUTS 3 regions (nama_10r_3gdp)
    - Average annual population to calculate regional GDP data (thousand persons) by NUTS 3 regions (nama_10r_3popgdp)

Railway transport (rail)

- Railway traffic (rail_tf)
  - Traffic flow of trains on the rail network (number of trains, 2010 data) (rail_tf_netseg10)
  - Passenger trains movements by speed (rail_tf_passmov)
- Railway transport measurement – passengers (rail_pa)
  - Railway transport - Total annual passenger transport (1 000 pass., million pkm) (rail_pa_total)
  - International railway passenger transport from the reporting country to the country of disembarkation (1 000 passengers) (rail_pa_intgong)
  - Railway transport - national and international railway passengers transport by loading/unloading NUTS 2 region (tran_r_rapa)

Air transport (avia)

- Detailed air passenger transport by reporting country and routes (avia_par)
  - Air passenger transport between the main airports of Belgium and their main partner airports (routes data) (avia_par_be)
  - Air passenger transport between the main airports of Bulgaria and their main partner airports (routes data) (avia_par_bg)
  - Air passenger transport between the main airports of Czech Republic and their main partner airports (routes data) (avia_par_cz)
  - Air passenger transport between the main airports of Denmark and their main partner airports (routes data) (avia_par_dk)
  - Air passenger transport between the main airports of Germany and their main partner airports (routes data) (avia_par_de)
  - Air passenger transport between the main airports of Estonia and their main partner airports (routes data) (avia_par_ee)
  - Air passenger transport between the main airports of Ireland and their main partner airports (routes data) (avia_par_ie)
  - Air passenger transport between the main airports of Greece and their main partner airports (routes data) (avia_par_el)
  - Air passenger transport between the main airports of Spain and their main partner airports (routes data) (avia_par_es)
  - Air passenger transport between the main airports of France and their main partner airports (routes data) (avia_par_fr)
  - Air passenger transport between the main airports of Croatia and their main partner airports (routes data) (avia_par_hr)
  - Air passenger transport between the main airports of Italy and their main partner airports (routes data) (avia_par_it)
  - Air passenger transport between the main airports of Latvia and their main partner airports (routes data) (avia_par_lv)
  - Air passenger transport between the main airports of Lithuania and their main partner airports (routes data) (avia_par_lt)

- Air passenger transport between the main airports of Luxembourg and their main partner airports (routes data) (avia_par_lu)
- Air passenger transport between the main airports of Hungaria and their main partner airports (routes data) (avia_par_hu)
- Air passenger transport between the main airports of Netherlands and their main partner airports (routes data) (avia_par_nl)
- Air passenger transport between the main airports of Austria and their main partner airports (routes data) (avia_par_at)
- Air passenger transport between the main airports of Poland and their main partner airports (routes data) (avia_par_pl)
- Air passenger transport between the main airports of Portugal and their main partner airports (routes data) (avia_par_pt)
- Air passenger transport between the main airports of Romania and their main partner airports (routes data) (avia_par_ro)
- Air passenger transport between the main airports of Slovenia and their main partner airports (routes data) (avia_par_sl)
- Air passenger transport between the main airports of Sweden and their main partner airports (routes data) (avia_par_se)
- Air passenger transport between the main airports of United Kingdom and their main partner airports (routes data) (avia_par_uk)
- Air passenger transport between the main airports of Norway and their main partner airports (routes data) (avia_par_no)
- Air passenger transport between the main airports of Switzerland and their main partner airports (routes data) (avia_par_ch)

Population (demography, migration and projections) (demo)

- Population (demo_pop)
  - Population change – Demographic balance and crude rates at national level (demo_gind)
  - Population on 1 January by age and sex (demo_pjan)
- Regional data (demopreg)
  - Population on 1 January by five year age group, sex and NUTS 3 region (demo_r_pjangrp3)
  - Area by NUTS 3 region (demo_r_d3area)
- Population projections (proj)
  - Main scenario - Population on 1st January by age and sex (proj_13npms)
  - Main scenario - Population on 1st January by age, sex and NUTS 3 regions (proj_13rpms3)

Other statistic offices

Schweizerische Eidgenossenschaft, http://www.bfs.admin.ch/bfs/portal/en/index.html

- Data of Switzerland, City Statistics 2016.
  - Urban Audit 2015: schweizerische Daten

Statistisk Sentralbyra, https://www.ssb.no/

- Regional accounts, 2013
  - Regional accounts, figures per inhabitant and per employed person. Regional value added is measured in basic value.

Turkish statistical institute, http://www.turkstat.gov.tr/Start.do;jsessionid=39tHXrZYmXJp2n1rhLF1GQJnD9XJ3d5QCBSnDJJyK2xzL0ZydW0y!1632290243

- 2000 Genel Nüfus Sayımı

Other data sources

Trivial information but vital in order to automate distance calculations and city airport matching based on measurements instead of trial and error. This includes IATA-codes, coordinate locations and alternative names.

Airport database, http://openflights.org/data.html.

- Airports.dat

Free world cities database, https://www.maxmind.com/en/free-world-cities-database

- World cities database.txt

GeoNames data, http://www.geonames.org/export/

- Cities15000.zip

Appendix A: Urban Hubs

City	Country	Language	Language 2	Schengen	Federalism
Brussels	BE	FR	NL	YES	YES
Antwerpen	BE	NL		YES	YES
Gent	BE	NL		YES	YES
Liege	BE	FR		YES	YES
Sofia	BG	BG		NO	NO
Plovdiv	BG	BG		NO	NO
Prague	CZ	CZ		YES	NO
Brno	CZ	CZ		YES	NO
Ostrava	CZ	CZ		YES	NO
Copenhagen	DK	DK	SE	YES	NO
Arhus	DK	DK		YES	NO
Berlin	DE	DE		YES	YES
Hamburg	DE	DE		YES	YES
Munich	DE	DE		YES	YES
Koeln	DE	DE		YES	YES
Frankfurt am Main	DE	DE		YES	YES
Stuttgart	DE	DE		YES	YES
Leipzig	DE	DE		YES	YES
Dresden	DE	DE		YES	YES
Duesseldorf	DE	DE		YES	YES
Bremen	DE	DE		YES	YES
Hannover	DE	DE		YES	YES
Ruhrgebiet (Essen)	DE	DE		YES	YES
Karlsruhe	DE	DE		YES	YES
Kiel	DE	DE		YES	YES
Saarbruecken	DE	DE		YES	YES
Mannheim	DE	DE		YES	YES
Aachen	DE	DE		YES	YES
Tallinn	EE	ET		YES	NO
Dublin	IE	EN		NO	NO
Athens	EL	EL		YES	NO
Thessaloniki	EL	EL		YES	NO
Madrid	ES	ES		YES	NO
Barcelona	ES	ES		YES	NO
Valencia	ES	ES		YES	NO
Sevilla	ES	ES		YES	NO
Zaragoza	ES	ES		YES	NO
Bilbao	ES	ES		YES	NO

City	Country	Language	Language 2	Schengen	Federalism
Paris	FR	FR		YES	NO
Lyon	FR	FR		YES	NO
Toulouse	FR	FR		YES	NO
Strasbourg	FR	FR	DE	YES	NO
Bordeaux	FR	FR		YES	NO
Nantes	FR	FR		YES	NO
Lille	FR	FR		YES	NO
Montpellier	FR	FR		YES	NO
Rennes	FR	FR		YES	NO
Grenoble	FR	FR		YES	NO
Toulon	FR	FR		YES	NO
Marseille	FR	FR		YES	NO
Nice	FR	FR		YES	NO
Rouen	FR	FR		YES	NO
Zagreb	HR	HR	SP	NO	NO
Rome	IT	IT		YES	NO
Milano	IT	IT		YES	NO
Napoli	IT	IT		YES	NO
Turin	IT	IT		YES	NO
Palermo	IT	IT		YES	NO
Genoa	IT	IT		YES	NO
Florence	IT	IT		YES	NO
Bari	IT	IT		YES	NO
Bologna	IT	IT		YES	NO
Catania	IT	IT		YES	NO
Venice	IT	IT		YES	NO
Verona	IT	IT		YES	NO
Brescia	IT	IT		YES	NO
Vilnius	LT	LT		YES	NO
Budapest	HU	HU		YES	NO
Amsterdam	NL	NL		YES	NO
Rotterdam	NL	NL		YES	NO
Utrecht	NL	NL		YES	NO
Eindhoven	NL	NL		YES	NO
Groningen	NL	NL		YES	NO
Vienna	AT	DE		YES	NO
Warsaw	PL	PL		YES	NO
Lodz	PL	PL		YES	NO

City	Country	Language	Language 2	Schengen	Federalism
Krakow	PL	PL		YES	NO
Wroclaw	PL	PL		YES	NO
Poznan	PL	PL		YES	NO
Gdansk	PL	PL		YES	NO
Lublin	PL	PL		YES	NO
Katowice	PL	PL		YES	NO
Rzeszow	PL	PL		YES	NO
Lisbon	PT	PT		YES	NO
Porto	PT	PT		YES	NO
Bucharest	RO	RO		NO	NO
Cluj-Napoca	RO	RO	HU	NO	NO
Iasi	RO	RO		NO	NO
Ljubljana	SL	SL		YES	NO
Bratislava	SK	SK		YES	NO
Helsinki	FI	FI		YES	NO
Stockholm	SE	SE		YES	NO
Goeteborg	SE	SE		YES	NO
London	UK	EN		NO	YES
Birmingham	UK	EN		NO	YES
Leeds	UK	EN		NO	YES
Glasgow	UK	EN		NO	YES
Liverpool	UK	EN		NO	YES
Edinburgh	UK	EN		NO	YES
Manchester	UK	EN		NO	YES
Newcastle upon Tyne	UK	EN		NO	YES
Oslo	NO	NO		YES	NO
Zurich	CH	DE		YES	NO
Geneve	CH	FR		YES	NO
Basel	CH	DE	FR	YES	NO
Ankara	TR	TR		NO	NO
Istanbul	TR	TR		NO	NO
Belgrade	BS	BS	SP	NO	NO
Chisinau	MD	RO		NO	NO
Kaliningrad	RU	RU		NO	YES
Moscow	RU	RU		NO	YES
St. Petersburg	RU	RU		NO	YES
Kiev	UA	UA	RU	NO	NO
Minsk	BY	RU		NO	NO
Podgorica	ME	SP	BS	NO	NO
Pristina	XK	SQ	SP	NO	NO
Sarajevo	SB	SP		NO	NO
Skopje	MK	MK	SQ	NO	NO

City	Country	Language	Language 2	Schengen	Federalism
Tirana	AL	SQ		NO	NO
Luxemburg	LU	DE	FR	YES	NO
Riga	LV	LV		YES	NO
Bergen	NO	NO		YES	NO
Kosice	SK	SK		YES	NO
Linz	AT	DE		YES	NO
Tampere	FI	FI		YES	NO

Rest zone	Country	Language	Language 2	Schengen	Federalism
Belgium	BE	NL	FR	YES	YES
Bulgaria	BG	BG		NO	NO
Czech Republic	CZ	CZ		YES	NO
Denmark	DK	DK		YES	NO
Germany	DE	DE		YES	YES
Estonia	EE	EE		YES	NO
Ireland	IE	IE		NO	NO
Greece	EL	EL		YES	NO
Spain	ES	ES		YES	NO
France (metropolitan)	FR	FR		YES	NO
Croatia	HR	HR	SP	NO	NO
Italy	IT	IT		YES	NO
Latvia	LV	LV		YES	NO
Lithuania	LT	LT		YES	NO
Luxembourg	LU	DE	FR	YES	NO
Hungary	HU	HU		YES	NO
Netherlands	NL	NL		YES	NO
Austria	AT	DE		YES	NO
Poland	PL	PL		YES	NO
Portugal	PT	PT		YES	NO
Romania	RO	RO	HU	NO	NO
Slovenia	SI	SI		NO	NO
Slovakia	SK	SK		YES	NO
Finland	FI	FI	SE	YES	NO
Sweden	SE	SE		YES	NO
United Kingdom	UK	EN		NO	YES
Norway	NO	NO		YES	NO
Switzerland	CH	FR	DE	YES	NO

Montenegro	ME	SP	BS	NO	NO
Macedonia,	MK	MK	SQ	NO	NO
Albania	AL	SQ		NO	NO
Serbia	SB	SP		NO	NO
Turkey	TR	TR		NO	NO
Belarus	BY	BY	RU	NO	NO

Bosnia and Herzegovina	BS	BS	SP	NO	NO
Kosovo	XK	SQ		NO	NO
Moldova	MD	MD	RU	NO	NO
Russia	RU	RU		NO	YES
Ukraine	UA	UA	RU	NO	NO

Appendix B: Network cities

Network		City	Phi	Lambda	Latitude	Lontitude
Rail	Road	Faro	0,646109894	-0,138443531	37,01937	-7,93223
Rail		Vigo	0,737101761	-0,152238787	42,23282	-8,72264
Rail	Road	Holyhead	0,930425268	-0,080861767	53,309441	-4,633038
Rail	Road	Biarritz	0,758871253	-0,027149993	43,48012	-1,55558
Rail	Road	Kassel	0,895644853	0,165806279	51,31667	9,5
Rail	Road	Kolding	0,968490183	0,165320379	55,4904	9,47216
Rail	Road	Nuernberg	0,863138793	0,193339197	49,45421	11,07752
Rail	Road	Innsbruck	0,82488903	0,19887224	47,26266	11,39454
Rail	Road	Salzburg	0,834257085	0,227660573	47,79941	13,04399
Rail	Road	Villach	0,813502851	0,241829854	46,61028	13,85583
Rail	Road	Graz	0,821468359	0,269653369	47,06667	15,45
Rail		Usti nad Orlici	0,872208571	0,286122471	49,97387	16,39361
Rail	Road	Timisoara	0,798553059	0,370458526	45,75372	21,22571
Rail	Road	Ancona	0,760862325	0,235678267	43,5942	13,50337
Rail	Road	Patra	0,667491399	0,379337539	38,24444	21,73444
Rail	Road	Cosenza	0,685895197	0,283669585	39,2989	16,25307
Rail	Road	Messina	0,666610007	0,271443379	38,19394	15,55256
	Road	Coimbra	0,701720796	-0,146948869	40,20564	-8,41955
	Road	Belfast	0,95289427	-0,103417914	54,59682	-5,92541
	Road	Le Mans	0,837758041	0,003490659	48	0,2
	Road	Calais	0,889279113	0,03239942	50,95194	1,85635
	Road	Brive-la-Gaillarde	0,788016157	0,026761657	45,15	1,53333
	Road	Dijon	0,825831683	0,087557409	47,31667	5,01667
	Road	Avignon	0,767043234	0,083931487	43,94834	4,80892
	Road	Osnabrueck	0,912329677	0,140495514	52,27264	8,0498
	Road	Aalborg	0,995675432	0,173113973	57,048	9,9187
	Road	Heilbronn	0,857653922	0,160928782	49,13995	9,22054
	Road	Rostock	0,944025903	0,211891523	54,0887	12,14049
	Road	Zadar	0,770034379	0,266026924	44,11972	15,24222
	Road	Dubrovnik	0,744349241	0,315767761	42,64807	18,09216
	Road	Lviv	0,86984173	0,419284635	49,83826	24,02324
	Road	Igoumenitsa	0,689512392	0,353700293	39,506150	20,265534
	Road	Edirne	0,727404188	0,463489113	41,67719	26,55597
Rail		Valladolid	0,727020042	-0,082444467	41,65518	-4,72372
Rail		Perpignan	0,745214401	0,050534438	42,69764	2,89541
Rail		Metz	0,857290195	0,107733764	49,11911	6,17269
Rail		Pastilly	0,832148762	0,071247866	47,678612	4,082202
Rail		Stranraer	0,958346836	-0,08769515	54,909229	-5,024562
Rail		Crewe	0,926732657	-0,042614134	53,09787	-2,44161
Rail		Preston	0,938338224	-0,047202779	53,76282	-2,70452
Rail		Katrineholm	1,029672177	0,282869177	58,99587	16,20721
Rail		Plasencia	0,698675545	-0,106263499	40,03116	-6,08845

Network	City	Phi	Lambda	Latitude	Lontitude
Rail	Merida	0,679214252	-0,110717754	38,91611	-6,34366
Rail	Fulda	0,882292211	0,168863747	50,55162	9,67518
Rail	Wuerzburg	0,869067677	0,173681379	49,79391	9,95121
Rail	Courtalain	0,839177535	0,019228886	48,081331	1,101734
Rail	Tours	0,826995119	0,011926358	47,38333	0,68333
Rail	Erfurt	0,889746163	0,192559209	50,9787	11,03283
Rail	Foggia	0,723586455	0,271431511	41,45845	15,55188

Appendix C: Trip Generation

	Code 1	Code 2	GDP/ capita [€]	Population [#]	Trips [#]	Trips/ capita
Brussels	BE001		46.123,38	2.967.513,00	39.492.563	13,31
Antwerpen	BE002		44.410,84	1.027.043,00	13.160.706	12,81
Gent	BE003		39.127,62	626.129,00	7.068.851	11,29
Liege	BE005		27.047,11	812.079,00	6.337.540	7,80
Sofia	BG001		10.663,78	1.679.207,00	5.166.744	3,08
Plovdiv	BG002		4.560,79	678.197,00	892.478	1,32
Prague	CZ001		22.725,29	2.545.537,00	16.691.310	6,56
Brno	CZ002		14.677,09	1.170.078,00	4.955.145	4,23
Ostrava	CZ003		13.230,62	1.221.832,00	4.664.373	3,82
Copenhagen	DK001	SE003	47.424,51	3.222.185,00	44.091.500	13,68
Arhus	DK002		39.792,73	851.769,00	9.779.736	11,48
Berlin	DE001		28.562,34	5.005.216,00	41.249.451	8,24
Hamburg	DE002		40.839,98	3.173.871,00	37.400.410	11,78
Munich	DE003		53.478,68	2.768.488,00	42.719.375	15,43
Koeln	DE004	DE034	39.526,00	2.823.603,00	32.202.385	11,40
Frankfurt am Main	DE005		47.271,77	2.573.745,00	35.104.997	13,64
Stuttgart	DE007		44.327,36	2.668.439,00	34.129.562	12,79
Leipzig	DE008		26.309,37	986.504,00	7.488.776	7,59
Dresden	DE009		24.745,27	1.328.759,00	9.487.242	7,14
Duesseldorf	DE011		49.024,70	1.515.921,00	21.443.372	14,15
Bremen	DE012		33.548,65	1.237.203,00	11.976.160	9,68
Hannover	DE013		37.305,33	1.275.125,00	13.725.406	10,76
Ruhrgebiet	DE005		47.271,77	2.573.745,00	35.104.997	13,64
Karlsruhe	DE035		41.694,97	728.289,00	8.761.712	12,03
Kiel	DE039		28.433,62	636.251,00	5.219.900	8,20
Saarbruecken	DE040		33.592,52	799.027,00	7.744.718	9,69
Mannheim	DE084	DE522	36.949,09	1.833.237,00	19.544.473	10,66
Aachen	DE507		30.604,79	545.067,00	4.813.277	8,83
Tallinn	EE001		18.992,29	572.103,00	3.135.112	5,48
Dublin	IE001		47.470,72	1.816.972,00	24.887.176	13,70
Athens	EL001		24.095,52	3.863.763,00	26.862.619	6,95
Thessaloniki	EL002		15.007,18	1.123.676,00	4.865.660	4,33
Madrid	ES001		30.912,89	6.378.297,00	56.891.307	8,92
Barcelona	ES002		26.467,20	5.445.616,00	41.586.903	7,64
Valencia	ES003		20.775,73	2.527.590,00	15.151.809	5,99
Sevilla	ES004		18.501,02	1.936.908,00	10.339.659	5,34
Zaragoza	ES005		24.562,61	968.553,00	6.864.351	7,09
Bilbao	ES019		27.796,05	1.140.285,00	9.145.302	8,02
Paris	FR001		52.210,61	12.005.077,00	180.852.819	15,06
Lyon	FR003		42.024,03	1.798.511,00	21.807.825	12,13
Toulouse	FR004		36.895,12	1.312.022,00	13.967.273	10,65
Strasbourg	FR006		31.795,82	1.110.416,00	10.187.258	9,17
Bordeaux	FR007		32.036,80	1.515.229,00	14.006.479	9,24
Nantes	FR008		32.360,20	1.343.259,00	12.542.165	9,34
Lille	FR009		27.976,83	2.595.539,00	20.952.103	8,07
Montpellier	FR010		28.019,03	1.107.730,00	8.955.474	8,08
Rennes	FR013		31.402,37	1.026.962,00	9.305.043	9,06
Grenoble	FR026		30.611,76	1.242.280,00	10.972.595	8,83
Toulon	FR032		24.237,67	1.030.489,00	7.206.689	6,99
Marseille	FR203		33.697,47	1.996.351,00	19.410.457	9,72
Nice	FR205		32.833,05	1.083.268,00	10.262.395	9,47
Rouen	FR015		30.352,60	1.255.335,00	10.994.035	8,76
Zagreb	HR001		15.429,34	1.115.545,00	4.966.335	4,45
Rome	IT001		36.968,54	4.321.244,00	46.093.815	10,67

	Code 1	Code 2	GDP/ capita [€]	Population [#]	Trips [#]	Trips/ capita
Milano	IT002		45.416,47	4.267.946,00	55.928.588	13,10
Napoli	IT003		17.671,18	3.127.390,00	15.945.905	5,10
Turin	IT004		30.288,24	2.297.917,00	20.082.138	8,74
Palermo	IT005		17.562,87	1.275.598,00	6.464.142	5,07
Genoa	IT006		32.391,11	868.046,00	8.112.788	9,35
Florence	IT007		34.593,29	1.007.252,00	10.053.831	9,98
Bari	IT008		19.682,95	1.261.964,00	7.167.022	5,68
Bologna	IT009		37.959,75	1.001.170,00	10.965.609	10,95
Catania	IT010		16.793,79	1.115.704,00	5.406.289	4,85
Venice	IT011		30.233,53	857.841,00	7.483.370	8,72
Verona	IT012		30.905,30	921.717,00	8.219.249	8,92
Brescia	IT029		30.597,65	1.262.295,00	11.144.241	8,83
Vilnius	LT001		15.930,76	806.106,00	3.705.358	4,60
Budapest	HU001		16.182,26	2.965.413,00	13.846.051	4,67
Amsterdam	NL002		47.465,93	2.437.114,00	33.377.930	13,70
Rotterdam	NL003	NL001	40.995,11	2.248.058,00	26.591.394	11,83
Utrecht	NL004		45.637,50	1.253.672,00	16.508.490	13,17
Eindhoven	NL005		42.901,30	748.326,00	9.263.239	12,38
Groningen	NL007		64.285,62	433.784,00	8.046.165	18,55
Vienna	AT001		42.049,38	2.680.667,00	32.524.006	12,13
Warsaw	PL001		20.275,53	3.304.641,00	19.332.947	5,85
Lodz	PL002		10.854,99	1.092.477,00	3.421.711	3,13
Krakow	PL003		11.479,85	1.452.496,00	4.811.192	3,31
Wroclaw	PL004		12.815,49	1.192.483,00	4.409.496	3,70
Poznan	PL005		15.550,06	1.160.364,00	5.206.284	4,49
Gdansk	PL006		11.603,71	1.287.221,00	4.309.745	3,35
Lublin	PL009		9.246,97	709.182,00	1.892.164	2,67
Katowice	PL010		11.386,49	2.743.929,00	9.014.970	3,29
Rzeszow	PL015		8.677,65	616.737,00	1.544.201	2,50
Lisbon	PT001		22.474,21	2.807.525,00	18.205.794	6,48
Porto	PT002		15.910,36	1.271.499,00	5.837.106	4,59
Bucharest	RO001		15.929,32	2.282.968,00	10.492.975	4,60
Cluj-Napoca	RO002		8.411,56	698.929,00	1.696.333	2,43
Iasi	RO502		5.106,35	780.948,00	1.150.626	1,47
Ljubljana	SI001		24.845,11	546.314,00	3.916.380	7,17
Bratislava	SK001		32.281,55	618.380,00	5.759.853	9,31
Helsinki	FI001		48.130,80	1.585.473,00	22.018.285	13,89
Stockholm	SE001		62.337,34	2.163.042,00	38.905.839	17,99
Goeteborg	SE002		43.286,77	1.615.084,00	20.172.135	12,49
London	UK001		44.242,85	14.031.830,00	179.126.144	12,77
Birmingham	UK002	UK025	27.240,70	3.342.422,00	26.271.275	7,86
Leeds	UK003	UK005	29.078,19	1.624.573,00	13.630.385	8,39
Glasgow	UK004		27.872,32	1.817.797,00	14.619.081	8,04
Liverpool	UK006		23.607,85	1.513.306,00	10.308.246	6,81
Edinburgh	UK007		38.458,82	853.697,00	9.473.300	11,10
Manchester	UK008		27.407,30	2.723.479,00	21.537.329	7,91
Newcastle upon Tyne	UK013		24.582,71	1.153.994,00	8.185.305	7,09
Oslo	NO001		81.442,61	1.209.992,00	28.433.855	23,50
Zurich	CH001	*	111.083	1.427.552,00	45.755.254	32,05
Geneve	CH002	*	84.416	471.447,00	11.483.116	24,36
Basel	CH003		135.796	689.934,00	27.033.119	39,18
Ankara		***	21.774	4.588.000	28.824.594	6,28
Istanbul		***	27.297	14.657.434	115.444.815	7,88
Belgrade		**	19.315	1.351.000	7.529.209	5,57
Chisinau		**	4.475	804.500	1.038.773	1,29
Kaliningrad		**	12.722	448.548	1.646.567	3,67
Moscow		**	36.725	16.800.000	178.019.157	10,60
St. Petersburg		**	22.749	5.191.690	34.078.334	6,56
Kiev		**	12.318	2.900.920	10.310.699	3,55

	Code 1	Code 2	GDP/ capita [€]	Popul ation [#]	Trips [#]	Trips/ capita
Minsk		**	19.430	2.101.018	11.778.944	5,61
Podgorica		**	6.275	187.085	338.720	1,81
Pristina		**	8.001	504.165	1.163.893	2,31
Sarajevo		**	18.367	688.354	3.647.973	5,30
Skopje		**	4.500	536.271	696.303	1,30
Tirana		**	3.713	418.495	448.398	1,07
Luxembourg	LU001		83.051,71	549.680,00	13.172.254	23,96
Riga	LV001		14.599,94	1.010.406,00	4.256.460	4,21
Bergen	NO002		64.111,18	505.090,00	9.343.382	18,50
Kosice	SK002		10.461,44	794.756,00	2.398.981	3,02
Linz	AT003		41.656,07	765.589,00	9.201.858	12,02
Tampere	FI002		35.358,64	500.166,00	5.102.832	10,20

Belgium			33.500,00	5.825.670,00	28.155.436	4,83
Bulgaria			5.100,00	4.844.794,00	3.564.651	0,74
Czech Republic			14.700,00	5.600.828,00	11.877.940	2,12
Denmark			43.500,00	1.585.761,00	9.951.729	6,28
Germany			32.100,00	48.725.047,00	112.823.320	2,32
Estonia			11.000,00	741.168,00	1.176.199	1,59
Ireland			36.400,00	2.811.977,00	14.766.743	5,25
Greece			16.200,00	5.870.579,00	13.720.424	2,34
Spain			22.100,00	28.052.316,00	89.440.160	3,19
France (metropolitan)			30.800,00	33.275.397,00	36.964.560	1,11
Croatia			10.200,00	3.109.771,00	4.576.149	1,47
Italy			26.500,00	37.209.528,00	35.564.083	0,96
Latvia			8.500,00	975.690,00	1.196.471	1,23
Lithuania			9.000,00	2.115.156,00	2.746.354	1,30
Luxembourg			77.900,00	13.278,00	149.225	11,24
Hungary			9.800,00	6.890.158,00	9.741.522	1,41
Netherlands			38.000,00	9.779.772,00	26.807.351	2,74
Austria			35.200,00	5.130.005,00	26.051.457	5,08
Poland			9.400,00	24.446.084,00	33.151.923	1,36
Portugal			16.000,00	6.295.798,00	14.532.567	2,31
Romania			6.300,00	16.107.802,00	14.640.247	0,91
Slovenia			17.400,00	1.516.560,00	3.806.978	2,51
Slovakia			12.400,00	4.008.213,00	7.170.411	1,79
Finland			34.900,00	3.386.114,00	17.048.987	5,03
Sweden			39.400,00	5.969.229,00	33.930.170	5,68
United Kingdom			28.900,00	37.814.067,00	283.788.837	7,50
Norway			66.200,00	3.451.411,00	32.962.963	9,55
Switzerland			55.900,00	5.648.733,00	45.554.830	8,06

*	National statistical authority data
**	Country specific data (PPP)
***	OECD-data

1 CHF = €0,81
1 Int.$ = €0,90

Appendix D: Trip Calibration

Domestic

Origin		Destination	C	L	S	F	Dist.	TT					Input capacity		Trips/year		Calibration		0,00001366	
	i	j					Dij	HST	Conv	Plane	Car	Bus	Yearly	Mode		Calculated	Ai	Aj	l	beta
ES	Madrid	Barcelona	0	0	0	0	507	150	9999	244	380	458	2573032	Plane	5.397.420	5.286.247	56.891.307	41.586.903	0,00001395	0,98
ES	Madrid	Valencia	0	0	0	0	304	101	120	227	218	332	262715	Plane	3.838.823	3.940.965	56.891.307	15.151.809	0,00001331	1,03
IT	Milano	Rome	0	0	0	0	481	160	9999	256	367	567	2908266	Plane	6.487.620	6.196.640	55.928.588	46.093.815	0,00001431	0,96
IT	Milano	Palermo	0	0	0	0	888	360	930	304	900	1228	460405	Plane	375.699	367.817	55.928.588	6.464.142	0,00001396	0,98
DE	Berlin	Munich	0	0	0	1	507	363	510	282	300	390	1872051	Plane	1.973.042	1.965.274	41.249.451	42.719.375	0,00000686	1,99
DE	Berlin	Frankfurt	0	0	0	1	426	251	340	247	340	524	1792786	Plane	2.074.265	2.064.216	41.249.451	35.104.997	0,00000687	1,99
FR	Paris	Lyon	0	0	0	0	395	104	306	300	285	373	671287	Plane	12.152.736	12.481.201	180.852.819	21.807.825	0,00001331	1,03
FR	Paris	Bordeaux	0	0	0	0	501	193	451	290	332	332	1544769	Plane	5.552.652	5.748.875	180.852.819	14.006.479	0,00001320	1,04
UK	London	Newcastle	0	0	0	1	448	168	293	250	281	330	582583	Plane	1.974.198	2.283.120	179.126.144	8.185.305	0,00000693	1,97
UK	London	Glasgow	0	0	0	1	558	278	363	216	399	470	2272646	Plane	1.737.878	2.555.396	179.126.144	14.619.081	0,00000465	2,94
PL	Warsaw	Krakow	0	0	0	0	254	9999	148	205	248	336	275389	Plane	548.918	547.307	19.332.947	4.811.192	0,00001370	1,00
PL	Warsaw	Wroclaw	0	0	0	0	303	9999	222	210	275	320	336256	Plane	388.554	390.898	19.332.947	4.409.496	0,00001358	1,01

Country

Origin		Destination	C	L	S	F	Dist.	TT					Input capacity		Trips/year		Calibration		
	i	j					Dij	HST	Conv	Plane	Car	Bus	Yearly	Mode		Calculated	Ai	Aj	beta
FR	Paris	Geneve	1	0	0	0	412	193	279	227	331	435	982094	Plane	1.624.408	1.231.494	180.852.819	11.483.116	3,82
FR	Paris	Brussels	1	0	0	1	266	82	159	270	170	799	173743	Plane	6.729.451	7.831.037	180.852.819	39.492.563	5,86
FR	Brussels	Marseille	1	0	0	1	847	319	371	285	600	949	105776	Plane	103.427	165.559	39.492.563	19.410.457	8,06
DE	Berlin	Zurich	1	0	0	1	673	9999	537	255	536	663	954529	Plane	521.807	562.271	41.249.451	45.755.254	5,42
DE	Berlin	Vienna	1	0	0	1	526	9999	589	260	459	1140	785973	Plane	457.894	564.654	41.249.451	32.524.006	6,21
DE	Vienna	Zurich	1	0	0	0	594	463	553	229	475	653	947601	Plane	525.562	528.172	32.524.006	45.755.254	5,06
EN	London	Dublin	1	0	0	1	464	9999	365	300	412	412	3205895	Plane	2.669.104	2.236.946	179.126.144	24.887.176	4,22
EN	Manchester	Dublin	1	0	0	1	268	9999	320	227	296	767	759333	Plane	651.044	581.307	21.537.329	24.887.176	4,49
EN	Edinburgh	Dublin	1	0	0	1	353	9999	487	245	460	615	478640	Plane	272.888	173.642	9.473.300	24.887.176	3,20
NL	Amsterdam	Brussels	1	0	0	1	174	110	195	215	153	165	251793	Plane	3.279.891	2.605.884	33.377.930	39.492.563	4,00
FR	Paris	Geneve	1	0	0	0	412	193	279	227	331	435	982094	Plane	1.624.408	1.231.494	180.852.819	11.483.116	3,82

Language

Origin	Destination	C	L	S	F	Dist.	TT					Input capacity		Trips/year	Calibration			
i	j					Dij	HST	Conv	Plane	Car	Bus	Yearly	Mode		Calculated	Ai	Aj	beta
Berlin	**Paris**	1	1	0	1	882	9999	516	300	651	938	1136100	Plane	649.625	664.364	41.249.451	180.852.819	11,80
Frankfurt	**Paris**	1	1	0	1	481	233	295	240	359	522	1053928	Plane	1.387.653	1.323.333	35.104.997	180.852.819	11,00
Munich	**Prague**	1	1	0	1	301	278	300	210	204	278	198640	Plane	271.112	285.951	42.719.375	16.691.310	12,17
Verona	**Munich**	1	1	0	1	306	308	367	240	280	278	116653	Plane	129.667	137.865	8.219.249	42.719.375	12,26
Ljubljana	**Munich**	1	1	0	1	322	294	360	185	261	260	76251	Plane	62.310	61.014	3.916.380	42.719.375	11,29
Warsaw	**Copenhagen**	1	1	0	0	675	9999	803	240	811	1249	228412	Plane	114.597	110.499	19.332.947	44.091.500	11,12
Budapest	**Copenhagen**	1	1	0	0	1017	9999	1182	289	1017	1440	95851	Plane	49.872	44.569	13.846.051	44.091.500	10,31
Budapest	**vienna**	1	1	0	0	215	141	198	165	155	200	107129	Plane	267.888	289.304	13.846.051	32.524.006	12,46
Valencia	**lisbon**	1	1	0	0	763	9999	675	282	573	1170	50760	Plane	27.614	30.088	15.151.809	18.205.794	12,57
Brussels	**Goeteborg**	1	1	0	1	912	9999	980	263	834	1440	144561	Plane	75.384	67.775	39.492.563	20.172.135	10,37
Berlin	**Paris**	1	1	0	1	882	9999	516	300	651	938	1136100	Plane	649.625	664.364	41.249.451	180.852.819	11,80

Schengen

Origin	Destination	C	L	S	F	Dist.	TT					Input capacity		Trips/year	Calibration			
i	j					Dij	HST	Conv	Plane	Car	Bus	Yearly	Mode		Calculated	Ai	Aj	beta
Paris	**London**	1	1	1	1	882	141	9999	249	300	455	15700*	HST	7.622.671	9.131.712	180.852.819	179.126.144	16,23
Brussels	**London**	1	1	1	1	481	126	9999	233	232	317	3750*	HST	1.911.435	2.201.467	39.492.563	179.126.144	15,61
Paris	**Dublin**	1	1	1	0	301	9999	9999		9999	9999	661394	Plane	343.925	403.473	180.852.819	24.887.176	15,90
Paris	**Moscow**	1	1	1	1	306	9999	9999		9999	9999	917048	Plane	476.865	568.561	180.852.819	178.019.157	16,16
Athens	**Istanbul**	1	1	1	0	322	9999	9999		9999	9999	656983	Plane	341.631	439.811	26.862.619	115.444.815	17,45
Thessaloniki	**Istanbul**	1	1	1	0	675	9999	9999		9999	9999	117243	Plane	60.966	91.660	4.865.660	115.444.815	20,37
Dublin	**Hamburg**	1	1	1	1	1017	9999	9999		9999	9999	81455	Plane	42.357	53.185	24.887.176	37.400.410	17,02

*Daily averages

Appendix E: Link loads

ID		Source	Target	Train Cur	Train Div	Train Quo	Train Int
1		Brussels	Antwerpen	8.421.704	6.090.939	9.995.041	15.672.011
2		Gent	Brussels	1.232.492	979.831	1.440.109	1.764.464
3		Liege	Brussels	10.514.543	8.214.551	14.702.233	24.573.012
4	YES	Lille	Brussels	19.869.814	14.467.588	25.441.930	42.945.602
5	YES	Luxemburg	Brussels	468.414	396.492	616.923	961.661
6		Gent	Antwerpen	1.157.033	721.060	1.242.288	2.107.984
7		Liege	Antwerpen	959.138	693.838	1.463.207	826.637
8	YES	Rotterdam	Antwerpen	6.672.393	4.422.120	8.016.174	13.106.563
9	YES	Eindhoven	Antwerpen	1.065.283	656.746	1.159.398	1.969.940
10	YES	Lille	Gent	1.353.977	841.856	1.485.327	2.635.692
11	YES	Aachen	Liege	10.025.232	7.727.474	14.754.912	24.041.725
12	YES	Eindhoven	Liege	77.226	45.747	79.417	123.523
13	YES	Luxemburg	Liege	440.025	279.777	517.296	833.276
14		Plovdiv	Sofia	334.259	243.418	371.006	468.814
15	YES	Thessaloniki	Sofia	217.817	147.346	227.289	695.913
16	YES	Cluj-Napoca	Sofia	20.839	15.411	24.000	33.438
17	YES	Belgrade	Sofia	212.401	184.868	291.528	722.723
18	YES	Skopje	Sofia	112.760	102.137	157.665	210.455
19	YES	Bucharest	Sofia	166.967	137.045	213.831	396.786
20	YES	Bucharest	Plovdiv	17.832	12.635	20.656	62.207
21		Edirne	Plovdiv	173.674	145.232	231.052	313.555
22	YES	Munich	Prague	470.833	329.388	828.424	4.430.612
23	YES	Dresden	Prague	884.328	733.774	2.025.854	8.607.862
24		Usti nad Orlici	Prague	1.530.521	1.421.138	249.170	271.499
25	YES	Krakow	Ostrava	109.439	86.068	355.293	878.587
26	YES	Vienna	Brno	1.021.255	789.314	3.352.306	6.034.544
27		Usti nad Orlici	Brno	1.268.130	1.105.394	-	-
28	YES	Kosice	Ostrava	97.408	79.744	177.811	227.684
29		Usti nad Orlici	Ostrava	1.134.553	972.548	249.170	271.499
30	YES	Katowice	Ostrava	407.031	278.135	1.102.427	2.470.079
31		Kolding	Copenhagen	2.885.959	4.476.516	6.058.677	6.651.047
32	YES	Goeteborg	Copenhagen	1.363.092	948.917	2.572.751	5.324.438
33	YES	Katrineholm	Copenhagen	449.664	633.339	4.082.514	6.492.740
34		Kolding	Arhus	3.225.136	4.752.119	6.489.671	7.499.112
35	YES	Poznan	Berlin	435.823	336.191	1.221.556	1.630.907
36		Hamburg	Berlin	2.742.182	2.138.024	6.220.305	9.579.798
37		Leipzig	Berlin	615.322	1.488.907	3.455.074	3.944.240
38		Dresden	Berlin	1.344.835	939.264	2.380.786	8.320.332
39		Hannover	Berlin	5.824.757	4.252.454	7.421.935	10.276.309
40		Bremen	Hamburg	1.167.921	857.805	8.931.393	13.249.071
41		Hannover	Hamburg	7.590.564	6.223.207	6.796.082	8.941.427

ID		Source	Target	Train Cur	Train Div	Train Quo	Train Int
42		Kiel	Hamburg	2.079.261	1.476.274	2.453.522	3.523.216
43		Stuttgart	Munich	4.453.477	3.295.082	15.815.236	23.041.826
44	YES	Zurich	Munich	1.196.558	707.239	955.539	1.756.651
45		Nuernberg	Munich	6.606.377	6.143.066	5.332.195	5.781.845
46	YES	Innsbruck	Munich	708.639	507.479	2.430.907	5.793.278
47	YES	Salzburg	Munich	2.706.623	1.939.521	5.622.388	10.268.969
48		Frankfurt am Main	Koeln	16.369.203	13.735.632	17.095.396	24.765.596
49		Duesseldorf	Koeln	11.653.938	10.223.969	22.099.208	32.993.642
50		Aachen	Koeln	11.665.253	8.757.040	16.228.284	25.584.060
51		Mannheim	Frankfurt am Main	13.737.800	12.801.101	27.416.880	37.634.817
52		Fulda	Frankfurt am Main	9.011.735	8.674.750	9.463.324	11.537.214
53		Wuerzburg	Frankfurt am Main	3.755.758	3.248.893	493.668	1.589.125
54		Karlsruhe	Stuttgart	3.162.080	2.081.857	3.110.155	4.758.948
55	YES	Zurich	Stuttgart	2.928.130	508.277	1.036.957	1.819.456
56		Dresden	Leipzig	1.175.846	1.078.449	1.407.247	850.317
57		Hannover	Leipzig	353.800	263.280	339.744	503.391
58		Erfurt	Leipzig	1.900.322	2.926.022	4.366.843	3.992.793
59		Tarragona	Zaragoza	7.836.746	4.539.485	6.818.961	8.202.309
60	YES	Wroclaw	Dresden	157.187	125.040	148.298	666.222
61	YES	Eindhoven	Duesseldorf	569.483	600.143	1.175.306	1.647.235
62		Ruhrgebiet (Essen)	Duesseldorf	10.726.683	7.864.267	20.026.925	30.193.463
63		Hannover	Bremen	1.463.791	1.500.686	2.241.897	2.897.140
64		Osnabrueck	Bremen	703.872	447.322	7.989.893	11.888.855
65		Ruhrgebiet (Essen)	Hannover	2.115.959	1.236.212	4.831.675	7.153.157
66		Kassel	Hannover	10.386.237	8.966.278	10.198.758	13.026.360
67	YES	Utrecht	Ruhrgebiet (Essen)	319.035	178.929	507.132	4.276.171
68		Kassel	Ruhrgebiet (Essen)	277.634	141.079	10.302	44.155
69		Mannheim	Karlsruhe	3.078.900	4.476.032	8.152.133	12.672.576
70	YES	Strasbourg	Karlsruhe	2.501.276	1.576.643	1.361.587	2.317.592
71	YES	Basel	Karlsruhe	931.273	2.993.612	6.557.075	10.990.653
72	YES	Kolding	Kiel	512.421	459.071	430.994	848.065
73	YES	Aalborg	Goeteborg	230.677	168.377	102.556	202.178
74	YES	Strasbourg	Saarbruecken	274.845	122.083	90.426	131.599
75		Mannheim	Saarbruecken	2.485.466	1.766.856	7.555.789	11.868.680
76	YES	Helsinki	Tallinn	374.178	304.831	469.946	1.030.870
77	YES	St. Petersburg	Tallinn	217.628	222.661	314.616	941.676
78	YES	Riga	Tallinn	178.303	158.178	237.858	669.402
79	YES	Holyhead	Dublin	1.362.198	1.376.641	2.096.828	3.043.441
80		Patra	Athens	822	611	1.022	784
81		Thessaloniki	Athens	1.700.628	1.084.050	1.538.948	3.798.469
82	YES	Istanbul	Thessaloniki	176.320	125.410	194.894	664.084
83	YES	Skopje	Thessaloniki	80.782	63.192	95.682	209.092
84		Valencia	Madrid	3.424.698	1.697.693	2.419.136	3.264.558

ID		Source	Target	Train Cur	Train Div	Train Quo	Train Int
85		Sevilla	Madrid	2.721.000	1.663.793	2.282.137	2.584.158
86		Zaragoza	Madrid	7.405.370	3.917.895	5.931.224	7.202.323
87		Valladolid	Madrid	1.027.521	1.166.666	2.241.711	3.342.168
88		Plasencia	Madrid	-	-	-	926.971
89		Perpignan	Montpellier	1.694.612	941.430	2.601.775	4.698.993
90		Tarragona	Barcelona	9.558.376	6.008.989	9.068.299	11.442.133
91		Tarragona	Valencia	1.734.350	1.918.120	2.907.952	4.091.420
92	YES	Perpignan	Barcelona	2.047.821	1.136.283	3.009.313	5.427.464
93	YES	Faro	Sevilla	189.989	100.970	72.958	132.269
94		Bilbao	Zaragoza	724.069	391.162	560.224	653.102
95	YES	Lviv	Rzeszow	33.797	32.125	74.204	85.670
96	YES	Biarritz	Bilbao	115.980	268.371	862.455	2.266.534
97		Pastilly	Paris	23.876.600	17.360.622	27.351.952	34.936.351
98		Metz	Paris	6.662.834	4.858.411	9.032.248	13.018.401
99		Brive-la-Gaillarde	Paris	9.209	6.043	188.620	205.975
100		Courtalain	Paris	10.823.701	13.015.179	20.364.004	25.027.718
101		Lille	Paris	23.357.738	15.931.091	25.489.084	35.499.125
102		Calais	Paris	11.701.939	9.426.899	15.750.501	27.979.613
103		Salzburg	Innsbruck	488.803	206.675	1.286.140	2.719.689
104		Rouen	Paris	3.405.039	2.357.276	6.130.654	7.882.172
105		Brive-la-Gaillarde	Lyon	207.054	164.850	312.674	355.274
106		Dijon	Lyon	393.120	448.261	2.030.517	2.821.962
107		Avignon	Lyon	11.352.933	8.100.106	13.044.324	15.454.925
108		Grenoble	Lyon	5.527.491	4.032.318	9.120.531	12.143.096
109		Pastilly	Lyon	21.546.063	16.261.889	24.567.160	30.193.985
110	YES	Geneve	Lyon	1.899.427	1.096.898	1.805.963	2.752.024
111		Bordeaux	Toulouse	789.888	2.044.569	5.100.394	6.147.082
112		Montpellier	Toulouse	2.498.617	1.251.853	2.153.193	2.888.875
113		Biarritz	Toulouse	32.851	21.585	74.769	208.444
114	YES	Basel	Strasbourg	1.035.610	643.354	1.115.143	1.597.594
115		Nantes	Bordeaux	392.625	213.112	431.923	597.998
116		Biarritz	Bordeaux	146.862	305.779	922.456	2.316.820
117		Rennes	Nantes	458.771	256.929	403.997	559.911
118		Rouen	Lille	332.921	194.214	272.045	488.734
119		Calais	Lille	8.326.954	7.153.216	12.126.398	21.567.355
120		Marseille	Montpellier	1.892.723	1.690.902	2.607.858	4.953.858
121		Le Mans	Rennes	4.062.258	4.361.443	6.447.623	7.918.285
122	YES	Turin	Grenoble	1.948.410	1.039.030	3.974.290	7.138.015
123	YES	Geneve	Grenoble	394.927	261.880	241.073	511.515
124		Marseille	Toulon	4.390.198	1.658.117	2.519.077	3.151.411
125		Nice	Toulon	2.407.317	180.927	294.028	541.734
126	YES	Genoa	Nice	397.256	565.090	939.794	4.566.761
127	YES	Budapest	Zagreb	59.770	44.179	64.914	295.056
128	YES	Ljubljana	Zagreb	510.698	452.674	750.719	2.738.165
129	YES	Belgrade	Zagreb	190.174	201.646	262.839	1.562.308

ID		Source	Target	Train Cur	Train Div	Train Quo	Train Int
130	YES	Sarajevo	Zagreb	192.041	212.078	367.371	727.628
131	YES	Graz	Zagreb	222.926	230.631	431.205	627.848
132		Napoli	Rome	8.683.652	5.882.493	9.008.681	12.629.571
133		Florence	Rome	12.765.447	9.007.295	14.329.854	19.401.036
134		Turin	Milano	10.400.196	6.848.553	12.086.915	16.198.973
135		Genoa	Milano	2.044.346	2.291.166	3.568.259	6.658.443
136		Bologna	Milano	11.496.626	7.606.382	11.391.556	14.005.776
137		Brescia	Milano	8.565.347	6.599.686	10.799.892	16.385.164
138	YES	Zurich	Milano	1.816.452	1.298.294	3.554.471	6.084.200
139	YES	Geneve	Milano	243.248	154.724	281.491	464.625
140	YES	Timisoara	Budapest	45.805	44.986	73.204	-
141		Cosenza	Napoli	287.855	478.465	974.268	3.112.126
142		Genoa	Turin	594.182	360.211	556.886	1.826.345
143		Messina	Palermo	291.902	322.879	978.470	2.253.130
144		Florence	Genoa	724.303	523.477	747.697	1.335.569
145		Bologna	Florence	13.106.013	9.294.626	15.169.681	20.322.254
146	YES	Linz	Prague	112.114	47.792	60.639	355.596
147	YES	Patra	Bari	822	611	1.022	784
148		Venice	Bologna	1.385.865	970.064	1.796.486	2.852.815
149		Verona	Bologna	1.212.588	1.431.862	3.707.907	5.918.571
150		Ancona	Bologna	6.571	7.066	9.033	10.606
151		Verona	Venice	1.697.444	2.099.486	3.066.050	5.420.811
152	YES	Ljubljana	Venice	466.441	746.833	923.411	3.461.059
153	YES	Villach	Venice	114.260	8.217	22.328	40.899
154		Brescia	Verona	4.061.043	4.791.898	8.290.438	13.749.383
155	YES	Innsbruck	Verona	876.282	546.232	3.377.043	7.732.621
156	YES	Kaliningrad	Vilnius	54.402	60.431	88.978	119.286
157	YES	Minsk	Vilnius	334.250	346.295	499.578	637.024
158	YES	Riga	Vilnius	166.587	155.517	236.515	394.170
159	YES	Vienna	Budapest	807.018	680.267	1.659.131	3.429.348
160	YES	Ljubljana	Budapest	91.117	91.609	94.885	905.362
161	YES	Bratislava	Budapest	136.150	114.746	174.659	2.719.247
162	YES	Cluj-Napoca	Budapest	60.245	58.543	89.654	234.868
163	YES	Belgrade	Budapest	301.974	324.230	618.260	1.383.694
164	YES	Lviv	Budapest	24.216	23.470	23.245	35.744
165		Rotterdam	Amsterdam	8.012.287	6.058.939	9.399.547	12.231.743
166		Utrecht	Amsterdam	3.872.007	2.953.084	4.512.311	7.316.955
167	YES	Osnabrueck	Utrecht	337.270	203.890	489.442	1.417.093
168		Utrecht	Rotterdam	3.077.496	2.165.404	3.545.029	6.715.504
169		Eindhoven	Rotterdam	704.873	524.548	736.615	766.236
170		Eindhoven	Utrecht	1.420.010	967.974	1.416.727	1.491.078
171		Groningen	Utrecht	2.108.019	1.508.692	2.157.253	2.998.441
172	YES	Bratislava	Vienna	915.228	745.237	1.461.975	2.491.284
173		Linz	Vienna	5.074.083	3.891.075	8.471.923	12.851.509
174		Graz	Vienna	305.201	622.779	705.733	1.105.784
175		Lodz	Warsaw	702.186	535.477	1.419.781	1.873.220

ID		Source	Target	Train Cur	Train Div	Train Quo	Train Int
176		Krakow	Warsaw	267.905	225.738	326.862	383.609
177		Poznan	Warsaw	478.471	399.155	1.420.364	1.745.198
178		Gdansk	Warsaw	491.051	409.901	530.129	584.949
179		Lublin	Warsaw	501.312	397.997	713.935	832.160
180		Katowice	Warsaw	755.199	561.032	1.116.610	1.499.707
181		Coimbra	Porto	1.299.985	813.171	1.586.897	2.593.876
182	YES	Minsk	Warsaw	196.507	181.376	431.082	557.043
183		Wroclaw	Lodz	290.565	241.007	697.606	1.031.311
184		Poznan	Lodz	106.347	75.354	642.664	724.574
185		Katowice	Lodz	201.216	132.752	591.664	707.659
186		Katowice	Krakow	802.613	595.856	804.781	940.056
187		Rzeszow	Krakow	292.166	220.265	357.080	582.736
188		Poznan	Wroclaw	439.475	338.206	291.520	226.334
189		Katowice	Wroclaw	552.378	409.668	355.328	487.418
190		Gdansk	Poznan	165.927	138.488	309.805	390.818
191		Rzeszow	Lublin	240.855	188.235	333.014	416.074
192	YES	Kiev	Lublin	50.482	45.594	101.836	121.887
193		Coimbra	Lisbon	1.263.538	806.971	1.835.892	2.591.911
194		Faro	Lisbon	189.989	100.970	72.958	132.269
195	YES	Vigo	Porto	-	-	137.698	655.754
196		Cluj-Napoca	Bucharest	221.083	238.661	360.821	380.256
197		Iasi	Bucharest	213.020	229.385	340.560	409.345
198	YES	Chisinau	Bucharest	43.261	49.304	70.078	138.665
199	YES	Timisoara	Bucharest	95.442	104.238	163.813	1.845.175
200		Iasi	Cluj-Napoca	66.236	67.637	106.545	135.831
201	YES	Kosice	Cluj-Napoca	77.975	69.837	117.115	100.878
202	YES	Timisoara	Cluj-Napoca	46.790	52.103	71.300	87.920
203	YES	Chisinau	Iasi	44.913	48.257	73.095	66.583
204	YES	Kiev	Iasi	89.267	91.722	145.171	193.306
205	YES	Villach	Ljubljana	370.759	261.236	442.211	1.061.698
206	YES	Graz	Ljubljana	147.709	420.263	299.696	525.928
207		Kosice	Bratislava	199.226	173.296	280.688	412.114
208	YES	Stockholm	Helsinki	872.899	791.412	1.619.358	3.676.527
209	YES	St. Petersburg	Helsinki	1.617.792	1.514.737	2.448.342	7.040.975
210		Tampere	Helsinki	1.410.382	1.110.031	1.645.198	2.196.027
211		Katrineholm	Stockholm	2.109.699	3.003.540	10.631.528	13.300.573
212	YES	Oslo	Stockholm	506.993	454.003	808.837	2.197.446
213	YES	Oslo	Goeteborg	651.930	501.588	1.354.420	4.217.406
214		Birmingham	London	10.539.628	15.830.506	24.156.691	34.879.296
215		Leeds	Birmingham	344.146	280.618	424.608	767.569
216		Crewe	Birmingham	4.969.017	7.875.989	12.042.304	18.708.470
217		Crewe	Liverpool	1.445.126	1.746.069	2.670.280	3.823.021
218		Holyhead	Birmingham	1.060.093	1.185.031	1.810.943	2.584.425
219		Manchester	Leeds	955.205	695.794	1.052.710	2.188.655
220		Newcastle upon Tyne	Leeds	1.666.259	1.172.378	1.901.150	2.683.102

ID		Source	Target	Train Cur	Train Div	Train Quo	Train Int
221		Preston	Glasgow	913.894	1.160.427	1.676.478	4.035.759
222		Edinburgh	Glasgow	633.061	477.561	1.212.193	1.632.989
223		Stranraer	Glasgow	208.687	133.752	212.153	480.505
224		Manchester	Liverpool	863.346	601.061	907.798	1.883.024
225		Holyhead	Liverpool	302.105	191.610	285.885	459.016
226		Newcastle upon Tyne	Edinburgh	701.188	199.153	429.898	510.068
227		Bergen	Oslo	1.728.008	1.587.899	4.466.799	5.292.602
228		Geneve	Zurich	598.916	292.331	177.982	268.270
229		Basel	Zurich	6.637.618	6.004.161	10.113.044	14.472.907
230	YES	Innsbruck	Zurich	321.160	167.922	340.004	780.346
231		Basel	Geneve	862.415	736.653	1.026.619	1.275.352
232		Istanbul	Ankara	17.990.215	17.399.211	25.493.108	30.950.147
233	YES	Podgorica	Belgrade	81.891	105.384	147.345	218.964
234	YES	Sarajevo	Belgrade	220.755	284.301	396.590	466.743
235	YES	Timisoara	Belgrade	96.427	111.355	161.909	464.792
236		St. Petersburg	Moscow	15.369.251	17.849.930	26.134.684	30.478.485
237	YES	Kiev	Moscow	418.111	534.847	764.084	992.445
238	YES	Minsk	Moscow	606.009	740.793	1.069.391	1.377.362
239	YES	Minsk	Kiev	466.835	555.409	790.606	906.342
240	YES	Minsk	St. Petersburg	210.938	227.787	334.083	455.804
241	YES	Pristina	Podgorica	126.031	143.318	209.640	272.769
242	YES	Sarajevo	Podgorica	88.252	97.758	152.183	194.697
243	YES	Tirana	Podgorica	21.293	27.552	43.026	61.933
244	YES	Skopje	Pristina	113.399	101.459	154.328	224.845
245	YES	Tirana	Pristina	4.584	6.248	8.516	9.651
246	YES	Tirana	Skopje	28.799	30.901	45.541	70.869
247		Salzburg	Linz	2.832.994	1.888.418	6.508.201	11.989.696
248		Graz	Linz	65.434	28.115	25.168	47.992
249		Messina	Cosenza	287.855	478.465	974.268	3.112.126
250		Villach	Salzburg	379.086	264.694	442.287	1.066.048
251		Messina	Catania	297.483	337.704	866.152	1.892.958
252	YES	Hamburg	Copenhagen	711.719	1.204.543	7.689.989	13.330.256
253		Aalborg	Arhus	365.522	301.378	189.945	444.458
254		Rostock	Berlin	-	-	-	-
255		Mannheim	Stuttgart	10.297.294	6.858.308	19.517.974	27.086.565
256		Nuernberg	Stuttgart	146.571	182.298	253.448	256.969
257		Osnabrueck	Hannover	286.891	176.809	4.954	48.415
258		Osnabrueck	Ruhrgebiet (Essen)	653.493	420.241	7.505.405	10.520.177
259		Heilbronn	Mannheim	-	-	-	28.249
260	YES	Eindhoven	Aachen	473.411	11.922	21.693	20.761
261	YES	Stockholm	Tallinn	34.292	32.508	62.303	136.195
262	YES	Belfast	Dublin	208.687	133.752	212.153	480.505
263	YES	Edirne	Thessaloniki	-	-	-	-
264	YES	Biarritz	Zaragoza	63.733	58.993	134.770	258.730
265		Valladolid	Bilbao	994.534	1.170.958	2.082.646	3.121.889

ID		Source	Target	Train Cur	Train Div	Train Quo	Train Int
266		Brive-la-Gaillarde	Toulouse	9.218	6.663	191.103	209.536
267		Perpignan	Toulouse	353.209	194.853	407.538	728.471
268		Metz	Strasbourg	5.004.990	3.802.876	3.912.958	4.171.712
269		Tours	Bordeaux	2.627.718	5.579.416	9.602.987	12.084.510
270		Brive-la-Gaillarde	Bordeaux	207.045	164.230	310.191	351.713
271		Le Mans	Nantes	4.215.949	3.430.476	4.995.826	5.987.824
272		Avignon	Montpellier	4.958.097	2.829.317	5.499.413	6.666.707
273		Marseille	Grenoble	685.220	483.131	882.606	742.656
274		Avignon	Marseille	6.394.836	5.270.789	7.544.911	8.788.218
275		Le Mans	Rouen	82.224	60.120	107.370	163.621
276	YES	Igoumenitsa	Bari	-	-	-	-
277	YES	Warsaw	Vilnius	61.913	46.538	117.699	196.219
278		Villach	Vienna	105.933	4.759	22.252	36.549
279		Katrineholm	Goeteborg	1.660.035	2.370.201	6.549.014	6.807.833
280		Preston	Liverpool	106.987	76.971	116.810	262.072
281		Crewe	Manchester	2.823.690	4.438.143	6.777.713	9.268.265
282		Preston	Manchester	228.974	176.522	267.719	596.215
283	YES	Aalborg	Oslo	134.845	133.001	87.389	242.280
284	YES	Dijon	Basel	2.718.127	1.542.815	4.654.816	7.352.025
285	YES	Edirne	Istanbul	391.368	359.581	578.582	1.112.550
286		Lviv	Kiev	48.391	48.471	85.617	121.404
287	YES	Metz	Luxemburg	2.213.269	1.611.649	3.321.666	5.169.703
288	YES	Riga	Stockholm	7.054	6.858	11.260	36.205
289		Fulda	Kassel	11.336.566	9.927.165	11.477.358	14.028.188
290		Heilbronn	Nuernberg	-	-	-	28.249
291		Wuerzburg	Nuernberg	6.080.589	4.501.308	2.507.702	4.080.099
292		Erfurt	Nuernberg	672.359	1.824.056	3.077.941	2.946.810
293		Foggia	Ancona	6.571	7.066	9.033	10.606
294	YES	Valladolid	Coimbra	48.621	40.538	254.283	4.303
295		Courtalain	Le Mans	8.196.015	7.586.643	11.051.879	13.347.756
296		Tours	Le Mans	32	150.880	290.862	404.548
297		Metz	Dijon	5.530	4.179	160.493	212.303
298		Pastilly	Dijon	2.330.537	1.098.733	2.784.792	4.742.366
299		Dubrovnik	Zadar	-	-	-	-
300		Stranraer	Belfast	208.687	133.752	212.153	480.505
301		Preston	Crewe	700.201	1.691.777	2.594.311	5.617.184
302		Merida	Plasencia	-	-	-	926.971
303		Wuerzburg	Fulda	2.324.831	1.252.415	2.014.034	2.490.974
304		Tours	Courtalain	2.627.686	5.428.536	9.312.125	11.679.962
305	YES	Calais	London	20.028.893	16.580.115	27.876.899	49.546.968
306		Foggia	Napoli	1.977.865	1.619.865	2.431.404	3.143.310
307	YES	Edirne	Bucharest	217.694	214.349	347.530	798.995
308		Foggia	Bari	1.984.436	1.626.931	2.440.437	3.153.916
309		Erfurt	Kassel	1.227.963	1.101.966	1.288.902	1.045.983
310	YES	Metz	Saarbruecken	1.430.833	862.243	5.354.619	9.466.597

ID		Source	Target	Train Cur	Train Div	Train Quo	Train Int
311		Valladolid	Vigo	-	-	137.698	218.314
312		Zadar	Zagreb	-	-	-	-
313		Leeds	London	3.319.779	2.982.491	4.567.319	7.483.226
314		Preston	Leeds	92.702	66.313	-	375.030
315		Preston	Edinburgh	214.970	851.156	1.302.362	2.814.742
316	YES	Groningen	Bremen	-	281.243	784.569	1.135.539
317		Nice	Marseille	-	2.881.323	4.039.864	6.497.155
318		Brno	Prague	-	4.201.720	4.201.720	9.599.883
319		Ostrava	Brno	-	2.980.963	2.980.963	5.464.249
320		Sevilla	Valencia	-	168.960	168.960	766.110
321	YES	Nuernberg	Prague	-	-	-	1.130.132
322	YES	Bratislava	Brno	-	-	-	2.846.833
323		Vigo	Bilbao	-	-	-	437.440
324	YES	Timisoara	Budapest	-	-	-	1.468.303
325	YES	Merida	Lisbon	-	-	-	926.971

Appendix F: Trip Distribution future

Train Cur				Train Div				Train Quo				Train Int			
1	10.808.559	London	Paris	1	8.754.319	London	Paris	1	13.479.757	London	Paris	1	21.743.466	London	Paris
2	6.216.988	Paris	Brussels	2	4.235.907	Paris	Brussels	2	7.347.950	Paris	Brussels	2	11.166.853	Paris	Brussels
3	3.004.329	London	Dublin	3	2.474.281	Minsk	Moscow	3	3.821.205	Stockholm	Copenhagen	3	5.488.049	Stockholm	Copenhagen
4	2.956.684	Goeteborg	Copenhagen	4	2.371.627	Kiev	Moscow	4	3.546.685	Minsk	Moscow	4	4.926.735	Goeteborg	Copenhagen
5	2.790.392	Stockholm	Copenhagen	5	2.306.766	Stockholm	Copenhagen	5	3.381.552	Kiev	Moscow	5	4.572.300	Minsk	Moscow
6	2.007.715	Minsk	Moscow	6	2.175.651	London	Dublin	6	3.277.781	Goeteborg	Copenhagen	6	4.564.273	London	Dublin
7	1.860.729	St. Petersb.	Helsinki	7	1.935.917	Goeteborg	Copenhagen	7	3.225.938	London	Dublin	7	4.342.486	Kiev	Moscow
8	1.836.007	Kiev	Moscow	8	1.651.285	St. Petersb.	Helsinki	8	2.528.620	St. Petersb.	Helsinki	8	3.920.868	St. Petersb.	Helsinki
9	1.827.187	Luxemburg	Paris	9	1.342.235	Bratislava	Vienna	9	2.295.442	Luxemburg	Paris	9	3.434.861	Luxemburg	Paris
10	1.750.371	Zurich	Munich	10	1.325.858	Luxemburg	Paris	10	2.065.064	Bratislava	Vienna	10	3.231.050	Zurich	Munich
11	1.680.079	Bratislava	Vienna	11	1.311.335	London	Brussels	11	1.977.363	London	Brussels	11	3.149.332	London	Brussels
12	1.606.475	Zurich	Stuttgart	12	1.089.160	Oslo	Stockholm	12	1.889.400	Zurich	Munich	12	3.038.468	Oslo	Stockholm
13	1.543.392	Geneve	Paris	13	1.021.048	Zurich	Munich	13	1.880.157	Oslo	Stockholm	13	2.798.778	Basel	Paris
14	1.523.345	Basel	Paris	14	1.018.506	Vienna	Munich	14	1.761.079	Vienna	Munich	14	2.794.153	Bratislava	Vienna
15	1.462.756	London	Brussels	15	1.008.133	Stockholm	Helsinki	15	1.705.262	Stockholm	Helsinki	15	2.730.740	Zurich	Stuttgart
16	1.421.827	Vienna	Munich	16	996.662	Minsk	Kiev	16	1.607.914	Basel	Paris	16	2.710.775	Vienna	Munich
17	1.411.254	Zurich	Paris	17	973.435	Minsk	St. Petersb.	17	1.561.646	Geneve	Paris	17	2.603.471	Stockholm	Helsinki
18	1.360.575	Milano	Paris	18	942.460	Moscow	Stockholm	18	1.517.924	Zurich	Stuttgart	18	2.395.763	Milano	Paris
19	1.262.439	Paris	Copenhagen	19	922.970	Paris	Copenhagen	19	1.448.829	Milano	Paris	19	2.319.003	Geneve	Paris
20	1.239.671	Paris	Barcelona	20	904.416	Geneve	Paris	20	1.448.785	Moscow	Stockholm	20	2.309.431	Zurich	Paris
21	1.209.771	Stockholm	Helsinki	21	890.472	London	Copenhagen	21	1.439.334	Zurich	Paris	21	2.205.581	Rotterdam	Brussels
22	1.208.746	Oslo	Stockholm	22	885.722	Moscow	Helsinki	22	1.418.291	Minsk	St. Petersb.	22	2.174.403	Moscow	Stockholm
23	1.180.908	Paris	Munich	23	883.360	Helsinki	Tallinn	23	1.417.347	Minsk	Kiev	23	2.172.391	St. Petersb.	Stockholm
24	1.163.685	Hamburg	Copenhagen	24	855.046	St. Petersb.	Stockholm	24	1.408.704	Paris	Copenhagen	24	2.153.925	Paris	Munich
25	1.110.506	Berlin	Copenhagen	25	854.625	Basel	Paris	25	1.361.832	Paris	Munich	25	2.024.873	Lille	Brussels
26	1.107.663	Rotterdam	Brussels	26	838.264	Zurich	Paris	26	1.348.728	Helsinki	Tallinn	26	1.980.907	Minsk	St. Petersb.
27	1.076.720	Helsinki	Tallinn	27	834.310	Oslo	Copenhagen	27	1.336.042	St. Petersb.	Stockholm	27	1.930.207	Paris	Copenhagen
28	1.009.445	Paris	Frankfurt .	28	831.173	Milano	Paris	28	1.334.346	Moscow	Helsinki	28	1.927.937	Hamburg	Copenhagen
29	999.691	Oslo	Copenhagen	29	809.567	Paris	Munich	29	1.308.499	Rotterdam	Brussels	29	1.909.795	Moscow	Helsinki
30	995.963	Lille	Brussels	30	796.853	Zurich	Stuttgart	30	1.297.496	Oslo	Copenhagen	30	1.882.697	Moscow	London
31	985.766	London	Copenhagen	31	783.609	Hamburg	Copenhagen	31	1.260.009	Hamburg	Copenhagen	31	1.877.363	Paris	Barcelona
32	977.593	Paris	Stuttgart	32	780.902	Berlin	Copenhagen	32	1.258.557	London	Copenhagen	32	1.876.383	Berlin	Copenhagen

Train Cur				Train Div				Train Quo				Train Int			
33	968.844	Paris	Liege	33	777.943	Moscow	Paris	33	1.245.183	Berlin	Copenhagen	33	1.847.954	London	Amsterdam
34	931.424	Zurich	Milano	34	714.674	Rotterdam	Brussels	34	1.173.780	Moscow	Paris	34	1.846.959	Oslo	Copenhagen
35	929.579	Istanbul	Athens	35	712.166	Vienna	Budapest	35	1.142.531	Paris	Barcelona	35	1.843.417	Paris	Frankfurt .
36	910.000	Paris	Koeln	36	703.869	Istanbul	Athens	36	1.113.580	Vienna	Budapest	36	1.840.586	London	Copenhagen
37	908.003	Paris	Ruhrgebiet .	37	672.938	Moscow	London	37	1.104.968	Moscow	London	37	1.803.454	Amsterdam	Brussels
38	906.950	Paris	Dublin	38	654.745	Paris	Barcelona	38	1.102.275	Lille	Brussels	38	1.759.319	Helsinki	Tallinn
39	896.818	Minsk	St. Petersb.	39	635.271	Moscow	Copenhagen	39	1.081.104	Paris	Frankfurt .	39	1.711.625	Moscow	Paris
40	879.048	Moscow	Helsinki	40	615.566	Paris	Frankfurt.	40	1.066.958	Istanbul	Athens	40	1.704.762	Oslo	Goeteborg
41	871.458	Vienna	Budapest	41	614.353	London	Amsterdam	41	1.047.925	Amsterdam	Brussels	41	1.692.730	Paris	Ruhrgebiet
42	848.403	Amsterdam	Brussels	42	604.865	Kiev	St. Petersb.	42	1.037.639	Paris	Liege	42	1.649.737	Amsterdam	Paris
43	846.286	Amsterdam	Paris	43	586.128	Paris	Liege	43	1.011.726	London	Amsterdam	43	1.641.960	Paris	Stuttgart
44	844.751	St. Petersb.	Stockholm	44	572.386	Lille	Brussels	44	1.007.963	Oslo	Goeteborg	44	1.639.529	Istanbul	Athens
45	828.975	Minsk	Kiev	45	571.281	Oslo	Goeteborg	45	987.395	Paris	Ruhrgebiet	45	1.629.258	Zurich	Milano
46	820.092	Moscow	Stockholm	46	569.879	Paris	Stuttgart	46	986.842	Paris	Stuttgart	46	1.626.978	Minsk	Kiev
47	818.189	Paris	Berlin	47	564.811	Amsterdam	Brussels	47	963.999	Amsterdam	Paris	47	1.606.351	Paris	Koeln
48	815.121	Moscow	Paris	48	560.598	Paris	Ruhrgebiet)	48	956.780	Vienna	Berlin	48	1.588.882	Paris	Liege
49	814.916	Paris	Madrid	49	557.826	Paris	Dublin	49	936.378	Stockholm	Paris	49	1.560.122	London	Rotterdam
50	813.320	Vienna	Berlin	50	552.733	Stockholm	Paris	50	934.029	Paris	Koeln	50	1.547.643	Vienna	Berlin
51	801.421	Rotterdam	Paris	51	551.834	Sarajevo	Belgrade	51	928.056	Zurich	Milano	51	1.520.247	Vienna	Budapest
52	800.484	Oslo	Goeteborg	52	544.415	Vienna	Prague	52	896.145	Paris	Berlin	52	1.507.487	London	Lille
53	791.894	Paris	Hamburg	53	542.063	Amsterdam	Paris	53	879.827	Moscow	Copenhagen	53	1.489.467	Paris	Berlin
54	776.289	London	Amsterdam	54	536.628	London	Rotterdam	54	876.630	Kiev	St. Petersb.	54	1.463.432	Rotterdam	Paris
55	753.364	Rome	Paris	55	535.826	Vienna	Berlin	55	873.088	Rotterdam	Paris	55	1.456.495	Stockholm	Paris
56	716.456	Ankara	Athens	56	535.081	London	Stockholm	56	872.077	London	Rotterdam	56	1.448.330	Paris	Madrid
57	700.252	Stockholm	Paris	57	529.927	Paris	Koeln	57	860.502	Vienna	Prague	57	1.413.526	Paris	Hamburg
58	699.643	London	Rotterdam	58	515.867	Paris	Berlin	58	850.897	Paris	Dublin	58	1.393.648	London	Stockholm
59	689.969	Vienna	Paris	59	515.599	Zurich	Milano	59	839.429	London	Stockholm	59	1.354.416	Rome	Paris
60	670.451	Moscow	London	60	505.888	Oslo	London	60	837.571	Paris	Hamburg	60	1.330.129	Oslo	London
61	662.049	London	Lille	61	503.277	Vienna	Paris	61	807.464	Vienna	Paris	61	1.278.645	London	Hamburg
62	653.177	Zurich	Frankfurt	62				62	795.233	Oslo	Paris	62	1.268.429	Moscow	Ankara
63	643.530	Milano	Munich	63				63	794.352	Rome	Paris	63	1.254.693	Milano	Munich

Appendix G: Connections

ID	Source	Target	TT	TT_{mod}	f_a	Transf	level	Name	pattern	f_n	TT_{dis}
1	Amsterdam	Paris	198	183	11		HST	Thalys	day	11	19
2	Amsterdam	Lille	155	117	2		HST	Thalys	day	2	105
3	Koeln	Paris	196	170	5		HST	Thalys	day	5	42
4	Brussels	Paris	82	116	2		HST	Thalys	hour	28	7,5
5	Brussels	London	126	127	10		HST	Eurostar	day	10	21
6	Brussels	Basel	472	267	2		IC+	EuroCity	day	2	105
7	Brussels	Luxemburg	207	147	1		IC	Intercity	hour	14	15
8	Liege	Luxemburg	154	117	0,5		IC	Intercity	hour	7	30
9	Brussels	Frankfurt am Main	173	124	4		HST	ICE	day	4	52,5
10	Brussels	Marseille	321	317	3		HST	TGV	day	3	70
11	Brussels	Nice	501	422	1		HST	TGV	day	1	210
12	Brussels	Lyon	217	229	1		HST	TGV	day	1	210
13	Sofia	Budapest	1280	419	1		Night	Night	day	1	210
14	Bucharest	Istanbul	1155	332	1		Night	Night	day	1	210
15	Sofia	Istanbul	770	330	1		Night	Night	day	1	210
16	Sofia	Belgrade	2006	225	1		Night	Night	day	1	210
17	Sofia	Thessaloniki	441	164	1		IC	Intercity	day	1	210
18	Sofia	Bucharest	557	201	1		IC	Intercity	day	1	210
19	Hamburg	Copenhagen	287	274	4		IC+	ICE	day	4	52,5
20	Hamburg	Arhus	260	211	1		IC+	ICE	day	1	210
21	Berlin	Arhus	402	334	1		IC+	ICE	day	1	210
22	Copenhagen	Stockholm	303	350	5		IC+	X2000	day	5	42
23	Amsterdam	Frankfurt am Main	230	191	6		HST	ICE	day	6	35
24	Amsterdam	Basel	402	334	1		HST	ICE	day	1	210
25	Hamburg	Innsbruck	615	298	1		HST	ICE	day	1	210
26	Vienna	Frankfurt am Main	407	364	3		HST	ICE	day	3	70
27	Vienna	Ruhrgebiet (Essen)	609	450	1		HST	ICE	day	1	210
28	Vienna	Hamburg	587	435	1		HST	ICE	day	1	210
29	Basel	Berlin	432	376	4		HST	ICE	day	4	52,5
30	Basel	Hamburg	410	333	1		HST	ICE	day	1	210
31	Zurich	Hamburg	472	340	10		HST	ICE	day	10	21
32	Zurich	Frankfurt am Main	235	185	1		HST	ICE	day	1	210
33	Paris	Frankfurt am Main	230	220	5		HST	TGV	day	5	42
34	Paris	Stuttgart	225	225	3		HST	TGV	day	3	70
35	Paris	Munich	311	343	1		HST	TGV	day	1	210
36	Karlsruhe	Paris	182	185	1		HST	TGV	day	1	210
37	Berlin	Warsaw	328	348	4		IC+	EuroCity	day	4	52,5
38	Munich	Zagreb	436	297	2		IC+	EuroCity	day	2	105
39	Munich	Villach	265	170	4		IC+	EuroCity	day	4	52,5
40	Munich	Bologna	389	269	2		IC+	EuroCity	day	2	105

ID	Source	Target	TT	TT_{mod}	f_a	Transf	level	Name	pattern	f_n	TT_{dis}
41	Munich	Venice	388	266	1		IC+	EuroCity	day	1	210
42	Munich	Verona	317	204	2		IC+	EuroCity	day	2	105
43	Munich	Innsbruck	105	71	1		IC+	EuroCity	day	1	210
44	Munich	Zurich	254	164	4		IC+	EuroCity	day	4	52,5
45	Linz	Frankfurt am Main	320	313	1		IC+	EuroCity	day	1	210
46	Hamburg	Budapest	847	562	2		IC+	EuroCity	day	2	105
47	Berlin	Budapest	709	539	2		IC+	EuroCity	day	2	105
48	Berlin	Bratislava	543	437	1		IC+	EuroCity	day	1	210
49	Berlin	Prague	233	209	2		IC+	EuroCity	day	2	105
50	Munich	Budapest	423	335	5		IC+	RailJet	day	5	42
51	Munich	Vienna	241	208	2		IC+	RailJet	day	2	105
52	Stuttgart	Zurich	180	114	6		IC	Intercity	day	6	35
53	Berlin	Amsterdam	386	319	6		IC	Intercity	day	6	35
54	Munich	Rome	734	365	1		Night	Night	day	1	210
55	Munich	Milano	724	264	1		Night	Night	day	1	210
56	Munich	Amsterdam	610	351	1		Night	Night	day	1	210
57	Zurich	Amsterdam	741	356	1		Night	Night	day	1	210
58	Ruhrgebiet (Essen)	Prague	649	361	1		Night	Night	day	1	210
59	Ruhrgebiet (Essen)	Warsaw	652	540	1		Night	Night	day	1	210
60	Berlin	Zurich	663	383	1		Night	Night	day	1	210
61	Prague	Zurich	887	350	1		Night	Night	day	1	210
62	Paris	London	141	167	16		HST	Eurostar	day	16	13
63	Marseille	London	470	368	1		HST	Eurostar	day	1	210
64	Paris	Koeln	196	170	2		HST	Thalys	day	2	105
65	Paris	Ruhrgebiet (Essen)	277	214	3		HST	Thalys	day	3	70
66	Paris	Zurich	243	231			HST	TGV	day	0	0
67	Paris	Geneve	192	209	12		HST	TGV	day	12	17,5
68	Geneve	Nice	383	273	1		HST	TGV	day	1	210
69	Frankfurt am Main	Marseille	463	421	1		HST	TGV	day	1	210
70	Paris	Barcelona	381	362	2		HST	TGV	day	2	105
71	Lyon	Barcelona	498	233	1		HST	TGV	day	1	210
72	Marseille	Madrid	475	363	1		HST	TGV	day	1	210
73	Toulouse	Barcelona	210	166	1		HST	TGV	day	1	210
74	Paris	Biarritz	315	363	1		HST	TGV	day	1	210
75	Milano	Nice	290	182	2		IC+	EuroCity	day	2	105
76	Milano	Marseille	452	275	1		IC+	EuroCity	day	1	210
77	Paris	Venice	864	457	1		Night	Night	day	1	210
78	Belgrade	Thessaloniki	917	357	1		Night	Night	day	1	210
79	Vienna	Belgrade	691	347	1		IC+	EuroCity	day	1	210
80	Budapest	Ljubljana	479	251	1		IC+	EuroCity	day	1	210
81	Budapest	Kosice	255	312	2		IC+	EuroCity	day	2	105
82	Budapest	Prague	403	364	3		IC+	EuroCity	day	3	70
83	Budapest	Brno	251	222	1		IC+	EuroCity	day	1	210
84	Vienna	Budapest	143	157	2		IC+	EuroCity	day	2	105
85	Budapest	Zurich	675	471	1		IC+	RailJet	day	1	210

ID	Source	Target	TT	TT_{mod}	f_a	Transf	level	Name	pattern	f_n	TT_{dis}
86	Budapest	Salzburg	311	253	1		IC+	RailJet	day	1	210
87	Budapest	Cluj-Napoca	371	240	1		IC	Intercity	day	1	210
88	Budapest	Bucharest	880	421	2		IC	Intercity	day	2	105
89	Budapest	Timisoara	306	167	1		IC	Intercity	day	1	210
90	Budapest	Zagreb	59	202	2		IC	Intercity	day	2	105
91	Budapest	Belgrade	477	216	1		IC	Intercity	day	1	210
92	Budapest	Sofia	1351	419	1		Night	Night	day	1	210
93	Vienna	Bucharest	1133	552	1		Night	Night	day	1	210
94	Budapest	Warsaw	687	558	1		Night	Night	day	1	210
95	Budapest	Krakow	584	427	1		Night	Night	day	1	210
96	Zurich	Milano	243	145	0,5		IC+	EuroCity	hour	7	30
97	Basel	Milano	246	191	3		IC+	EuroCity	day	3	70
98	Geneve	Milano	240	161	4		IC+	EuroCity	day	4	52,5
99	Milano	Vienna	763	402	1		Night	Night	day	1	210
100	Villach	Zagreb	249	127	1		IC	Intercity	day	1	210
101	Luxemburg	Paris	131	160	7		HST	TGV	day	7	30
102	Amsterdam	Brussels	197	87	1		IC+	Intercity	hour	14	15
103	Vienna	Ljubljana	373	191	1		IC+	EuroCity	day	1	210
104	Zurich	Graz	574	381	1		IC+	EuroCity	day	1	210
105	Innsbruck	Ruhrgebiet (Essen)	632	313	1		IC	Intercity	day	1	210
106	Vienna	Warsaw	441	431	0,6		IC+	EuroCity	day	0,43	490
107	Prague	Warsaw	480	398	3		IC+	EuroCity	day	3	70
108	Vienna	Krakow	498	300	1		Night	Night	day	1	210
109	Krakow	Prague	535	267	1		Night	Night	day	1	210
110	Madrid	Lisbon	2080	377	1		Night	Night	day	1	210
111	Villach	Ljubljana	100	56	1		IC	Intercity	day	1	210
112	Zurich	Zagreb	845	433	1		Night	Night	day	1	210
113	Prague	Kosice	480	347	5		IC+	X2000	day	5	42
114	Lisbon	Biarritz	2222	534	2		Night	Night	day	2	105
115	Oslo	Stockholm	302	275	1		IC+	X2000	day	1	210
116	Oslo	Goeteborg	222	190	4		IC+	X2000	day	4	52,5
117	Paris	Moscow	2610	1414	0,6		Night	Night	day	0,43	490
118	Nice	Moscow	2897	1657	0,2		Night	Night	day	0,14	1470
119	Helsinki	St. Petersburg	204	207	3		IC+	X2000	day	3	70
120	Gent	Lille	74	57	1		IC	Intercity	hour	14	15
121	Saarbruecken	Dresden	415	364	1		HST	ICE	day	1	210
122	Saarbruecken	Paris	108	128	5		HST	ICE	day	5	42
123	Goeteborg	Copenhagen	151	174	0,33		IC+	X2000	hour	4,62	45
124	Dublin	Holyhead	120	142	4		Ferry	Ferry	day	4	52,5
125	Strasbourg	Basel	78	86	1		Regio	Regio	hour	14	15
126	Strasbourg	Saarbruecken	102	63	0,25		Regio	Regio	hour	3,5	60
127	Stockholm	Helsinki	960	267	2		Ferry	Ferry	day	2	105
128	Eindhoven	Duesseldorf	101	67	1	1	Regio	Regio	hour	14	15
129	Kiev	Minsk	684	282	1		IC	Intercity	day	1	210
130	Eindhoven	Aachen	90	61	1	2	Regio	Regio	hour	14	15
131	Helsinki	Tallinn	100	124	16		Ferry	Ferry	day	16	13

ID	Source	Target	TT	TT_{mod}	f_a	Transf	level	Name	pattern	f_n	TT_{dis}
132	**Minsk**	**Vilnius**	155	130	5		Regio	Regio	day	5	42
133	**Geneve**	**Grenoble**	130	88	0,25		Regio	Regio	hour	3,5	60
134	**Utrecht**	**Ruhrgebiet (Essen)**	83	105	0,25		IC+	ICE	hour	3,5	60
135	**belgrade**	**ljubljana**	591	311	1		Night	Night	day	1	210
136	**Vigo**	**Porto**	136	77	3		IC	Intercity	day	3	70
137	**Igoumenitsa**	**Bari**	540	420	2		Ferry	Ferry	day	2	105
138	**Patra**	**Bari**	930	643	2		Ferry	Ferry	day	2	105
139	**Riga**	**Stockholm**	1020	536	2		Ferry	Ferry	day	2	105
140	**Bucharest**	**Plovdiv**	1426	186	1	1	Regio	Regio	day	1	210
141	**Cluj-Napoca**	**Sofia**	1215	302	3	1	Regio	Regio	day	3	70
142	**Lviv**	**Rzeszow**	286	97	0,8	1	Regio	Regio	day	0,57	368
143	**Stockholm**	**Tallinn**	1050	361	2		Ferry	Ferry	day	2	105
144	**Chisinau**	**Bucharest**	579	233	1		Regio	Regio	day	1	210
145	**Chisinau**	**Iasi**	320	80	3	1	Regio	Regio	day	3	70
146	**Timisoara**	**Cluj-Napoca**	360	142	3		Regio	Regio	day	3	70
147	**Kiev**	**Warsaw**	1020	459	2		IC	Intercity	day	2	105
148	**Kaliningrad**	**moscow**	1134	719	1		IC	Intercity	day	1	210
149	**Warsaw**	**Vilnius**	780	267	0,6	2	Regio	Regio	day	0,43	490
150	**Biarritz**	**Zaragoza**	364	147	0,25		IC	Intercity	hour	3,5	60
151	**Eindhoven**	**Liege**	109	67	1	1	Regio	Regio	hour	14	15
152	**Kosice**	**Cluj-Napoca**	923	194	1	5	Regio	Regio	day	1	210
153	**Skopje**	**Thessaloniki**	1704	138	1		Night	night	day	1	210
154	**Podgorica**	**Belgrade**	614	190	1		Regio	Regio	day	1	210
155	**Kiev**	**Iasi**	1033	277	1	1	IC	Intercity	day	1	210
156	**Timisoara**	**Belgrade**	293	84	3	1	Regio	Regio	day	3	70
157	**Linz**	**Prague**	295	194	2		Regio	Regio	day	2	105
158	**Skopje**	**Pristina**	180	68	2		Regio	Regio	day	2	105
159	**Vienna**	**Venice**	459	286	2		IC+	EuroCity	day	2	105
160	**Aalborg**	**Oslo**	510	251	1	1	Ferry	Ferry	day	1	210
161	**Wroclaw**	**Dresden**	240	164	1	1	Regio	Regio	day	1	210
162	**Sarajevo**	**Zagreb**	532	194	1		Regio	Regio	day	1	210
163	**Belfast**	**Dublin**	125	99	8		IC+	EuroCity	day	8	26,25
164	**Minsk**	**St. Petersburg**	770	438	2		IC	Intercity	day	2	105
165	**St. Petersburg**	**Tallinn**	382	213	1		IC	Intercity	day	1	210
166	**Vienna**	**Zagreb**	392	198	1		IC+	Intercity	day	1	210
167	**Aalborg**	**Goeteborg**	305	111	4	1	Ferry	Ferry	day	4	52,5
168	**Eindhoven**	**Antwerpen**	82	58	1	2	Regio	Regio	hour	14	15
169	**Kiev**	**budapest**	1295	577	4	3	Regio	Regio	day	4	52,5
170	**Kiev**	**chisinau**	977	334	2		IC	Intercity	day	2	105
171	**Cluj-Napoca**	**Chisinau**	914	267	0,6	1	IC	Intercity	day	0,43	490
172	**Prague**	**Moscow**	1731	1088	1		Night	Night	day	1	210
173	**Amsterdam**	**Rotterdam**	41	34	32		IC	Intercity	day	32	6,6
174	**Kiev**	**Moscow**	748	476	0,25		IC	Intercity	hour	3,5	60
175	**Bratislava**	**Vienna**	60	55	1		Regio	Regio	hour	14	15