Multi-scale assessment of intermodal freight networks in Europe: geo-spatial approach

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Multi-scale assessment of intermodal freight networks (European vs. national interest) geo-spatial approach

by

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Thesis submitted to the University of Twente, faculty ITC, in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation for Environmental Modelling and Management

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Abstract

The successful integration within the European Union could only be achieved when the sustainable trans-European transport is provided. It will increase the mobility across the EU and provide the high competitiveness of the European market on a global scale. Although the proposed TEN-T plan for implementation seeks to achieve these goals there are however several challenges which slow it down. One of such a challenge is seen in a spatial mismatch which occurs between the proposed TEN-T and the real state of transport in Europe being the main focus of the thesis.

The research method used includes the combination of remote sensing, network analysis, trip distribution and allocation techniques. First, the travel attraction patterns were assessed using the nighttime lights imagery acquired from DMSP-OLS. The implementation of the Network Analysis drew the possible connection along the proposed trans-European networks with the implicated impedance. After the completion of travel generation exercise the trip distribution assessment based on the Gravity method was executed. Next, the results were incorporated into the line features which represent the routes across the TEN-T and the reference network. Finally, the spatial mismatch assessment by NUTS2 level region using the intersection function was done which allowed identifying possible missing links in the evaluated networks.

The acquired results identified medium to strong spatial mismatch between the proposed TEN-Ts and the reference-based network which points out the imperfectness of the trans-European networks to be introduced. The problem of spatial mismatch is rather universal across the EU space being referred to the capacity problems in the centrally central congested regions and the infrastructure shortages in the remote regions. It was recommended to initiate the official evaluation of the current TEN-T plan in order to decrease the detected spatial isolation of some urban areas and improve the connectivity of the proposed routes.

Keywords: EU, TEN-T plan, rail, road, network, spatial mismatch assessment, nighttime lights, gravity model.

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Table of contents

List of figures

List of tables

List of acronyms

DN	Digital number
DMSP-OLS	Defense Meteorological Satellite Program Operational Linescan System
EEA	European Economic Area
EFTA	European Free Trade Union
ERTS1989	European Terrestrial Reference System 1989
EU	European Union
G8	The Group of Eight
GDP	Gross Domestic Product
GIS	Geographical Information System
LUZ	Larger Urban Zone
OD	Origin-Destination
NGDC	National Geophysical Data Center
NUTS	Nomenclature of Territorial Units for Statistics
TEN-T	Trans-European Network Transport
TEN-T EA	Trans-European Network Transport Executive Agency
UN	United Nations
UNECE	United Nations Economic Committee for Europe

1. Introduction

The EU being one of the most important trade and political Union of the states in the world seeks to achieve the high level of economical integration based on the introduced open market between its member states. Such an achievement could not be seen without one common transport system which provides cheap, fast and reliable services across the European space for movements of goods and passengers making each member state and their citizen benefit out of being in the Union. Hence the EU proposed an ambitious plan for implementation of Trans-European transport networks which included most of the commonly used transport modes and covered the area of all the EU member states. However the desired expectations were achieved neither in time nor in space facing unexpected problems of various backgrounds. Thus, the proposed TEN-T plan needs to be evaluated in order to find the weak points and correct them if possible.

1.1. Background and significance

The first attempts to establish the common European space were done soon after the Second World War emerged from the idea to unite Germany and France followed by the European Union was officially introduced by the Treaty of Rome singed by seven European states in 1957 and has passed several organisational, structural and territorial changes.

The ongoing integration process in the EU is based on the comprehensive and harmonious development of social, economical, political and cultural life of its member states. Economical development and integration has been initially prioritised in the EU as the sector which directly benefits the society being a starting point for further integration after Second World War in Europe. The European Commission being the main executive body of the European Union kept on declaring a great European success across the member states for more than 50 years although by the end of 1980s a number of serious economical (and hence integration) problems became evident. By 1990 the underdevelopment of common transportation system within the EU was officially considered as the key constraint slowing down the economical development and integration (European Commission, 1990). The transport networks are the circulatory system of the Economy which implies that without sustainable and effective transport system the integration effects will be minimised and distorted. Thus, it is vitally important for the EU to develop the consistent and integrated pan-European transport system which will increase the mobility, economical efficiency and decrease the environmental impacts on the European continent (European Commission, 2006).

By the end of 1980s the role of transport and infrastructure in general were considered undeniably important for the development on the global and European scales. Hence a new corridor-based concept of global and transcontinental transportation linkages was adopted by the UN and the UNECE. Moreover it forced the European Commission to elaborate the first paper on a new vision of transportation development within the EU (European Commission, 1990) based on the TEN-T. It had indicated the first great success since the Rome Treaty of 1957 and TEN concept definition.

1.1.1. Towards common EU transport policy and TENs

The Maastricht Treaty of 1992 which had legally transformed the EU to its present form was followed by the number of important Programmes among which the White Paper on Transport development was adopted (European Commission, 1992). It included the list of 14 priority projects of European importance to be completed by 2000 which had placed the White paper as the significance policy tool in the EU for the coming 10-year period. Furthermore the paper had its strong methodological influence on the future of the transport, economy and environment in the EU providing with the main concepts of the transport of the 21st century. The sustainable transport was aimed to maintain the economic growth by increasing the mobility, effectiveness and "greenness" which would benefit both the society and Environment.

The concept of intermodality was introduced as the most important methodological approach to achieve the goals of the Policy and practically as an effective treatment to the current transportation problems which the EU was faced with in the beginning of 1990s. The most general definition of intermodality is the technology of transporting the cargo and passengers by at least two modes of transport (UNECE, 2009). The combination and number of modes might vary but the main purpose of the paper was to provide the conditions for rail-road and water-road intermodal connections in order to decrease the influence of road transport in the transportation distribution between modes and hence to contribute the air pollution decrease and Environment "greenness" (European Commission, 1992).

The first 9 years of the Programme showed the initial overestimation of the integration process' speed and underestimation of the emerged constraints in their complexity. In fact the White paper remained an optimistic forecast of the EU transportation future instead of being a real Agenda for implementation (Sichelschmidt, 1999). As a result the 2nd edition of the White paper was created in

2001 in order to eliminate the shortages of the previous version and provide the member states with more coherent and real to implement Policy (European Commission, 2001). The intermodal networks and their components were defined and mapped: rail, road, inland and sea waterways, and airports. The TEN-T was reassessed and improved setting already 30 priority projects to be completed by 2010 referred to the networks optimisation and combined transport development. In the mid-term the White paper was revised and reassessed in order to evaluate the achieved progress as well as to integrate new EU members into the current prospective (European Commission, 2006). The main result was quite critical and indicated almost 20 years of successful paper work with much more modest results in practice.

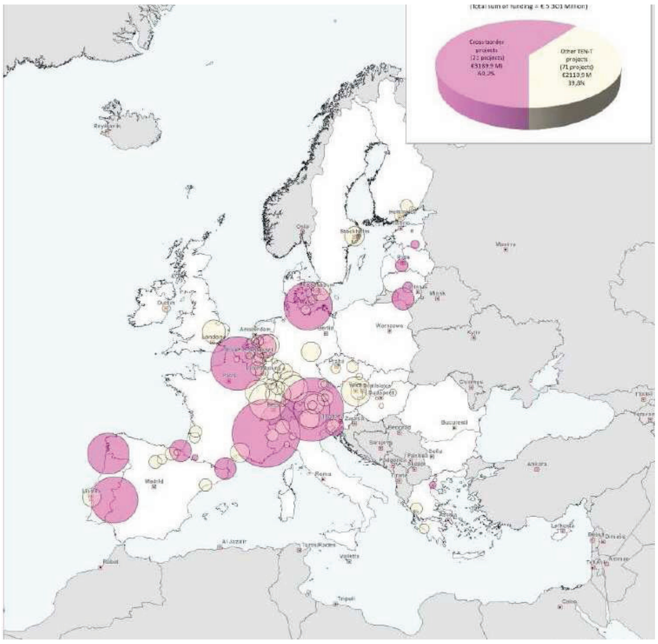


Figure 1. TEN-T 2007 – 2013 mid-term review (TEN-T EA, 2010).

The mid-term review (European Commission, 2010) presented by the European Commission points out the financial problems faced during White paper goals implementation and delays many projects for the 2015 – 2020 perspective (figure 1). This implies that despite the attempts to improve the project management and decrease the environmental threats the overall progress development speed remains unchanged.

One of the main reasons for such a failure is related to the lack of national transport programmes component in the EU policies (Vieira, 2007). Current TEN-Ts represent rather general idea on how to trace the route and the direction with a wide swath instead of precise plan for implementation. Moreover the spatial content is missing in the majority of the projects narrowing the planning of the route to the costs-benefit analysis and economical methods of assessment. Another important drawback refers to the EIA and SEA which are usually done on the regional or national level instead of one universal European approach which does not currently exist. Oppositely European intermodal networks proposed in Brussels are lacking the spatial component on the national and regional scale being traced with high level of approximation and "cut off" the real ground. Hence, the multi-scale assessment should be implemented to the projects in order to increase their efficiency and applicability.

Other important constraints refer to the methodological concept of the intermodal network structure and modes included. According to the UNECE recommendation all the modes of transport should be included in the intermodal scheme but practically only 2 – 3 modes maximum are taken into consideration by the companies and researches which distorts the real-scale picture and shortens the additional opportunities for optimisation. Furthermore the existing research experience implementation is directly applied for the nodes of the network (intermodal terminals) which are considered as weak point of the system influencing the traffic dramatically (EIRAC-SIRA, 2005). However the lines of the network are somehow neglected in the research which leads to the investment distortion. The majority of the EU policies on intermodality are shifted to new intermodal terminals' construction and work optimisation of the existing ones. However the improvements of linear elements of intermodal networks should be equally important in order to provide the sustainable development of the networks and their harmonised development without distortions and overloads.

1.1.2. Modern transport methods and techniques

The history of transport planning development could be followed within the human progress in transport achieved. The more complicated the means of communication got the more planning activities involvements occurred. They tended to be increased in complexity and spatial coverage. The rapid evolution and conceptualisation of transport planning occurred after the Second World War when both computation and later visualisation were revolutionised along with the increase in need of highly comprehensive transport plans for the large-scale projects (Banister, 2005). These could be pictures with examples of the US highway network, Trans-European networks.

Since both transport and GIS are tightly linked with the concept of space and spatial interaction the GIS-applications became rapidly popular for transport planning purposes. GIS in general serves at least three purposes: data storage and managements, analysis and visualisation; which are interrelated and coincided. Obviously the network analysis and flow maps development could be the best example of GIS and transport planning integration and tool usage tandem. Apart from the technical side the visualisation in GIS-space seemed to be very attractive which benefited the proposed transport plans in terms of understanding and perception (Wang, 2004).

The remote sensing has become an important part of transport planning for the last 40 years. It passed through the evolution from a airborne photo which represents the current state of pace in a study area to a powerful tool subject to complex analysis and data extraction. Recently the growing interest to the nighttime lights imagery usage in socio-economic application could be observed (Ghosh, 2010). The first recorded lights date back to the beginning of 1970s. Since that time the image calibration and refining techniques were improved dramatically (Elvidge, 1999) which with the new generation of GIS software allowed to use nighttime lights as a proxy for urban areas identification (Small, 2005), land-cover change detection (Imhoff, 1997), energy consumption assessment in the remote areas (Amaral, 2005). All those studies referred to the high correlation between the nighttime lights intensity and several socio-economic indicators (e.g. GDP, Ghosh, 2010).

Some of the currently used methods came to the transport planning from physics like the Gravity method. It is based on the Newton gravity law which referred to the interaction between bodies being the function of their weights and the distance (in fact the reversed and squared) between them. It does also fulfil W. Tobler's law which stresses on the spatial interaction which occurs more within the closely located objects (Banister, 2005). This gravity law's benefits were easily incorporated into the four-stage classical transport model being used for the trip distribution assessment task (Zuidgeest, 2011). This model type also found its implementation in a large-scale strategic transport plan for the European motorways (Fournier, 1994).

The spatial mismatch assessment is a rather novel approach and not yet very well developed. Among the recent findings the study developed by Rouwette (2005) could be noted. The development of so-called "Cycle through" method for the non-motorised transport done in Tanzania seems to be interesting for implementation of missing links identification and network imperfectness assessment. The commonly used in planning zoning approached was successfully combined with the network analysis task giving the proxy estimation for the real-based flows and the desired ones built on the shortest-path distance reference network execution.

The current state of the transport planning is described by the high level of project complexity and the scalar variations (from local to global). However the implementation of wise range of methods and techniques developed within transport planning, geography and GIS as well as borrowed from other sciences are seen as the comprehensive solution for such complexity to be faced with. Finally, the proper and efficient combination of selected methods would increase the quality of the results and simplify the work to be done.

1.2. Research problem

The proposed TEN-Ts are expected to improve the current transport networks in Europe significantly by increasing the speed and volumes of freight movement, decreasing the time and distance of travel. Even though the on-going TEN-T plan for implementation adopted by the EU is more than 50% complete and expected to increase the mobility and transport efficiency across the member states there is still a place for arbitrary judgements done on some projects and dramatic spatial mismatch neglecting for some regions. Hence the research problem of the thesis is to elaborate and to implement the coherent methodology of multi-scale geo-spatial assessment of the proposed TEN-T intermodal networks on the large scale for the spatial deficiencies identification.

1.3. Research objectives

Based on the identified research problem several research objectives could be stated where the general objective is supported and described by the specific ones.

1.3.1. General objective

One of the main spatial deficiencies being typical for the large geographical scale is the low proximity of the planned lines to the desired ones. Hence, the general objective of this study is to evaluate and map the spatial mismatch of the proposed Trans-European Transport Networks (rail and road) to the reference network built for rail and road modes respectively.

1.3.2. Specific objectives

The proposed general objective is expanded by the specific objectives stated below:

To estimate freight attractiveness of selected LUZs.

To model the trip generation across the EU based on identified and mapped proposed TEN-Ts.

To model trip distribution across the EU with the respect to selected ODs and networks.

To quantify and map the spatial mismatch of proposed TEN-T rail and road and Euclidian-based network.

To suggest possible network design improvements for rail and road TEN-T based on the conducted research.

1.4. Research questions

The operationalisation of the objectives is presented by the set of research questions:

How can nighttime lights imagery be used for LUZs travel attraction assessment? How to quantify and extract gross light intensity for LUZ in a consistent manner?

Which features should be used as origins and destinations? Which impedance should be used for trip generation modelling?

Which method is applicable for trip distribution modelling on a large scale? What can be used as a reference network for the desired traffic flows assessment?

Shall we split the desired lines computation for rail and road networks?

How to quantify and interpret the spatial mismatch of the network? How the expected qualitative changes will affect the spatial mismatch?

How to identify the missing links? Which routing alternatives could be suggested?

1.5. Research Hypotheses

The main scope of the proposed research refers to the spatial mismatch of the proposed and desired transport networks identification. Hence it is important methodologically and practically to prove or disprove its occurrence in general. Based on the elaborated research objectives and questions there are several hypotheses stated:

Hypothesis 1

H_0: Under 0.95 confidence level LUZ nighttime lights produced are significantly related with LUZ total tonnages per selected transport modes (rail and road).

H_1: LUZ nighttime lights produced are not significantly related with total tonnages per selected transport modes (rail and road).

Hypothesis 2

H_0: Under the proposed TEN-T there is a significant spatial mismatch with the adopted reference transport networks.

H_1: The spatial mismatch between the proposed TEN-T and desired transport networks is insignificant.

The first hypothesis refers to the role of nighttime lights satellite imagery in the socio-economic in general and transport research in particular. If H_0 will be proved then these imagery could be used a reliable data source for transport research. Otherwise it implies that such data source is unsuitable for transport research. The second hypothesis refers to the proposed TEN-T effectiveness with the respect to constant model conditions. The zero hypothesis claims that the adopted TEN-T plan is not enough to reach the transport goals stated by the EU the whilst the alternative one claims that there is no or little spatial mismatch between TEN-T and desired networks

1.6. Research outline

The overall thesis was logically divided into five chapters as follows: Introduction, Study area description, Material and Methods, Results and Discussion and, finally, Conclusion and Recommendations.

Chapter 1 gives a brief introduction to the research topic explaining the background of common European transport policy, its elaboration and implementation. Moreover some large-scale transport planning issues, methods and concerns are explained as well as the previous scientific experience in a related field.

Chapter 2 represents some core physical, socio-economic and transport, in particular, characteristics of the study area, the European Union.

In chapter Chapter 3 the description of used spatial and attribute datasets is given along with the software. Research methodology, techniques and data analysis aspects are elaborated with the application to data acquired. Some data limitations and methods constraints are stated.

The results of nighttime lights satellite image processing, network analysis, gravity model and traffic assignment are presented in Chapter 4. Furthermore the spatial mismatch assessment is undertaken and visualised. The discussion part of the chapter is devoted to the results interpretation, pros and cons of method identification seeking for knowledge gaps and proposed improvement.

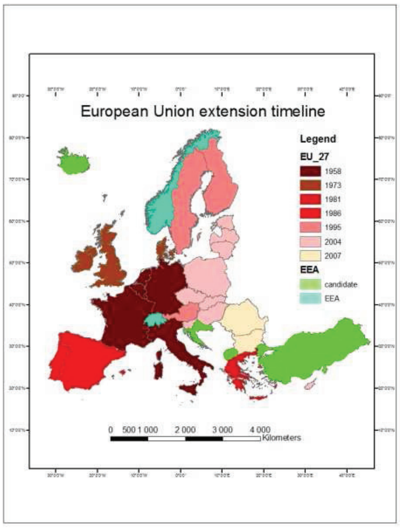
Chapter 5 represents the conclusions and recommendations based on the results of the research done.

2. Study area desctiption

The study area covers the entire European Union expect foreign departments of France and the Netherlands, Orkney Islands, Greenland, Canary and Azores Islands which do not participate in TEN-T. Being spatially aligned the areas of European microstates as well as Norway and Switzerland are included in order to form one common EU/EEA transport space. The countries with the official status of the EU candidate (Croatia, Macedonia, Turkey and Iceland) were not included due to the remoteness from the TEN-T (Iceland case) or the lack of attribute data (Croatia, Macedonia and Turkey case). The continuing TEN-T over the EU external borders were preserved as the rudiments of bigger TEM and TER networks and might be used for the further research within greater space if necessary.

2.1. General information

The EU is economical and political union of its member states. Since the last extension took place in 2004 it includes 27 Member states which account the majority of European continent states (figure 2). It is washed by the Atlantic Ocean and its seas in the West and South. European microstates (Vatican, Monaco, San-Marino, Andorra) as well as Switzerland are surrounded by the EU whilst some territories of the EU are situated outside of the continent (Canaries, Azores, Antilles, Reunion, Guiana etc.). Being a part of a larger EEA the EU borders with its members Lichtenstein, Norway and Iceland (by sea). In the South-East the EU has terrestrial borders with its candidate member states (Croatia, Macedonia and Turkey) and potential member states (Serbia) whilst in the East it has borders with Russia, Belarus, Ukraine and Moldova. Total area covered by the EU is equal to 4,324,782 km^2 which is slightly less than half of the size of the USA. Total population of the EU recently exceeded 500 million inhabitants making it the 3rd largest in the world after China and India. Three official capitals of the EU are Brussels, Strasbourg and Luxembourg located close by Germany-France-Benelux triangle. The member states of the EU forms a single market and ensures the free movement of people, goods, services and capital across its space united by Schengen passport agreement.



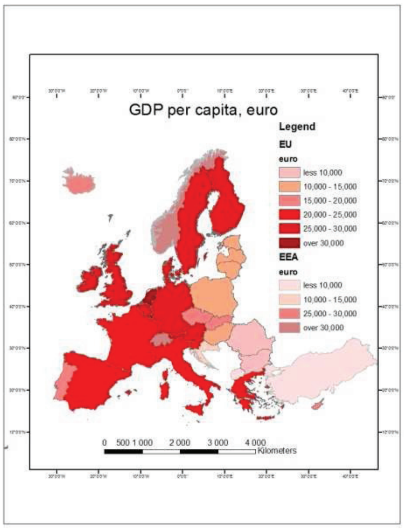


Figure 2. The EU entry timeline map. Figure 3. GDP per capita in 2010, euro.

2.2. Socio-economic statistics

The EU represents the greatest economic power in the world having a GDP of 11.03 trillion euro (21%) and followed by the USA and China. It accounts 20% of global trade. Out of 27 EU member states four (Germany, France, UK and Italy) are the part of G8 organisation ranked in top-10 economies of the world. 17 EU member states are united by the common currency use – euro. Though the EU is generally a strong economical power of highly developed countries there are several economic variations on the national and regional levels could be discovered (figure 3). EU average GDP per capita is around 24500 euros whilst the difference between the highest (Luxembourg) and the lowest (Romania) values is over 52,000 euros (7 times) which the economics mosaic rather complicated and regionalised. On the one hand we have rich and very rich states located in the North and West, on the other hand we have relatively poor states located on the South and East. Regional differences inside the member states might be even stronger, especially in the East.

After the credit crunch followed by global financial and economic crisis in 2008 the EU had 4% decrease of economy but recovered in 2010 showing 1.7% economic growth. Still some member states (Greece, Spain, Ireland) are facing the recession and economic decline caused by the crisis of 2008. The inflation rate in the EU is about 1.7% making it one of the smallest in the world. It is expected that the sustainable growth will continue across the EU in coming years though the national variations are still the case. The EU has over 225 million labour forces with 9.5% unemployment distributed by occupation: agriculture 5.6%, industry 27.7% and services 72.9%. Excluding intra-Union trade the EU accounts around 1.5 trillion euro exports and 1.4 trillion euro imports scoring the positive trade saldo.

2.3. Transport networks

The EU has highly developed modern transport system which covers the entire area and connects all member states, regions and cities (figure 4). It is a birthplace of many means of transport which had been intensively developed through centuries forming a highly dense, well-equipped transport network of various modes. Around 6,000,000 km of roads, 230,000 km of railways, 52,500 km of inland waterways, 3400 airports (2000 with paved runaways) and over 4,000 ports provide the EU with sustainable and reliable communication which enhances the economic integration and mobility. Different modes of transport occupy a specific position in the freight and passenger movement. Roads are the most common and easy accessible mean of communication which holds the majority of internal cargo and passenger flows followed by railways which recover their important role in the transport sector after a long decline, especially with high-speed passenger connections being developed. Inland waterways used to be the only reliable mean of communication long time ago but still play an important role in freight movement across the Rhine and the Danube basins. EU seaports are the gates for global trade and important intermodal hubs serving global export-import cargo flows. The biggest sea and combined ports rank in the top-20 of world busiest ports (Rotterdam, Antwerp, Hamburg). Same role but for passenger transport belongs to airports which serve the increasing inter-Union and external flights. The biggest airports are located in London, Paris, Amsterdam, Frankfurt-on-Main, Madrid being in the top-world busiest hubs.

The density of different transport networks varies from state to state reaching its maximum in a “blue banana” area and decreasing towards North and East. It is highly influenced by previous history on the European continent, different size of the states, population density and neighbourhood. The most notable example could be observed within the railway network which accounts at least four different track gauge widths across the network of common use: 1435 mm, 1520 mm (Finland and the Baltic States), 1600 mm (Ireland), 1668 mm (Spain and Portugal).

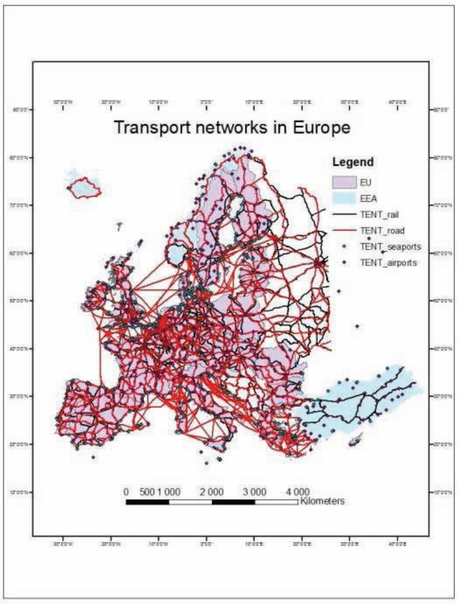


Figure 4. Transport networks in Europe.

3. Materials and methods

The following chapter is focused on the description of desired, required and downloaded data. A brief description of spatial and attribute data acquired is given and supported with examples. Due to the fact that inputs highly affect the analysis and results the statement on data accuracy is given. Moreover some data limitation factors and used software are mentioned. The overall methodology being developed is presented in this chapter with detailed explanation on data manipulations and steps made. The general workflow of the research could be seen on the figure 5. Some constraints faced during the data processing and analyses are expected to be identified and discussed in the next chapter.

3.1. Materials

In order to conduct the successful research it is required to obtain up to date, reliable and precise data. International statistical sources on transport are required to conduct sufficient research. The EU policy for openness and easy access to the information obliges its member states to inform the central bodies of the EU and Eurostat on a number of statistical parameters defined including the transportation. All national statistical departments are well-equipped and has unified interface in English which made it easy to reconsult some numbers or update information which was less recent in Eurostat databases if necessary.

In order to stratify the data required for the research there was developed a minimum dataset which included spatial and attribute datasets being enough to conduct the research under the worst case conditions on data availability and accessibility (table 1). The first dataset was necessary to estimate travel attraction proxy and was in open access. GeoTiff format is widely used, reliable and easy convertible when working with raster images. The next three datasets were required as a basic layers representing the urban areas, regions, states and their boundaries as well as providing the borders for the study area and being clip features. The datasets marked 5 to 9 represent the European intermodal network and its elements (by mode of transport) and serve as the linkages between major urban areas of the EU. Finally, 10 – 12 datasets were selected to provide general and specific attributes on a relevant scale (region, LUZ) or in a specific field (freight turnover).

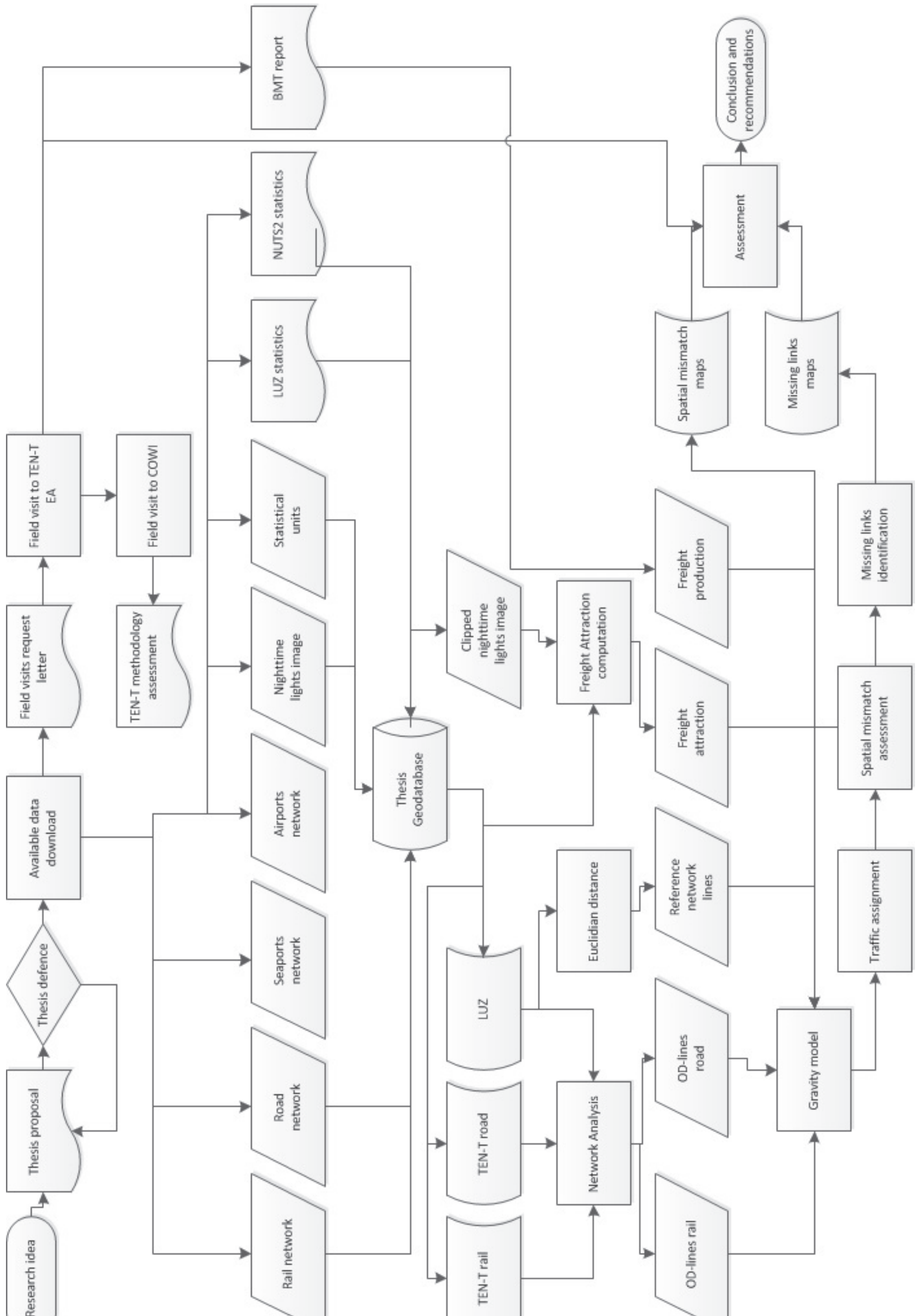


Figure 5. Research workflow.

Table 1. Minimum dataset required.

No.	Name	Format	Organisation
1.	Nighttime lights image	GeoTiff	NOAA-NGDC
2.	Boundaries (EU/EFTA, national, regional)	Line, .shp	Eurostat
3.	LUZ	Polygon, .shp	Eurostat
4.	EU/EEA/NUTS2	Polygon, .shp	Eurostat
5.	TEN-T rail network	Line, .shp	TEN-T EA
6.	TEN-T road network	Line, .shp	TEN-T EA
7.	TEN-T waterway network	Line, .shp	TEN-T EA
8.	Seaports	Points, .shp	TEN-T EA
9.	Airports	Points, .shp	TEN-T EA
10.	Rail and road annual turnover per LUZ, ton	Text tables	BMT Gmbh
11.	NUTS2 regional statistics	.csv tables	Eurostat
12.	Urban Audit data	.csv tables	Eurostat

3.1.1. Satellite data

In order to derive the attraction patterns for the gravity model radiance-calibrated clouds free nighttime lights satellite image produced by DMSP-OLS sensor is used. The DMSP satellites are using polar orbits making 14 rounds of data collection per day. OLS sensor has a swath of 3,000 km and sends the complete set of images twice a day. The image resolution is 30 arc seconds making a grid cell size approximately 1 km which is good enough to work on the continental (in our case European) scale. The used image avg_lights_x_pct F16_2009 was downloaded as a .zip archive from NDGC server in October 2010 for the time period 1 year, 2009 (figure 6).

Before being ready for download from NDGC the image was processed with automatic algorithms adopted identifying the best quality lights during the year time period (Croft, 1979). According to data provider the data composition was done based on the following criteria: absence of sun and moon light, solar glare contamination. The clouds were thermally detected and removed as well as auroral emissions. In order to get the best geolocation, reduce noise and sharpen the features the orbital swath was half centred.

The nighttime lights image is derived from the average visible band digital number (DN) of cloud-free light detections multiplied by the percent frequency of light detection. The inclusion of the percent frequency of detection term normalises the resulting digital values for variations in the persistence of lighting.

Figure 6. Fragment of acquired nighttime light satellite image (NGDC, 2009).

3.1.2. Spatial datasets

The basic spatial datasets containing the general geographical information about EU/EEA, NUTS2 and LUZ had to be acquired from Eurostat under GISCO project. The boundaries for the EU, EEA and candidate countries were acquired in one layer with NUTS 1 to 3 levels which means that they had to be sorted out and separated. Spatial data for LUZ was obtained separately. Both NUTS2 and LUZs were acquired as polygon-based layers containing the attribute table (figure 7).

Attributes of EU_27_urban_areas

OBJECTID 1	Shape *	Shape Length	Shape Area	OBJECTID	URAU LUZ I	CNTR CODE	LUZ NAME	NAME ASCI	NAME HTM	SHAPE Leng
1	Polygon	438963,284239	4567728115,16428	1	AT001L	AT	Vienna	Vienna	Vienna	5,036414
2	Polygon	208054,286043	1219842190,66712	2	AT002L	AT	Graz	Graz	Graz	2,329684
3	Polygon	291983,662886	1726439226,85294	3	AT003L	AT	Linz	Linz	Linz	3,348846
4	Polygon	283191,515464	1729004481,43042	4	AT004L	AT	Salzburg	Salzburg	Salzburg	3,224963
5	Polygon	218633,501344	2072646774,60465	5	AT005L	AT	Innsbruck	Innsbruck	Innsbruck	2,462699
11	Polygon	131914,727729	405674117,468799	11	BE006L	BE	Bruges	Bruges	Bruges	1,551271
10	Polygon	212192,875125	1045509156,1851	10	BE005L	BE	Liege	Liege	Liege	2,43642
9	Polygon	164693,65298	610973044,674675	9	BE004L	BE	Charleroi	Charleroi	Charleroi	1,916572
8	Polygon	130978,886368	531795595,786013	8	BE003L	BE	Gent	Ghent	Ghent	1,533147
12	Polygon	122083,400469	394960457,722811	12	BE007L	BE	Namur	Namur	Namur	1,45207
7	Polygon	178412,314466	932224553,902737	7	BE002L	BE	Antwerp	Antwerp	Antwerp	2,116828
6	Polygon	293015,515338	1603323333,09423	6	BE001L	BE	Brussels	Brussels	Brussels	3,493771
19	Polygon	143344,050643	515553597,638993	19	BG007L	BG	Vidin	Vidin	Vidin	1,573115
14	Polygon	190257,604646	1231517023,49069	14	BG002L	BG	Plovdiv	Plovdiv	Plovdiv	2,021401
18	Polygon	159022,21621	889351131,034873	18	BG006L	BG	Ruse	Ruse	Ruse	1,69657
17	Polygon	278566,350676	1788729679,41524	17	BG005L	BG	Pleven	Pleven	Pleven	3,01889
16	Polygon	265202,588754	1398423936,20943	16	BG004L	BG	Burgas	Burgas	Burgas	2,805518
15	Polygon	208712,090505	880141135,507739	15	BG003L	BG	Varna	Varna	Varna	2,201619
13	Polygon	343742,095872	3421059118,71907	13	BG001L	BG	Sofia	Sofia	Sofia	3,688267

Figure 7. Example of LUZs attribute table (Eurostat, 2006).

Due to the necessity for the EU regions unification Eurostat introduced the multi-level statistical sub-divisions for the member and candidate states called NUTS. It includes 3 levels of division and mainly based on the region's population though this rule is not applied rigidly. The NUTS1 level is the highest statistical division level which is represented by the regions with population of 3-7 mln inhabitants and do not necessarily present in all EU member states but rather in the biggest ones and account 115 units (figure 8). The best example of NUTS1 level units is the German bundesland system. NUTS2 level is occupied by middle-sized regions with the population of 0.8 – 3 mln inhabitants with a total number of 317 units (figure 9). The best example of NUTS2 units could be Polish voevodship system. The smallest statistical units are represented on NUTS3 level with 0.15 – 0.8 mln inhabitants (figure 10). One of good examples of NUTS3 regions is the Estonian maacond (districts) system. NUTS2 level was considered important for the research because of two reasons: there were more data available for the second level of administrative units; it is the most wide-spread type of administrative units across the EU.

Figure 8. NUTS1 level.

Figure 9. NUTS2 level.

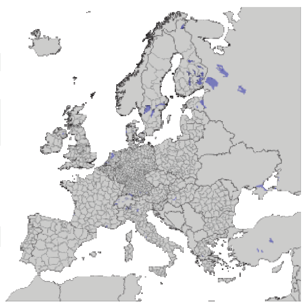


Figure 10. NUTS3 level.

In order to get inputs for Network Analysis and the analysis it was necessary to define a point-based layer with origins and destinations. Based on the data availability and spatial coverage it was decided to use LUZ acquired after Urban audit programme held by Eurostat in 2006. Unfortunately the data collected during 2010 Urban Audit campaign was not yet available which affected the exclusion of EU candidate states from the research. LUZs were introduced by Eurostat to reach the relative unification between widely ranged EU cities and somehow standardise the spatial definition of the city, urban area and metropolitan zone. Based on the Urban Audit 2006 definitions all 27 EU capitals, NUTS2 centres, urban areas with the population over 1 mln inhabitants were included into the selection. Despite Marseille, Lille and Montpellier were excluded from the data collection as not qualifying for new LUZ requirements all three cities were included in the research as important origin/destination points generating a significant traffic. Total of 309 LUZs were selected for this study as an input data for Network Analysis. The morphology of LUZ could be observed on the figure 11. The example of LUZ distribution across Benelux is given on the figure 12 with NUTS2 and cities borders added in order to get a relative size impression.

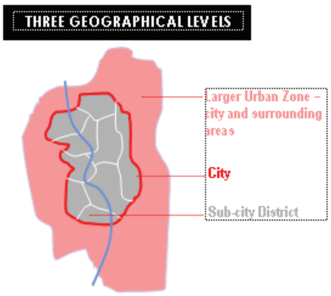


Figure 11. Geographical levels of Urban Audit (Urban Audit, 2005).

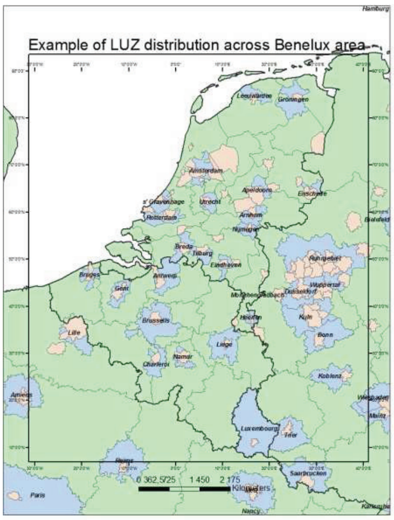


Figure 12. Example of spatial dataset acquired from Eurostat.

3.1.3. Attribute datasets

Eurostat as the EU Agency responsible for statistics holds a big amount of data of various themes which is both collected itself and acquires from other EU Agencies (figure 13). The most recent datasets are stored in databases and older ones in archive databases both available for download by the EU institutions and general public via registration procedure. Both socio-economic and transport statistics were necessary to conduct the research and were acquired for both NUTS2 and LUZ layers.

Population is one of the main socio-economic parameters which describe the region or city and is an important input for the linear regression analysis in case there are no data on trip production available; hence the recent population numbers were downloaded for both NUTS2 and LUZ for the year 2008 and 2006 respectively. The population was accompanied by unemployment rate being important social parameter related to economic activity and development features. Unemployment rates were both available for NUTS2 and LUZs whilst economic activity rate was only collected for NUTS2. On the regional level GDP and GDP per capita were available being important features for trip attraction assessment. Finally, NUTS2 projected population for the year 2020 was acquired in case of making future travel demand assessment. All the datasets were downloaded in .csv format and processed in MS Excel.

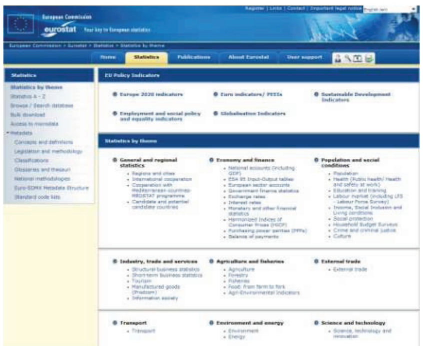


Figure 13. Example of Eurostat databases available for download (Eurostat, 2010).

The most difficult task was to acquire traffic datasets which had to be placed in OD-matrices for Gravity model implementation. Initially it was decided to request for these data in TEN-T EA being a responsible body for transport planning on the EU scale. Unfortunately it took too much time to get in contact with their officials and the traffic data was acquired for NUTS2 regions. However it was neither recent nor complete which made it unsuitable for the gravity model input production. At the last moment the BMT report issued at the end of 2010 was found. This report presented the TRANS-TOOLS model, its implementation and the results for traffic assessment within European networks. The model outputs for the 2005 traffic flow assessment were used for derivation of rail and road transport modes turnovers for selected LUZ. These data is considered being reliable enough as if it was approved by the EU and applied for transport planning purposes of TEN-T.

3.1.4. Transport network datasets

Transport network datasets were downloaded from archives of GISCO project running by Eurostat. These layers were initially produced by Transport and Mobility Direction in 2004 and redistributed to Eurostat. The most recent dataset announced were supposed to contain TEN-T by transport mode but were not available for download being expected from TEN-T EA (as of December 2010). Hence the posted rail and road networks, sea and airport transport modes' spatial data were downloaded. Besides it was necessary to select the networks' elements participating in TEN-T out of the entire European networks provided. It would require more time to be spent on data pre-processing in order to get the expected Network Analysis inputs. The network data for both rail and road modes are fully topological equipped with country code system for all line features participating (figure 14).

Attributes of TENT_rail

OBJECTID *	Shape *	FNODE	TNODE	LPOLY	RPOLY	LENGTH	RWEU1MV4	RWEU1MV4_ID	RWSGCD	RWSGSQ	RWSGCDSQ	Shape_Length
334	Polyline	32421	32415	0	0	0,089176	1076	1076	ES000918	0	ES0009180	8067,624756
335	Polyline	32437	32421	0	0	0,151343	1077	1077	ES000919	0	ES0009190	13805,481656
336	Polyline	32535	32497	0	0	0,169595	1078	1078	ES000920	0	ES0009200	14837,514715
337	Polyline	32578	32535	0	0	0,124868	1079	1079	ES000921	0	ES0009210	11740,924493
338	Polyline	32612	32578	0	0	0,11974	1080	1080	ES000922	0	ES0009220	10542,476616
339	Polyline	32619	32612	0	0	0,053172	1081	1081	ES000923	0	ES0009230	4502,624198
340	Polyline	32497	32430	0	0	0,284547	1082	1082	ES000931	0	ES0009310	24748,888035
341	Polyline	32430	32437	0	0	0,086266	1083	1083	ES000932	0	ES0009320	7204,182906
342	Polyline	32770	32776	0	0	0,116573	1084	1084	ES000958	0	ES0009580	9975,117799
343	Polyline	32776	32791	0	0	0,137684	1085	1085	ES000959	0	ES0009590	11910,382046
344	Polyline	32791	32789	0	0	0,04983	1086	1086	ES000960	0	ES0009600	4157,148417
345	Polyline	32828	32770	0	0	0,164325	1087	1087	ES000961	0	ES0009610	16211,586752
346	Polyline	32835	32828	0	0	0,018295	1088	1088	ES000962	0	ES0009620	1838,2754
347	Polyline	32789	32827	0	0	0,101348	1089	1089	ES000963	0	ES0009630	9630,032433
348	Polyline	32807	32802	0	0	0,061736	1090	1090	ES000964	0	ES0009640	5370,432524
349	Polyline	32934	32835	0	0	0,112965	1091	1091	ES000965	0	ES0009650	11983,103772
350	Polyline	32853	32807	0	0	0,152597	1092	1092	ES000966	0	ES0009660	13750,665399
351	Polyline	32849	32853	0	0	0,051971	1093	1093	ES000967	0	ES0009670	4494,284797
352	Polyline	32827	32877	0	0	0,137782	1094	1094	ES000968	0	ES0009680	12603,484236
353	Polyline	32802	32845	0	0	0,104736	1095	1095	ES000969	0	ES0009690	9891,981015
354	Polyline	32877	32849	0	0	0,132592	1096	1096	ES000970	0	ES0009700	11557,139921
355	Polyline	33003	32934	0	0	0,102655	1097	1097	ES000971	0	ES0009710	10996,615003
356	Polyline	32845	32918	0	0	0,139623	1098	1098	ES000972	0	ES0009720	13139,771639
357	Polyline	33028	33003	0	0	0,047692	1099	1099	ES000974	0	ES0009740	4828,811824
358	Polyline	32954	33041	0	0	0,252649	1100	1100	ES000977	0	ES0009770	23853,143614
359	Polyline	33041	33065	0	0	0,039207	1101	1101	ES000978	0	ES0009780	3839,258402
360	Polyline	33065	33091	0	0	0,062062	1102	1102	ES000979	0	ES0009790	5647,690106
361	Polyline	33091	33110	0	0	0,112791	1103	1103	ES000980	0	ES0009800	9725,179138
362	Polyline	33110	33126	0	0	0,053027	1104	1104	ES000981	0	ES0009810	4664,85811
363	Polyline	33126	33195	0	0	0,148422	1105	1105	ES000982	0	ES0009820	14319,476638
364	Polyline	33195	33222	0	0	0,147991	1106	1106	ES000983	0	ES0009830	13202,080164
365	Polyline	33222	33231	0	0	0,084635	1107	1107	ES000984	0	ES0009840	7472,709755
366	Polyline	33231	33272	0	0	0,06223	1108	1108	ES000985	0	ES0009850	6512,832816
367	Polyline	33272	33293	0	0	0,054436	1109	1109	ES000986	0	ES0009860	4996,898196
368	Polyline	33293	33340	0	0	0,081321	1110	1110	ES000987	0	ES0009870	7845,705356
369	Polyline	33340	33362	0	0	0,069885	1111	1111	ES000988	0	ES0009880	6280,859662
370	Polyline	33362	33394	0	0	0,085634	1112	1112	ES000989	0	ES0009890	7951,690014

Figure 14. Example of network dataset attribute table.

3.1.5. Software used

Modern research is usually based on a chain of complex processes and calculations which makes it necessary to employ programmes of various applications. The software particularly used to conduct the research is represented in a table 1; it is certified and provided by ITC-UT (except MS Visio 2010) based on the licence agreement.

Table 2. Software used.

Software	Application	Extensions
MS WindowsVista SP2	Overall working space	
MS Office 2007	Text writing, gravity models	Word, Excel
OpenOffice 3.3	Editing of DBF files	Calc
SPSS 18.0	Linear regression, correlation	
ArcGIS 10	Data processing, analysis and its visualisation	ArcCatalog, ArcMap: ArcToolBox, Editor, Network Analyst
MS Visio 2010	Conceptual diagram building	
EndNote X4	Reference management	
7zip	Unpacking satellite data	

3.1.6. Data limitations

Although the acquired data are of good quality and consistency there were still some notable problems identified for both spatial and attribute one. Data interoperability was one of the key issues because even such a well-organised data-centred structure as Eurostat provided spatial data in 2 different formats: shapefiles (.shp) and export files (.e00). Thus, the implementation of data format conversion became necessary for network data given in .e00 format. Although attribute data acquired from Eurostat initially had .csv format it was processed in .xml and .dbf formats. There were also a lot of xml-dbf and vise versa conversions took place during the analysis operations which can bring some error in the datasets.

Despite the download date of different datasets was not critical in the research there was still a time mismatch observed. Some newly issued datasets and updates of the existing ones could be made by producer after the date of acquisition. Moreover spatial, attribute and satellite datasets were made in different time in the part which can be also the source of error. Finally, even though Eurostat data is highly unified and standardised there are still some problems with the LUZ and NUTS names being given in local languages are observed.

3.2. Methods

The methodology and its choice represent one of the most important parts of the research which explains the overall philosophy and the sequence of steps applied. Followed the introduction, study area and data description in methods part the attempt done was to describe the manipulations applied to data and bridges it with the results and discussion. The overall idea developed is presented and reviewed on the conceptual framework (figure 14). Due to the fact that the field visits were supposed to be done for methodology clarification there were also briefly mentioned in this chapter. Spatial data pre-processing was described for the acquired steps in the relative sub-chapters except the one commonly used during the whole research which is put separately.

3.2.1. Conceptual framework and agencies visits

The conceptual diagram depicted from the figure 15 refers to the research framework being developed which can be split into three modules. After the required data was downloaded and pre-processed the Network Analysis module could be executed providing the relevant TEN-T rail and TEN-T road OD-matrices based on the distance as impedance for further use in gravity model as inputs.

Before the second module could be executed the vast preparations should be done starting with nighttime lights intensity and total turnover computation for derived LUZ from the acquired sources. When finished the correlation between both should be checked in order to prove or disprove the first hypothesis. If the zero hypothesis is accepted the nighttime lights data could be used as an attraction input in the gravity modelling. Alternatively the attraction should be computed based on the acquired GDP data being processed and distributed between LUZ. Total turnover per transport mode refers to the production part of the gravity model in any case. Finally, the Euclidian distances between the OD-points should be derived in order to serve as an input for the desired flows computation in the gravity model block. When done the gravity model for rail, road and desired networks could be computed using a number of iterations enough to maintain high accuracy of outputs.

In spite the fact that the minimum dataset developed was easily accessible for download (except tonnage data) there were some methodological issues on TEN-T planning left unclear. Two possible agencies visits were proposed: TEN-T EA and COWI. The first agency was responsible was the networks datasets used in the studies and the overall planning procedure of the Trans-European corridors. COWI had the significant experience of transport engineering work undertaken which refers to the real-based experience of planning. Hence it was possible to compare the difference in both planning and execution approaches for transport infrastructure. In order to organise the visits there was an official request letter prepared (see Appendix-1).

The third module includes the spatial mismatch assessment process which is based on the outputs of the gravity model for rail and road modes of transport which represent the real traffic flows whilst the Euclidian based (desired) flows are considered optimal. If the spatial mismatch occurs the second hypothesis will be proved. The TEN-T policy implementation expectations could be used as a trigger for the best case scenario when the improved network will benefit from the distance influence decrease for both transport modes which will affect the spatial mismatch. Based on the subtraction and division techniques the spatial mismatch is identified for both modes of transport on the NUTS regional basis. Thus, the main direction of missing links could be identified and mapped and further used as recommendation material for the TEN-T improvement.

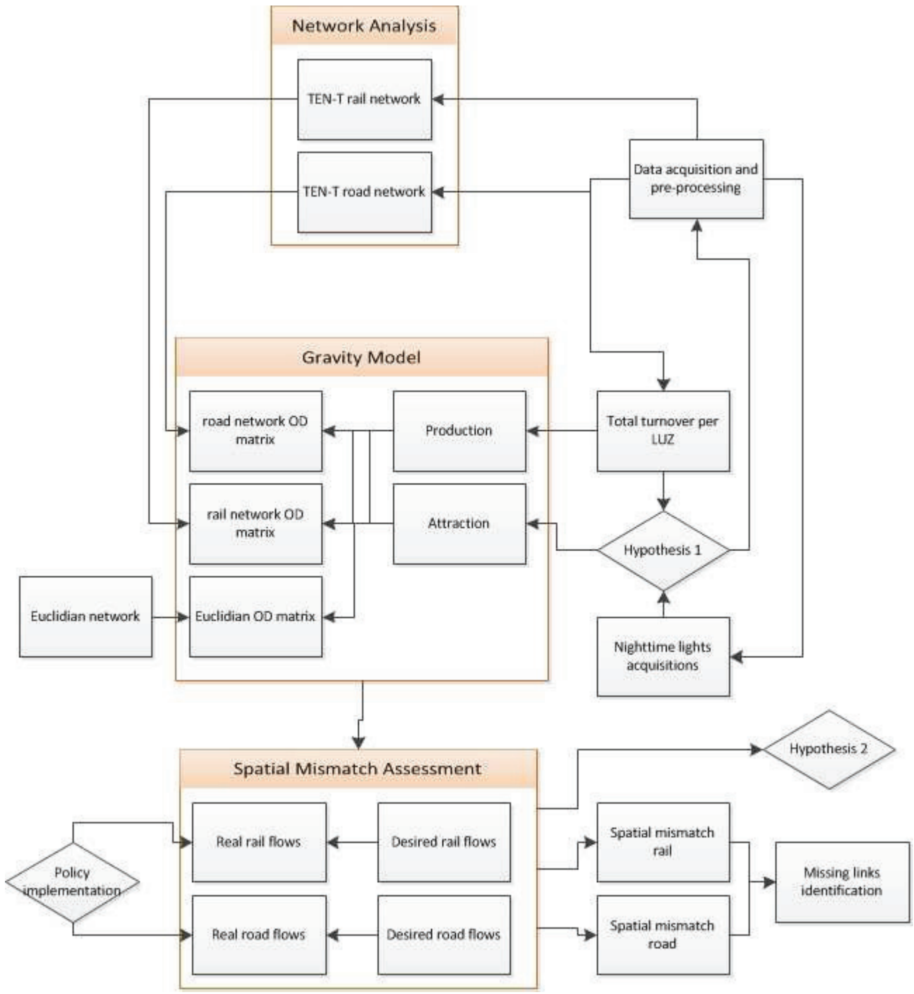


Figure 15. Conceptual framework of the research.

3.2.2. Data pre-processing

After all data were acquired it was necessary to make some major preparations in order to organise, unify and input it to the workspace prepared beforehand. It is important to remember that using the data from different sources and time acquisitions might cause several problems if "garbage in – garbage out" rule is neglected. Hence all data were checked before and after pre-processing procedures for its quality and reliability.

A new Geodatabase was created in ArcCatalog of ArcGIS 10 becoming a workspace for future data input and analysis. It was located on a C drive in order to minimise address paths whilst doing data manipulations and analysis. 40 Gb of the hard drive space was left free which is enough to maintain the work of the system and programmes with the desired speed and quality. Due to the fact that all spatial data acquired from the EU sources already have defined coordinate system it was wise to keep it as it is projected in Europe Conic Equidistance projection commonly used for transport maps by TEN-T EA.

The spatial datasets used for visualisation purposes and as clip features (NUTS2, boundaries, LUZ) had to be processed first. Downloaded datasets contained all features provided by the producer which were not applicable for the research without selection. The boundaries of all administrative levels in the EU were initially stored in one file which slowed down the project and overloaded the layout with unnecessary information. Besides the boundaries layer attribute table was sorted based on the administrative level codes allowing the EU state borders and NUTS2 boundaries to be extracted and saved as separate layers. Same procedure was applied to the polygon-based layer contained European units of all administrative levels where the EU member and candidate states along with NUTS2 regions were acquired and saved as separate layers. For the LUZ polygon-based layer it was necessary to remove urban areas located on remote islands which do not participate in TEN-T project which was done by using the Editing tool of ArcGIS.

3.2.3. Nighttime lights image pre-processing and analysis

The DMSP-OLS nighttime lights satellite image was unpacked using 7zip software which increased its size up to 3 Gb which could considerably slow down GIS software used. Hence a frame layer which covers the study area was created and used as a clip feature for the image which became around 350 Mb in size after and was re-projected into previously accepted Europe Conic Equidistance projection. However the acquired image did not have an attribute table required for LUZ light extraction. In order to use "build raster attribute table" function the image was converted into 8-bit format instead of initial 32 bit and saved as GRID occupying around 50 Mb of disk space at the end. The nighttime lights are stored as stretched values which should be retrieved as integer for LUZ the “round down” function was applied to the image. Finally, the attribute table containing the values for each single pixel ranged 0 to 63 was built being ready to be used in the analysis.

After DMSP-OLS nighttime lights satellite image was projected and pre-processed it was necessary to do its visual assessment and interpretation in order to assess the suitability for data extraction (figure 15). The range of values presented lies between 0 and 63. 0 DN value refers not lighted (completely dark) areas being typical for the water bodies and flows, remote and distant areas whilst the most lighted areas are assigned the DN values of 63 being observed in the biggest cities’ central districts.

Obviously LUZs have large variations in their geographical and socio-economic pattern across the EU which creates difficulties to compare the light intensity. Hence the summation of all pixel values caught within LUZs’ borders was implemented as the universal comparison parameter. This procedure required the separate extraction of 303 elements of nighttime light satellite image with the respect to acquired LUZs borders being used as a clip feature. After all LUZs images were extracted from the initial image the new field “light_count” was added to each of them being a function of multiplication of acquired DN numbers and their frequencies of occurrence. Then, summary statistics within was calculated to score the gross night light intensity. Lastly, the acquired values were imported to LUZ layer as a separate field being further used in a gravity model.

3.2.4. TEN-T pre-processing and Network Analysis

Network Analysis being the most complicated GIS-based process of the current research required an extensive network data pre-processing as well. The provided rail and road datasets contain the entire networks for Europe which were not classified. The expected TEN-T being data used for Network Analysis with assigned corridors were not obtained from TEN-T EA. Hence it was necessary to select TEN-T for road and rail modes manually based on the entire network comparison with TEN-T schemes available from Transport and Mobility division of the European Commission. After TEN-T selection was completed two new separate layers were produced: TEN-T_rail and TEN-T_road.

In order to connect Ireland and Sardinia with the rest of TEN-T rail and Cyprus with the rest of TEN-T road respectively the virtual links were drawn using the editing tool. The required topological information was added straight away. Now the network part was ready to use for the network dataset building which was done in ArcCatalog. For both rail and road network the required operations are similar.

First a new network dataset “TENT_net” was created in the Geodatabase where two pre-processed datasets were imported as new feature classes. The impedance to be used for the analysis was defined as “Distance”. This choice was dictated by large size of networks to be solved as well as very diverse and unknowns precisely speed limits and network conditions across different parts of TEN-T. In the Evaluators settings were left as follows: type as “cost” and “double” using the data from the field “ShapeLength”. The measure unit of impedance was set in kilometres, the connectivity, elevation and turn settings were used as default. Finally, the network dataset was obtained after the command “Build network” being used.

After both TEN-T were built and added to ArcGIS NetworkAnalyst application was started. Despite the high degree of trusts to the fully topological network data issued by TEN-T EA it was necessary to check the topology before starting OD-matrices building. Selection of TEN-T out of the entire networks within the adding of virtual links connecting the island could affect the topology and the quality of the dataset respectively. In order to test both networks for connectivity there were randomly selected 20 LUZ to be “stops” inputs across the “route” to be traced. In both cases the tests showed the positive result which proved the good condition of network datasets for OD-matrices building (figure 16).

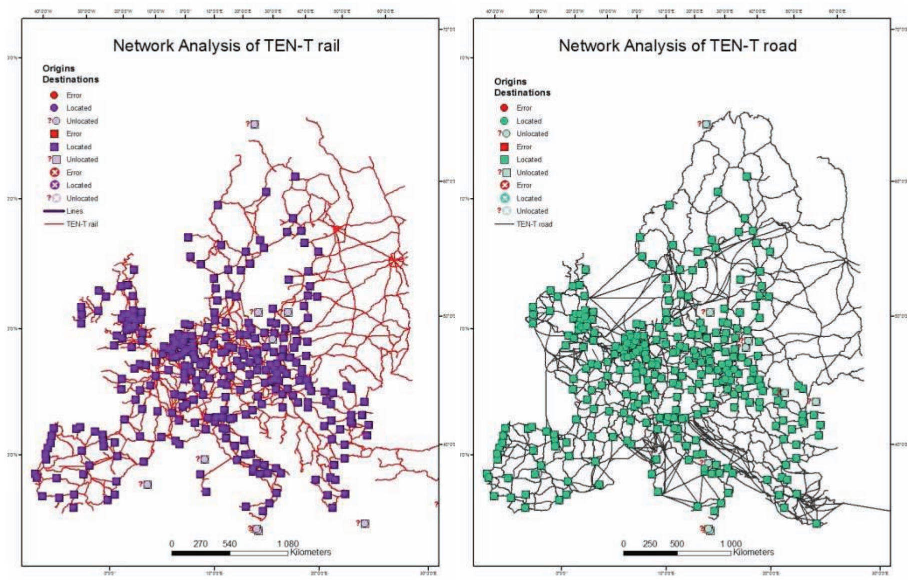


Figure 16. Network Analysis OD inputs for TEN-T rail (left) and road (right).

After the built network dataset was loaded to ArcGIS and NetworkAnalyst application was run a new OD-matrix task was started. For both modes of transport the procedure described is similar. The impedance was kept as "Distance" with the "kilometre" unit to be used. Using "load the locations" function the origins and destinations were loaded from point-based layer which represents acquired LUZs centroids. Network proximity was set to 50 km as of ½ of the TEN-T corridor width and OD names were loaded from the respective LUZ table field. The origins and destinations were the same and their number completely matched. Thereafter the unlocated ODs were checked and excluded from the lists which finally account 295 ODs for rail and 297 ODs for road TEN-T respectively. Finally, "solve the network" function of Network Analyst was used to produce a new line-based layer which contains all set and computed connections between OD placed in the attribute table. Due to the high number of rows in the output tables exceeding MS Excel and OpenOfficeCalc limits both tables were divided into 2 smaller ones each and exported as new layers.

3.2.5. Reference nwtwork computation

Since the network-based distances representing the current state of transport movement across TEN-T were calculated it was necessary to develop a reference network for a spatial mismatch comparison. Such a solution was found in the Euclidian distances computation which represents the shortest possible routes between the origins and destinations. This network is neither desired nor reachable but is a good maximum basis to compare with the real situation happening. Using "Euclidian distance" function of Data management Tools of ArcToolBox and LUZ centroids as input feature the shortest possible distances were computed and placed in the output table. However this function does not build the line features which could be used for the spatial mismatch intersection. Moreover it uses only numeric data to calculate the OD with had to be replaced by LUZ names after. Like the Network Analysis process the output table was too big to be handled in software used. Hence it was split into two smaller ones and exported to be processed in OpenOfficeCalc.

3.2.6. Trip distribution modelling and the Gravity method

After the travel distances between all ODs for both selected transport modes together with the Euclidian distances are known, it was necessary to assess the interaction between ODs in case of real (3.2.4) and reference (3.2.5) distributions. This so-called trip distribution modelling aims to identify where the produced features (bottom triangle) are moving to and where from the attraction (top triangle) comes from (see the example in Appendix 3). In order to fill in the OD matrix table so-called deterrence function should be computed (2) which are varying in type (time, cost, distance).

$$c_{ij} = \min_r(T_{ij} + \frac{C_{ij}}{\gamma})\ (2)$$

Where,

c_{ij} – minimum generalised travel cost

T_{ij} – travel time from origin *i* to destination *j*

Cij – money cost

γ – value of time

In our case for computation simplicity the deterrence function is based on the network analysis results acquired (3.2.4): shortest paths by the relevant network mode between the ODs involved; which made formula (2) look like: $c_{ij} \approx d_{ij}$. Thus, it is an important assumption that the trip distribution is influenced by how big is the distance between selected ODs whilst other factors are neglected. There were also more assumptions done before starting the mode. The trip lengths are constant and all made within the proposed TEN-T which is in real life cannot be that solid because of the road construction work, network connections improvement, individual logistics choice. The travel distances between the origins and destinations do not have any barriers which will force the vehicle/train to slow down. In fact this is also not true because there are different speed limits on the roads/rails, junctions, sharp turns and other existing barriers. The particular country transport specifications and modal split are neglected by the model which artificially increases the real and potential turnover. For instance it is more likely to expect some goods to be shipped by inland waterways instead of rail between two Dutch LUZ or to transport some goods in Finland by rail instead of road. Moreover the exact trip and route decision is done by one single company and can vary from time to time. Finally, the decision to use the nighttime lights as an attraction pattern is rather novel and arbitrary.

Before starting the executing of the gravity model several preparatory steps had been passed through. First, the chosen origins and destinations were exported to the separate spreadsheet and sorted in ascending order. Second, the impedance values for each OD were derived from resulting attribute tables o Network Analysis and incorporated into the OD cost-based matrix. It is necessary to remind that after the Network Analysis was executed for rail and road transport modes the number and content of ODs for each of them were different. Hence, instead of having three tables (rail_network, road_network and Euclidian) there were four tables built with the modification of Euclidian-based results acquitted for each transport mode. Thus, there were initial four cost based matrices developed: rail_network, road_network, Euclidian_rail and Euclidian_road; which implies that the gravity model had to be implemented four times instead of three.

Due to the fact that production and attraction values came from different sources: TEN-T EA and nighttime light derivation; the balancing formula (3) should be implemented before using them as target values in the gravity model. Since the production values (total tonnages per LUZ) and their sum is likely to have a higher accuracy the attraction sum (gross nighttime lights per LUZ) was balanced to the production: $\widetilde{D}j = fDij$. Because the network analysis yielded with different number and content of ODs involved into TEN-T rail (295) and TEN-T road (297), the balancing should be done two times separately: for rail and for road mode.

$$f = \frac{\sum_{i=1}^{i} O_i}{\sum_{j=1}^{j} D_j} \; (3)$$

Where,

f – balancing function

$\sum_{i=1}^{i} O_i$ – origins total

$\sum_{j=1}^{j} D_j$ – destinations total

The next step done was to weight the "likeliness" ($f(C_{ij})$) of a certain trip to be done. It refers to the logical conclusion that such a function increases with the generalised costs (C_{ij}) decrease and vice versa (4).

$$f(C_{ij}) = C_{ij}^{-\alpha} = \frac{1}{C_{ij}^{\alpha}} \; (4)$$

In our case5 when $c_{ij} \approx d_{ij}$ and α=2 formula 3 can be modified as:

$$f(C_{ij}) = \frac{1}{d_{ij}^{2}} \; (5)$$

Formula (5) was implemented to four previously acquired distance cost-based tables (see the example in Appendix 4). Here it is necessary to make another important assumption taken to the model. All the diagonal lines of cost-based and "likeliness"-based matrices which represent intrazonal trips remain with null values. Even though some of the LUZs have the size equal to NUTS2 region and obviously have intrazonal traffic flows the data on rail and road freight turnover values contain only the intrazonal traffic and exclude the intrazonal movements which counted separately on LUZ level. Finally, it is necessary to mention that all extrazonal trips (outside of the EU) are excluded from the research either.

After all the assumptions were stated and matrices preparations were completed it became possible to run the gravity model based on the bi-proportional fitting. The generalised formula of the gravity model (1) was modified for the case considered and had the following view:

$$D_{ij} = a_i b_j f(\frac{1}{d_{ij}^2}) \text{ (6)}$$

Formula (6) implies that we have coefficients a_i and b_j still undefined. In order to solve this problem the so-called Furness method was employed. With the initial $f(c_{ij})$ table both coefficients are computed as the subtraction function between the target values assigned and the total row/column sum (formulas 7 and 8). When done the first gravity model step takes place with all b_j=1 and a_i being as they are. The second gravity model step works in the reverse order when a_i=1 and b_j are as they are. This is the way how the gravity model moves towards the acceptable results of 5% total difference between the row/column sum and the target value. When this condition was satisfied the iterations of the gravity model were stopped.

$$a_i = \frac{\Sigma O_i}{\Sigma f(\frac{1}{d^2{}_{ij}})} \text{ (7)}$$

$$b_j = \frac{\Sigma D_j}{\Sigma f(\frac{1}{d^2{}_{ij}})} \text{ (8)}$$

Each gravity model was run four times based on a number of input OD-matrices (rail_network, road_network, rail_euclidian, road_euclidian) in MS Excel 2007 and took at least 11 iterations in order to get the reliable and accurate result. In transport planning the accuracy of 0.95 is considered good enough (Zuidgeest, 2011) which in our case reached 0.97. The resulting tables from the gravity model implementation had to be further processed and assigned to the OD lines previously created in Network Analyst.

3.2.7. Traffic flow assignment

After the gravity model iterations were completed and final results extracted it was necessary to make a traffic flow assignment procedure. There were four output tables acquired: 2 for network based (rail and road) and 2 for Euclidian based (rail and road) matrices with the total number of cells around 87,000 each. This value exactly matches the number of rows in two output tables produced for rail and road networks by Network Analyst Tool earlier which made it possible to use the same line features in order to assess the spatial mismatch. Due to the fact that Euclidian-based distances were built drawing of the corresponding lines it was decided to use the existing line-based features with an additional field for desired (Euclidian) flow.

Hence each attribute table was updated with two new numeric fields which would represent the real and desired flows depicted from the gravity model: “network” and “Euclidian”.

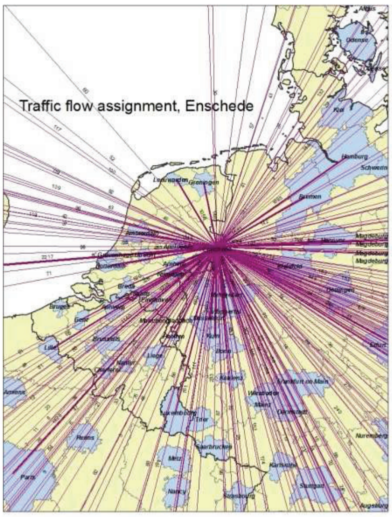


Figure 17. Desired flow lines for selected LUZ (Enschede).

After both existing attribute tables were sorted ascending the gravity model output tables’ fields which contained the flow values were ready to be imported. This procedure took place in ArcGIS editing mode in order to avoid rows mixing up while using OpenOfficeCalc for field import. After all the values were added to new fields the editing was saved and both real and desired traffic flows were assigned to the drawn lines (figure 17). However traffic assignment implementation for all the involved LUZs resulted a dense net of lines with which was difficult to interpret and operate (figure 18). Thus, the next step was to convert this information into understandable mode and “project” it on the underneath surface.

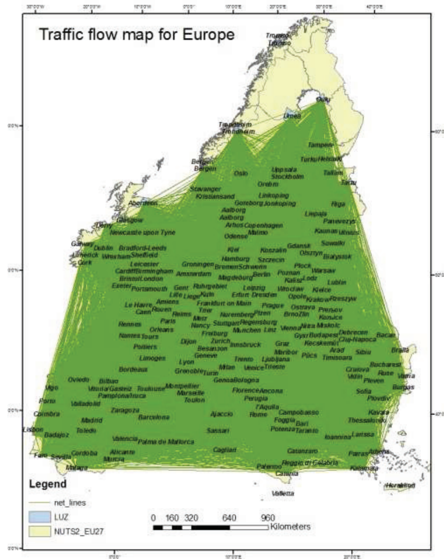


Figure 18. Traffic assignment done for the study area.

3.2.8. Spatial mismatch assessment and missing links

After the gravity model implementation (3.2.6) and traffic assignment (3.2.7) procedure the resulting outputs looked like two layers with 87,000 lines each with formed a visual representation of traffic flow for both network and Euclidian based flows. However it was almost impossible to interpret a highly dense net of lines which covered the whole study area (figure 17). Thus, there should have been developed some other method in order to satisfy the claim of general objective to define and map the spatial mismatch between proposed TEN-T and Euclidian networks.

Following the logic of the methodology applied by Rouwette (2005) the study area had to be split into zones. For this case NUTS2 level administrative unites could utilise such a function being spatially homogenous and representative on the European scale. To conduct this task "Intersect" function of ArcGIS ToolBox Analysis Tool was employed. Since this function could not handle more 2100 lines per session the entire tables for road and tail modes were split into 43 smaller tables. Each table accounted the traffic flow lines for 7 LUZs and was intersected with all NUTS2 regions selected. When all tables for both transport modes were processed the resulting tables were again merged into two big tables accounted approximately 1,000,000 rows each: one for the rail and one for the road traffic flows assigned. Next, the "Summary Statistics" function was applied to the resulting tables to select and sum up all the network-based and Euclidian-based flows for each intersection NUTS2 regions. Finally, using ArcGIS Editor the resulting features were added to newly created columns of NUTS2 regions' layer: net_rail, Euclin_rail, net_road, Euclid_road. Thus, both network-based and Euclidian-based network traffic flows for two transport modes were available and ready for comparison.

According to Rouwette (2005) the spatial mismatch function could be simply described as a difference (ΔT) between Euclidian (T_e) and network based (T_n) traffic flows (3). The Euclidian connection is likely to yield more traffic values due to the optimal route length whilst the network based flow will be smaller. Hence all the resulting values of spatial mismatch should be always positive producing the simple linear dependence: the higher value represents the higher spatial mismatch occurring.

$$\Delta T= T_r - T_n \quad (9)$$

The previously updated with real and reference network based traffic flows NUTS2 attribute were expanded with two more "long integer" fields for spatial mismatch computation for both transport modes. For both fields the field calculator function was executed to find the difference (ΔT) for rail and road networks. Later the ratio based mismatch assessment was done where the adopted ratio was based on the formula (10). Hence, there were two new fields representing the acquired ratios added to the NUTS2 attribute table and executed with the field calculator. After the changes had been made the table was saved and ready for graphical interpretation and visualisation.

$$\Delta T= T_r/T_n \quad (10)$$

The missing links identification assignment was done after the spatial mismatch data were available. Due to the fact that it was calculated in two different ways (formula 9 and 10) the task was to present the missing links based on both scenatio separately. Four line-based feature classes were added to the database: two mismatch cases for two transport modes. Based on the acquired absolute and ratio values of mismatch it was decided to define three categories of missing links in the degree of importance: high, medium and low level. After all four layers were added to ArcGIS each table was updates with a new field which corresponded to a missing link category. Using the editing tool there were draws lines which connect the NUTS2 level regions with relatively the same mismatch values. Next, the acquired lines were classified according to the defined mismatch categories and saved. Thus, both TEN-T networks (rail and road) had got their probable missing links based on the mismatch studies (table 3). Obviously the level of precision for such a procedure is relatively low though there was no goal to make a highly-précised routing task which could be the topic of another study.

Table 3. Missing links classification.

Class	Rail subtraction	Rail division	Road subtraction	Road division
High	288003 – 689490	2.02 – 4.32	1285007 – 4508670	1.39 – 1.76
Medium	181127 – 288002	1.71 – 2.01	759638 – 1285006	1.76 – 2.28
Low	75554 – 181126	1.47 – 1.70	355739 – 759637	2.29 – 5.37

4. Results and discussion

This chapter is devoted to the research results based on the sequence of steps applied in the materials and methods chapter. The description of acquired outputs is conducted in this chapter. For LUZ nighttime lights computation, Network Analysis, gravity model implementation, traffic flow assignment and spatial mismatch assessment the interpretation and visualisation of the results are given. A brief discussion on the constraints faced in the research and the limitations of studies is held. The explanation, applicability and usability of the produced outputs are widely discussed in the discussion sub-chapter.

4.1. Results

This section illustrates the results acquired after the developed methodology for spatial mismatch assessment was implemented. The nighttime lights imagery is overviewed, interpreted and supported by comparative maps for the study area. After the traffic flows' assignment procedure for the busiest lines in Europe the traffic flow maps are acquired. The spatial mismatch is mapped and interpreted with the respect to different assessment technique. At the end, the missing links identification based on the spatial mismatch assessment is presented.

4.1.1. Gross nighttime lights intensity calculation for LUZ

From the visual interpretation of acquired nighttime lights image it could be concluded that the most of the lights are from human settlements and ephemeral fires (figure 19). The biggest European cities, agglomerations, conurbations and metropolitan areas could be easily detected. Most of the lights are concentrated in so-called "blue banana" which covers England, Benelux, North and East of France, West and South-West of Germany, Western Switzerland and Northern Italy. Significant concentrations of nighttime lights were likewise observed in the Silesian basin, Mediterranean cost (Italy, France, Spain) and the Atlantic ocean cost (Portugal). The least lighted areas are typically located in the remote and sparsely populated areas of Europe (North of Finland, Sweden, Norway, Scotland and Alpine region). It could be also noted that the most of recent EU members are much less lighted than their Western partners. However this is not the case for Czech Republic, Malta, Slovenia and Cyprus which highly correlates with GDP per capita data observed in the Chapter 2.

There was also non-settlement light detected which is mainly located on the offshore areas of the Northern and Norwegian Seas. These are the gas flares coming from oil and gas extraction platforms. These lights are usually isolated from the mainland and do not affect the urban light which was considered in the research.

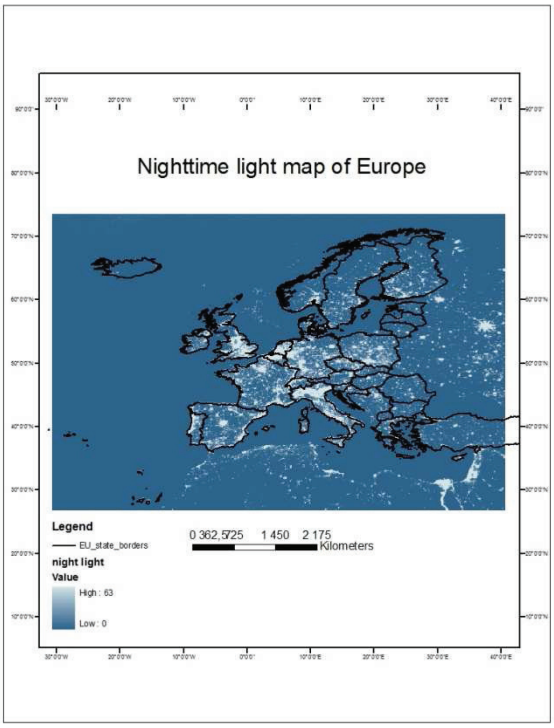


Figure 19. Nighttime lights map for Europe.

After each LUZ was assigned with individual gross nighttime lights intensity it was necessary to test whether it can be used as an attraction pattern in a gravity model to be computed later. The acquired total tonnage per LUZ is used as a production pattern which could be compared with the attraction one by using the stochastic method. Hence the nighttime lights intensity was plotted against the total tonnages known. As it can be depicted from the graphs (figure 20) there is a high correlation between these two parameters which makes it suitable to be used in a gravity model. Thus, it can be concluded with the high confidence that the nighttime lights values represent the traffic attraction pattern which proves the Hypothesis 1 stated.

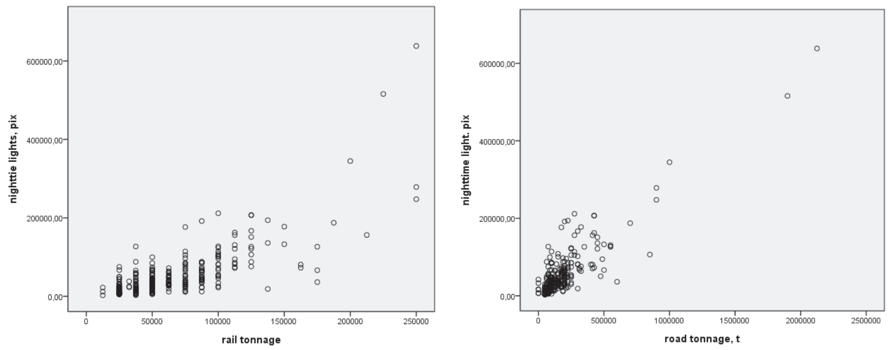


Figure 20. Scatter plots: rail (left) and road (right) freight against nighttime lights.

The comparative picture of city nighttime lights distribution on the European scale could be viewed on the figure 21 and in Appendix 2 in table-format. As we can see LUZs with the biggest gross nighttime lights values are located in so-called "blue banana" region which represents the European core area of economic activity and produces the majour transport flows. There is also the high concentration of "well-lighted" LUZ in Poland and Czech Republic which could be described by the arbitrary selection procedure for LUZs too place.

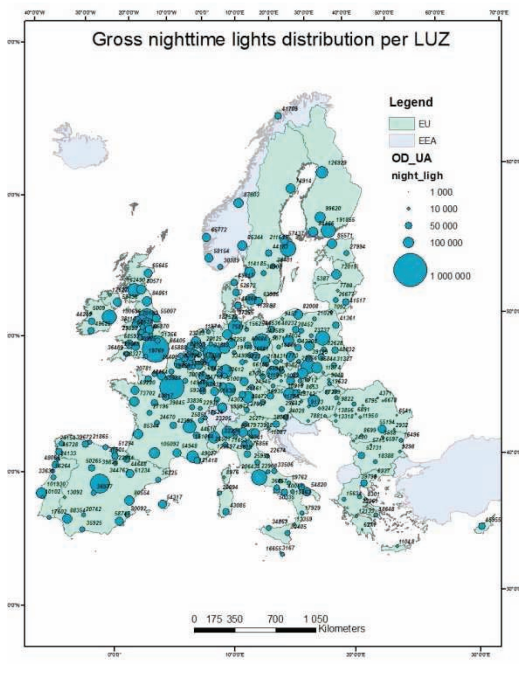


Figure 21. The map of gross nighttime lights distribution per LUZ.

Due to the fact that the selected LUZs are different in size and shape the gross nighttime lights were normalised by the area known (figure 22). In fact this map shows the average brightness estimation for a single square kilometre of LUZ area. Hence we can observe that the "brightest" LUZs are predominantly located in Benelux area, England and Italy. Such a result could be related to the city area morphology involved (the central district occupies most of LUZ space) as well as the policies of the exact municipality on the city lights. It is also visible that such a parameter could be linked with the level of urbanisation which is the highest in Benelux region, England and West Germany.

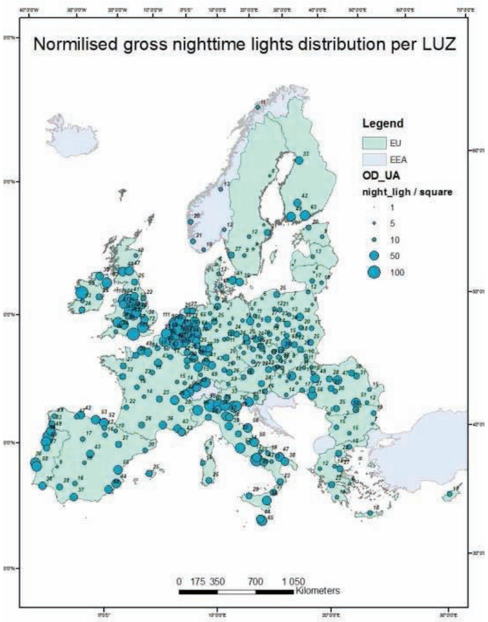


Figure 22. The map of normalised gross nighttime lights distribution per LUZ.

4.1.2. Network analysis outputs for TEN-T rail and TEN-T road

Before the Network Analysis was executed for both networks it is important to mention that several locations were not located with defined proximity. Except the remote islands of Azores, Canaries and Malta, there were excluded several LUZs which have rail/road connection but lay too far from the proposed TEN-T. For the rail mode there were Palma de Mallorca (Spain), Ajaccio (France), Tromso (Norway), Olsztyn, Koszalin and Kalisz (Poland). For the road mode there were

Radom and Konin (Poland), Braila and Targu Mures (Romania), Campobasso (Italy).

The results of OD-cost matrix build application of the Network Analyst for both rail and road TEN-T are shown on a figure 23. As it can be observed on the maps the traced OD-lines form the dense net of straight-lines between the input LUZs where each line represents the actual traffic flow via network. Such a shape could be described by the high complexity and number of the lines produces by Network Analyst which we can prove by seeing the network-based values in the relevant attribute tables (figure 24).

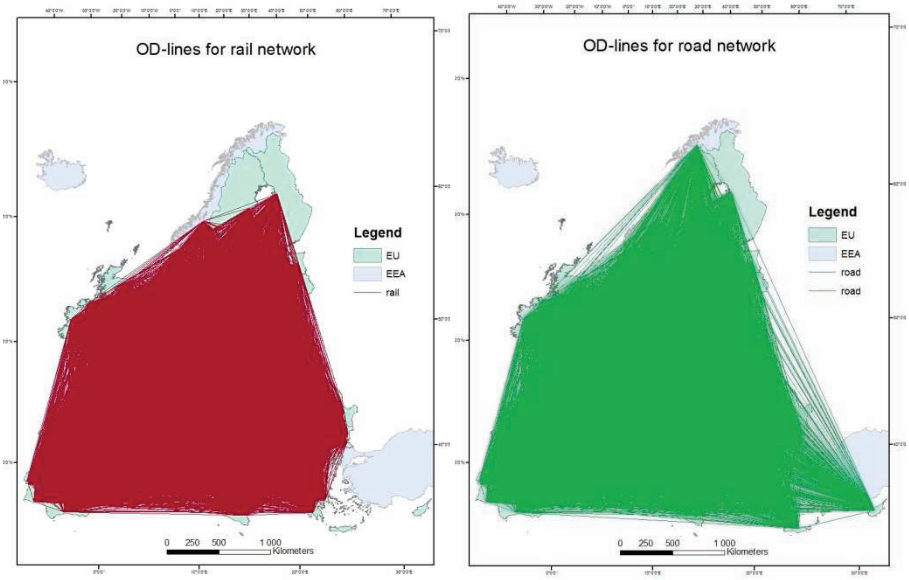


Figure 23. Computed OD-lines for rail (left) and road (right) transport modes.

FID	Shape *	ObjectID	Name	OriginID	Destinatio	Destinat 1	Total Dist	network	Euclidian
2028	Polyline	20288	Aalborg - Aalborg	72	72	1	0	0	0
2028	Polyline	20289	Aalborg - Aarhus	72	70	2	119,590341	1085	8295
2052	Polyline	20524	Aalborg - Aberdeen	72	308	237	2471,745795	30	129
2050	Polyline	20504	Aalborg - Alba lulia	72	248	217	2164,457594	41	47
2055	Polyline	20556	Aalborg - Alicante	72	95	269	2841,96584	27	28
2039	Polyline	20394	Aalborg - Amiens	72	111	107	1358,201737	49	54
2033	Polyline	20334	Aalborg - Amsterdam	72	186	47	986,932595	233	330
2049	Polyline	20496	Aalborg - Ancona	72	161	209	2011,358455	39	38
2035	Polyline	20355	Aalborg - Antwerp	72	7	68	1101,327174	191	214
2032	Polyline	20322	Aalborg - Apeldoorn	72	197	35	923,886678	120	112
2049	Polyline	20491	Aalborg - Arad	72	242	204	1969,319523	88	90
2032	Polyline	20323	Aalborg - Arnhem	72	193	36	930,567491	113	131
2057	Polyline	20574	Aalborg - Athens	72	127	287	3193,514279	337	281
2037	Polyline	20376	Aalborg - Augsburg	72	60	89	1242,589808	107	97

Figure 24. Fragment of attribute table for rail OD lines.

4.1.3. Gravity model and traffic assignment outputs

After the gravity model was executed four times (rail, road, Euclidian rail and road) and the computed values were assigned to the OD-lines (4.1.2) the traffic flows' values were acquired. Figures 25–26 represent the greatest flows for Europe by the transport mode considered (rail and road respectively). For the road TEN-T the lines with values over 10,000 were selected and drawn whilst for the rail TEN-T these value was selected as 5,000. In West Europe for the road mode it could be observed that the desired flow map includes almost the same directions as the network one but with greater values. The picture is rather different in the North and East of Europe where the desired flows network becomes denser and with more directions compare to the initial one. Same state could be observed for the TEN-T rail but with lesser numbers and greater difference towards the North and East.

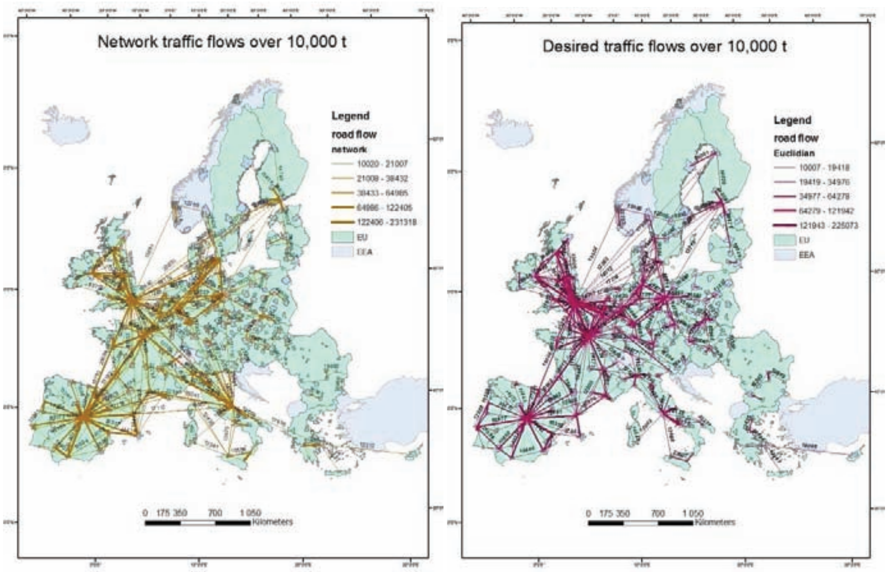


Figure 25. Network versus desired traffic flows for road transport.

Thus, it can be concluded that it is likely to expect the spatial mismatch across both TEN-T networks on the European scale with the respect to regional variations and the type of mismatch: capacity or infrastructure.

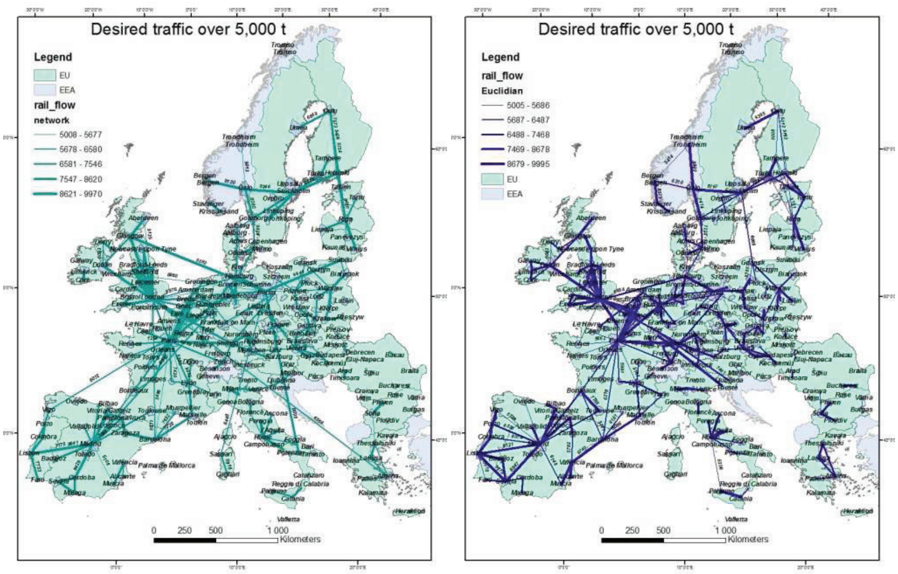


Figure 26. Network versus desired traffic flows for rail transport.

4.1.4. Spatial mismatch assessment and missing links identified

Since the intersection with NUTS2 level regions of the network-based and Euclidian-based flows was done the acquired values for demand and latent demand density could be presented per relevant transport mode (figures 27–28). From the figure 26 it could be observed that the latent demand densities for rail are much higher in values than the real ones and score the highest values in Germany, Central and West Poland, Northern Italy, Northern France and England. The latent demands densities are higher in Central and East Europe. Most of the distant regions have both low demand and latent demand density due to lesser traffic happening which is caused by their remoteness, low population density and hence the attractiveness.

The demand and latent demand density for the road transport mode could be seen on the figure 27. As for the rail mode the latent demand density values are much higher though the spatial distribution it different. The higher values are observed in East Sweden, South Finland, West Bulgaria and Romania, West Germany, England and North-East France. The low values are again typical for the remote regions: Ireland, North of Europe, East Romania and Scotland which corresponds with the results of the nighttime lights studies.

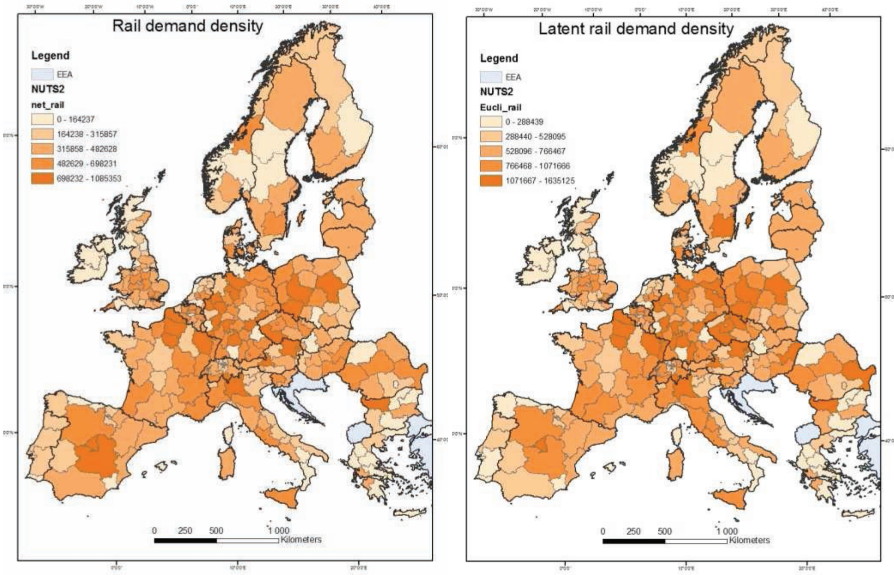


Figure 27. Demand density (left) and latent demand density (right) for rail mode.

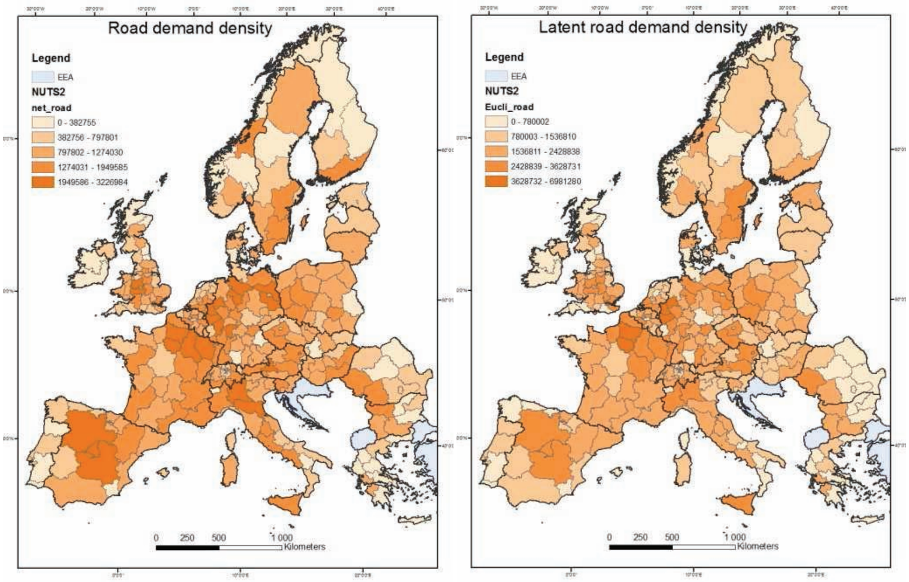


Figure 28. Demand density (left) and latent demand density (right) for rod mode.

The spatial mismatch is seen as the deference which occurs between the desired (reference) and real networks represented by latent demand and demand densities respectively for this study. There are at least two ways to assess the difference between these two parameters: subtraction and division; which were used both making it possible to compare the results of two approaches.

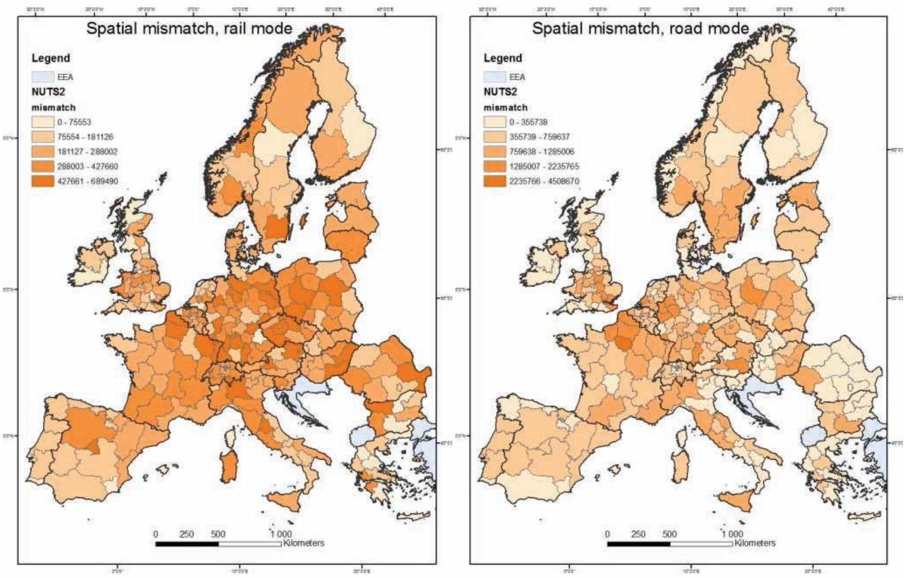


Figure 29. Subtraction based spatial mismatch for rail (left) and road (right) TEN-T.

The results of the subtraction based mismatch assessment are varied between null and 689490 for rail mode, null and 4508670 for road mode; and both classified with 5 classes which can be seen on the figure 29. As we can observe for the rail mode the spatial mismatch is very high in general. However it is rather low in Portugal, South of Spain, Greece, East Bulgaria, Ireland, North of Finland and Central Romania. At the same time the highest values are observed in West and Central Poland, Southern Sweden, North and East of France, Central Czech, several locations in Germany and Italy, Eastern Hungary and Romania. Summarising it can be concluded that there is a strong spatial mismatch for proposed TEN-T rail network across Europe. When looking at the road mode the most spatial mismatch occurs in England, Northern France and Ruhr basin locations whilst other areas are characterised with medium or low spatial mismatch. Thus, it can be stated that there is a medium spatial mismatch on road TEN-T across Europe detected.

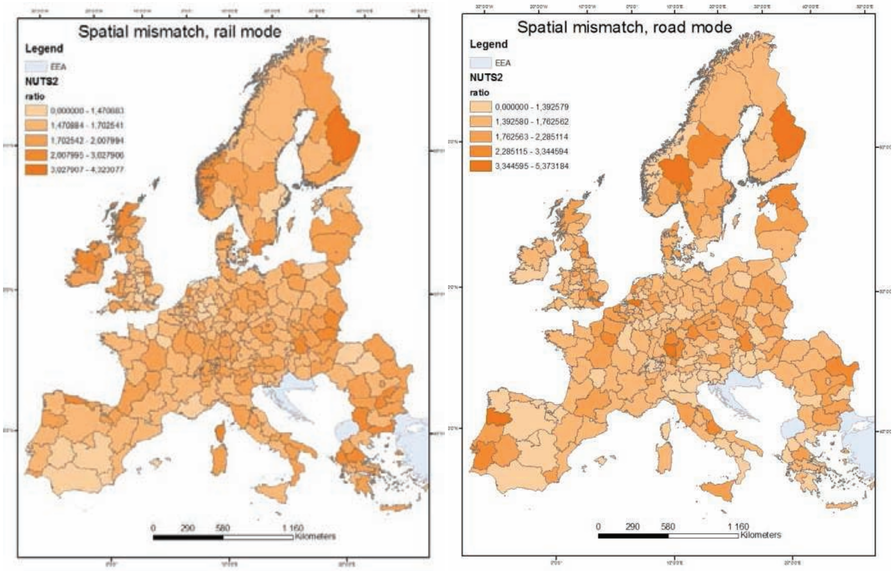


Figure 30. Division based spatial mismatch for rail (left) and road (right) TEN-T.

The division based ratio was also used to assess the spatial mismatch which can (figure 30). For the rail mode the ratios are in the interval of 0 and 4.3 in the mismatch increase order. The higher mismatch values are observed mostly in the remote areas: Ireland, Scotland, Western Norway, East and North of Finland, Eastern parts of Poland, Romani and Hungary south Bulgaria and Central Greece. At the same time the South of Spain, Central Romania, Central England have relatively low spatial mismatch. Summarising, there is a medium mismatch occurs within proposed rail TEN-T across Europe. When looking at the road mode the values of mismatch have the magnitude of 5.4. The highest spatial mismatch could be detected in Portugal, East Bulgaria and Romania, South Germany, Central England and Italy, Oslo region and East Finland. On the other hand North Italy, Central Spain, South and North of Greece, West Hungary and Ireland have relatively low spatial mismatch. Hence it can be concluded that there is a medium spatial mismatch identified within proposed road TEN-T across Europe.

Based on the results of two different approaches to quantify the spatial mismatch there were several missing links identified for rail and road TEN-T which can be seen on the figures 31–32. The spatial mismatch layers were used as the background whilst the line thickness represents the degree of priority of the link to be fixed: high, medium, low (table 3). In case of the rail mode the most of the highly prioritised missing links are located in Central Europe (Germany, Poland, France) and Italy. There were also traced some important routes in Hungary, Bulgaria and

Romania. Compare to the subtraction-based map the division-based map prioritises the links in the remote regions of Ireland, Scotland, and Norway as well as in Hungary, Bulgaria and Romania.

If we take a look at the missing links identified for road mode they are generally less in number and length than for the rail in both assessment cases. As we look at the subtraction techniques results the highly prioritised missing links are between England and France, in Ruhr basin, Western Poland, Germany and Austria. As the same time the division-based solution prioritises the links in Portugal, Oslo region, South Germany and Ruhr – Rotterdam connection.

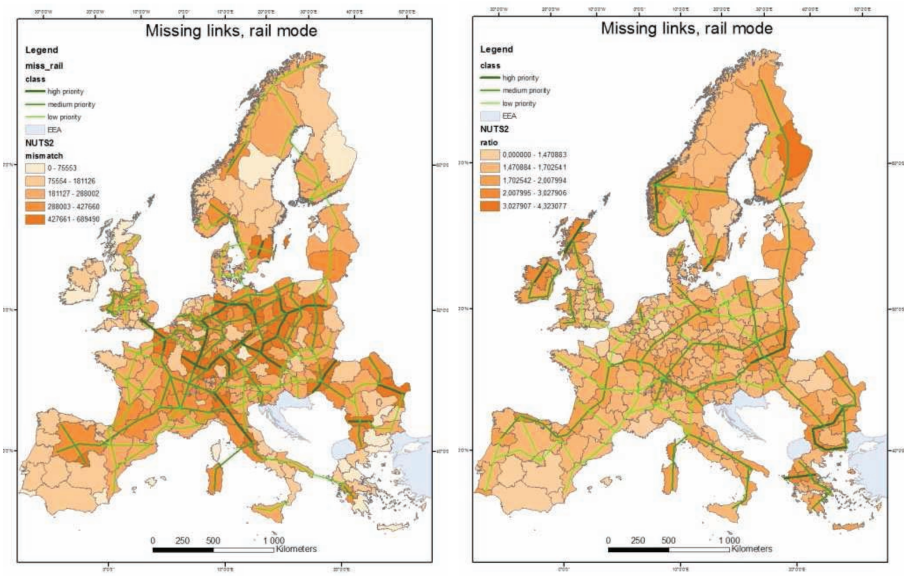


Figure 31. Missing links identified for rail TEN-T: subtraction (left) and division (right) based.

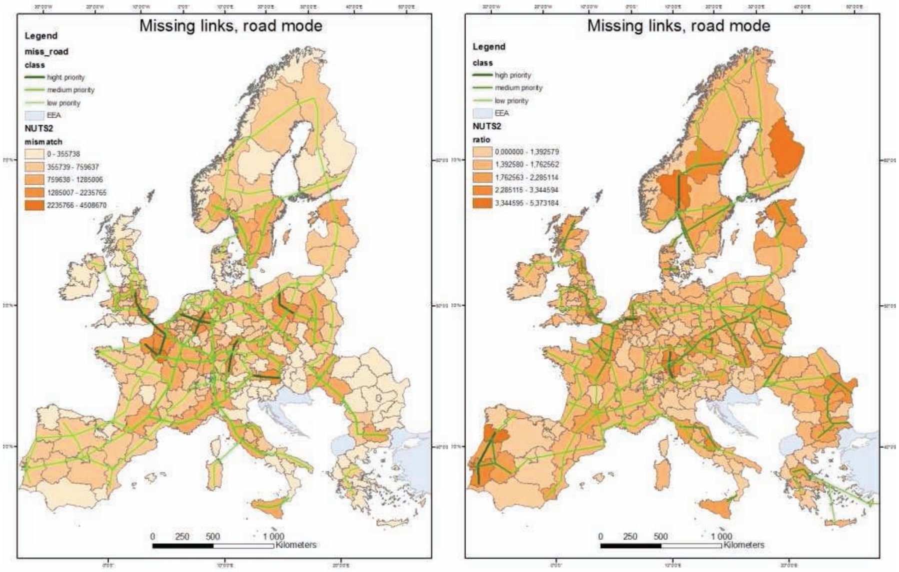


Figure 32. Missing links identified for road TEN-T: subtraction (left) and division (right) based.

4.2. Discussion

Based on the acquired results of the study developed it is possible to assert the existence of high spatial mismatch between the proposed by the EU TEN-Ts for both rail and road transport modes on the European scale. It implies that even though the transport networks are expected to significantly rise in quantity (length, width) and quality (speed, signalling) the overall result of the TEN-T plan implementation will be insignificant under the current conditions. However the expected growth of the freight traffic across the networks (European Commission, 2001) which was not included in the study would make the results of the plan implementation insignificant. Thus, by the end of the Programme in 2020 it is likely to expect the same amount of problems or even more despite 5300 billion euro investment done.

If we zoom into proposed TEN-T for rail the spatial mismatch has the wider spread compare to road one and covers the majority of Central and West European states. This could be one of the significant indicators showing the current state of European freight rail routes which are rather underused. Not surprisingly the EU allocated most of TEN-T budget for rail links improvement aiming the goals to balance the modal split across Europe and in some particular counties as well as to decrease carbon dioxide emissions. However even executing the Network Analysis for TEN-T rail several LUZs were un-located with the proximity of 50 km to the railway lines. This proximity is used as the half of the TEN-T corridor width which should be easily accessible. In case of Palma de Mallorca and Ajaccio neither the ferry connection to Spain nor the islands' rail networks were included into TEN-T rail which makes relatively big LUZs more remote and difficult to access compare to Sardinia and Ireland included in the network. Another case is the traversing the LUZs which are surrounded by proposed TEN-T but are too far to approach it which happens in case of Polish cities of Olsztyn, Kalisz and Koszalin. Such a case looks rather controversial with the official EU polity to improve the accessibility in new member states of the last entries (2004 and 2007) and increase the mobility in the region. Thus, despite the efforts done the spatial exclusion of LUZs from proposed TEN-T for rail is still present and could rise with a number of LUZ being increased in future.

Taking a look at proposed TEN-T for road the spatial mismatch looks more dramatic in the resulting total values unlike the rail mode. Such a picture is affected by existing modal split which take place across the EU with the predominant position of road transport. The loser spatial mismatch compare to the rail indicates the high level of road network development in general which serves the needs of Europe quite well. However if we move to more remote areas the spatial mismatch gradually increases. It corresponds with the amounts of EU funds invested to the road and highways network construction across East Europe, Portugal and Ireland. Moreover is proves the concept of the transport marginalisation of the European South previously states by Terranova (1995). When executing the Network Analysis for TEN-T road networks same case as for TEN-T rail happened – several LUZs were un-located. Again the EU defined proximity was not enough to involve LUZs in Poland, Romania and Italy. All those locations are situated in inland parts which increases their unfavourable location within the spatial exclusion from TEN-T. Thus, it can be concluded that despite the efforts taken by EU the spatial exclusion and lower connectivity takes place across proposed TEN-T road network.

Consider the both cases spatial mismatch caused by poor connectivity of LUZs and networks' imperfectness makes fairly weak conditions for intermodality and multimodality development especially in the areas of East Europe where it is in need. Although the TEN-Ts were proposed and 70% completed by now there is still no conception on intermodal connections development and the hubs locations which are left for the future. Hence the overall expected effects of TEN-T plan implementation might be considered as overestimated whilst TEN-Ts themselves as arbitrarily planned.

When looking at the results acquired from two different approaches for spatial mismatch calculation it is simple to notice the difference. The subtraction-based approach tends to identify more mismatches in the central locations whilst the division-based points out the spatial mismatch in the remote parts of the EU. Such a situation could be explained by the various nature of spatial mismatch. In other words subtraction-based approach represents the quantitative mismatch which increases with the absolute number difference in traffic passing by the region. Hence this type of mismatch can point out the regions which tend to have the capacity mismatch where the available capacity is less than desired for the assigned traffic one. Oppositely the division-based approach represents the qualitative mismatch which increases with the ratio difference between the desired and real allows in the region. Hence this type of the mismatch can point out the regions where there is a significant lack of transport infrastructure occurs. Thereafter the schematically shown identified missing links for both TEN-T rail and TEN-T road represented the directions where either significant network improvements should be done or a new rail/road should be created. This could be proved by the high level of match between the existing TEN-T and the missing links in the first case and almost no match in the second case. Thus, both approaches are equally important to consider in the spatial mismatch assessment in order to get the complete picture of the event.

Based on the previous references to the nighttime lights images to be used as indicators of the economic activity, GDP (Ghosh, 2010) and energy consumption there was an assumption done that the nighttime lights can also represent the transport activity. In case of current study it strongly correlates with the provided data on LUZs traffic which can be used as travel attraction pattern for the travel distribution modelling. In general terms the more night light sum detected will cause the higher attractiveness of certain origin or destination considered. However such a parameter can be also linked to a travel production patterns which is logically explained as the more lighted areas produces more goods and the demand on these goods to be delivered. Thus, nighttimes lights implementations could vary depend on the particular research and data availability.

The last but not the least, the universal applicability of the so-called gravity method for trip distribution modelling was identified. Even though the gravity method is widely used in transport planning it is difficult to predict the model behaviour when working on larger scale with greater amounts of data and larger numbers. Despite the quantity of ODs for each case was almost equal to 600 which made the overall matrix being around 90,000 calls the gravity model scored an accurate results within 11 iterations been done in each case. Thus, the reliability of results and methodological applicability of such model type for large-scale transport modelling is likely to be high.

4.2.1. Limitations of study

Despite the overall research conducted is considered successful there are still a lot of limitations could be identified. These limitations are mainly addressed to the input data quality and accuracy, the model assumptions and executions, software and human limits.

Although most of the data were acquired from reliable sources presented by European and American agencies with high quality control there are still some weaknesses to be aware of. DMSP-OLS project is being run for more than 30 years and is equipped with highly complex methods for image refining and enhancement (Elvidge, 1999). However the existence of background noise and the outliers toward the North are stated. Moreover the blurring of the lights in the cities located on the shore could be observed. All those factors decrease the accuracy of the nighttime lights identification for the cities above 60 degrees latitude and located near the sea where Oulu and Tromso are the best examples.

The selection of NUTS2 regions and LUZs was rather subjective and in case of the last one arbitrary. Not all the biggest and most important urban areas were either included into Urban Audit Programme of Eurostat or the current study which makes a lack of real origins/destinations for the study. Moreover there correspondence between NUTS2 and LUZ is weaker than NUTS3 and LUZ. However the current state of data collection within Eurostat and relative national Statistical departments on NUTS3 level is not reliable caused by its great number and limited funds. Thus, the hard linkage to the currently available data make the research highly dependent on it and inflexible.

The data for LUZs turnovers per rail and road transport modes were acquired from the study which employed TRANS-TOOL2 model to be used for traffic distribution across the whole European network. First, the input data used for this model was incomplete and subject to the availability from the freight traffic producers or collected by the governments. The degree of incompleteness rises towards the East and South-East Europe. Second, TRANS-TOOL2 tends to be less precise when moving from the centre producing high outliers in the remote areas. Finally, these data was collected and computed for 2005 which is not that recent.

The adopted model assumptions are also considered as the limitations of the current study. The employed gravity method and the relative model approach scored well but with a lot of assumptions being done. The intrazonal traffic was excluded when it might be significant especially when working with region-sized urban areas and road transport mode. The distance as impedance use was also a big simplification in order to decrease the calculation and save time. In fact there are a number of factors which influence the travel behaviour which make the particular firm to make a choice of optimal route, transport mode, speed and capacity which are very subjective. Neither the actual modal split within the EU member states nor the networks indicators were included which are obviously different and affect the trip generation and distribution. Moreover the external traffic was excluded which is not the case for the EU having a vast connections with the candidate states and Eastern neighbours. The so-called reference network was somehow tightening by Network Analyst to the existing one which distorted the results for the expected traffic flows. The traffic flow assignment and intersection were conducted in a simplified way. In fact it is rather complex to compute the real traffic flow distribution and which part of it yields in a particular region. Lastly the missing links identification was done schematically instead of implementing the complete routing task research. This decision was dictated by time limitations and the scope of the study.

Finally, it is important to mention that the used software did not always satisfy with the expectations assumed. There were slight difficulties in gravity model computation in MS Excel workspace caused by the data volumes being processed. There were significant difficulties observed while working with the main GIS Programme – ArcGIS 10 developed by ESRI. The weakest parts are addressed to the big satellite images processing, network analysis making shape simplification and the intersection function being unable to work with big number of expected intersections (over 20,000 per zone). These software constraints were always affected the researcher's human limits and shortened the time for conceptualisation of research.

5. Conclusion and recommendations

After the research was successfully completed there are several conclusions could be stated:

Based on the acquired nighttime lights image the freight attractiveness of selected LUZs was assessed and used as an input for trip distribution modelling exercise. Thus, nighttime lights imagery can be widely used for large-scale transport planning despite some improvements to be done with extremely north and seashore locations.

The proposed by the EU Trans-European networks were identified and mapped subject to the accuracy of the data provided. It was identified that the proposed networks do not provide an access to all LUZs selected.

The trip generation across the EU was modelled executed by Network Analyst application for road and rail networks proposed. However the simplification of taking a distance as impedance decreases the model outputs proximity to the real situation. Finally the lines' feature simplification led to the traffic flows assignment distortion.

Trip distribution modelling across Europe with the respect to selected ODs and networks was conducted with gravity model employed. As a reference network Euclidian-based distances were used. However when using the gravity method the routing and modal split are tend to be generalised with the role of individual choice minimised which makes the distance factor constant and unchanged. Moreover the exclusion of intrazonal and extrazonal trips within the networks could cause the underestimation of real freight traffic moving across the network.

The stated spatial mismatch occurrence within proposed rail and road TEN-Ts was identified, quantified and mapped. It implies that the effectiveness of transport planning on such a large scale in general still needs to be improved. Although the significant spatial mismatch was identified the real values are expected to be less because of the possible underestimation of real traffic.

Two spatial mismatch quantification strategies were linked to the difference in nature of spatial mismatch being the capacity limitations for the subtraction-based one and infrastructure limitations for the division-based one.

With the nature of spatial mismatch identified the missing links drawn across the EU represents the parts of the network to be improved or created. It implies that the decision on the TEN-T selection for rail and road transport modes in some cases was done arbitrary which is pictured with some LUZs being passed by the TEN-T or not connected at all.

Based on the conducted research it is recommended to use nighttime lights imagery for large-scale research projects when socio-economic data for the study area are difficult to access or to evaluate. The imagery are in open-access, up to date which make them serve as reliable, easy processed and interpreted source of socio-economic data.

It can be recommended for TEN-T EA to review the methodology applied for the proposed Trans-European networks creation and develop an assessment study based on the new data available and the extended to new member states spatial extent. The selected statistical units (NUTS, LUZ) should be widely involved into EU transport planning and be better interrelated.

The detailed study on the missing links across the EU should be undertaken paying an attention to the network shortages in remote areas with low traffic and congestion in the densely populated areas with high traffic numbers. It can be also advised to include the missing connections to the external countries lying in Eurasian transport corridors defined by UNECE.

There is also a strong suggestion to introduce additional rail and road links which will improve the connectivity of unlocated LUZs within currently proposed TEN-T. The alternative unfavourable solutions could be in increasing the proximity thresholds when planning the networks.

Although it is hardly possible to consider the results of the studies done on a current stage of TEN-T plan completion it is widely hoped that the updated research findings could be used for the next stage of TEN-T planning after 2020.

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7. Appendicies

1. ***Field visit request to TEN-T EA***
2. ***Example of derived Nighttime lights per LUZ***
3. ***Fragment of Cij input values for gravity model computation, TEN-T rail***
4. ***Fragment of f(cij) input values for gravity model computation, TEN-T rail***

Appendix-1

Field visit request to TEN-T EA

Hello! My name is Mikhail a Russian student of Erasmus Mundus MSc course "Geo-information Science and Earth Observation for Environmental Modelling and Management". Currently I proceeded to the research phase of the Programme studying in the Netherlands, Twente University, Faculty of Geo-Information Science and Earth Observation (ITC). I am doing my research in transportation team of Sustainable urban-regional dynamics (SURD) department of ITC, Twente University. Having the background in cartography and geo-ecology I was driven by the personal interest for the transport research field to the topic of my thesis work "Multi scale assessment of intermodal networks (European vs. national interest), geo-spatial approach".

This work seeks to identify the spatial mismatch based on the corridor swath analysis while proceeding from European to the lower project levels (e.g. national). In other words the research will test the influence of zooming effect while coming from an upper scale to a lower scale transport networks' planning. Stakeholders interests involved into the freight market on the EU and national level (Poland in my case) will be analysed and used as a demand side of the transportation process which generates the infrastructure and rooting needs in particular. Another important issue is to analyse the current transport networks structure and the level of intermodality in order to get the supply part in the transport process. Obviously the supply part will be affected by existing infrastructure problems and proposed projects (solutions). My task is to check spatially whether Trans-European Networks (TEN-T) proposed matches the needs of stakeholders involved on various scale levels. For instance the proposed TEN-T corridor might avoid important stakeholders (oil refinery, urban area) or affect some objects of Natural protection network (Natura 2000). Alternative routing task is the last but not least important step of the work refers to the networks' optimisation based on the results of research conducted.

In order to conduct the successful research it is necessary to have good quality spatial and attribute data. I have already approached the Eurostat where I got enough support and data I requested. Currently spatial and attribute data on regional economies and basic transport statistics was acquired. However some of the transport data were unavailable there and I was advised to request it in some other places where Transport and Mobility Department is considered as a focal point. Practically rail, road and inland waterway networks were missing in Eurostat databases and are missing in my research for now. In addition the research will benefit from having annual freight transport data by transport mode and country (region, urban area) preferably in a form of origin-destination matrices which will allow me to analyse the stakeholders' interests leading to the demand-supply analysis being very essential in any transport planning activity.

As far as I know Mobility and Transport department is dealing with TEN-T networks' planning and corridors of various transport modes within the EU and candidate countries scale. I already contacted Mr. A. Sorin from the Transport and Mobility department as well send my request via the request form, nevertheless I have gotten no reply. I am interested in some of the data you might have on TEN-T networks and the methodological issues on how they were created. Unfortunately I am not able to find such information and I was wondering if you could help me by releasing such data or by guiding me to someone that could take care of my case. I would also appreciate to get any dataset I mentioned and a brief explanation on the methodology of TEN-T networks planning procedure. From my side I guarantee to follow all the data security restrictions, copyright and privacy issues in the research if it will be requested. I hope you can help me to make Europe and my thesis better.

Best regards,
Mikhail Grishchenko.

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Appendix-2

Example of derived Nighttime lights per LUZ

name	*value*	*name*	*value*	*name*	*value*
Aalborg	49013	Brno	62996	Faro	17602
Aarhus	52673	Bruges	26409	Florence	49019
Aberdeen	65645	Brussels	1E+05	Foggia	19762
Ajaccio	8976	Bucharest	55194	Frankfurt-Main	166983
Alba Iulia	6891	Budapest	1E+05	Frankfurt-Oder	5071
Alicante	30092	Burgas	9298	Freiburg	33066
Amiens	29569	Bydgoszcz	40232	Galway	5009
Amsterdam	87712	Caen	48464	Gdansk	82008
Ancona	22674	Cagliari	43085	Geneva	25851
Antwerp	80749	Calarasi	2932	Genoa	25501
Apeldoorn	20125	Cambridge	31356	Ghent	48984
Arad	13856	Campobasso	15728	Gijon	21865
Arnhem	31332	Cardiff	68593	Giurgiu	3558
Athens	18648	Caserta	36857	Glasgow	162490
Augsburg	41561	Catania	32405	Gorzyw Wielkopolski	14176
Aveiro	16264	Catanzaro	17929	Gothenburg	114185
Bacau	6678	Ceske Budejovice	16935	Gottignen	19173
Badajoz	13092	Charleroi	36691	Graz	29642
Banska Bystrica	6424	Clermont-Ferrnad	42393	Grenoble	44510
Barcelona	36225	Cluj-Napoca	16549	Groningen	23283
Bari	42243	Coimbra	33631	Gyor	11705
Belfast	59438	Cologne	1E+05	Halle	36681
Bergen	65772	Copenhagen	1E+05	Hamburg	187522
Berlin	247589	Cordoba	20742	Hanover	72830
Bern	23205	Cork	49625	Heerlen	17550
Besancon	22938	Coventry	54272	Helsinki	191855
Bialystok	41361	Craiova	8699	Heraklion	11048
Bielefeld	97258	Cremona	22226	Hradec Kralove	21196
Bilbao	51294	Czestochowa	39129	Innsbruck	27957
Birmingham	132666	Darmstadt	33612	Ioannia	15634
Bologna	76856	Debrecen	17219	Jelenia Gora	11773
Bonn	53568	Derry	12627	Jihava	10042
Bordeaux	85344	Dijon	33836	Jonkoping	30900
Bradford-Leeds	207342	Dresden	65942	Kalamata	6271
Braga	24133	Dublin	2E+05	Kalisz	43208
Braila	6541	Dusseldorf	94692	Karlovy Vary	12095
Bratislava	43742	Edinburgh	80571	Karlsruhe	51001
Breda	29990	Eindhoven	28229	Katowice-Zory	177615
Bremen	75815	Enschede	22542	Kaunas	26677
Brescia	40479	Erfurt	33499	Kavala	6237
Bristol	70985	Exeter	36409	Kecskemet	9247

Appendix-3

Fragment of C_{ij} input values for gravity model computation, TEN-T rail

	Aveiro	Augsburg	Athens	Arnhem	Arad	Apeldoorn	Antwerp	Ancona	Amsterdam	Amiens	Alicante	Alba Iulia	Aberdeen	Aarhus	Aalborg
Aalborg	0	119,59	2471,75	2164,46	2841,97	1358,20	986,93	2011,36	1101,33	923,89	1969,32	930,57	3193,51	1242,59	3064,62
Aarhus	119,59	0	2352,16	2044,87	2722,38	1238,61	867,34	1891,77	981,74	804,30	1849,73	810,98	3073,92	1123,00	2945,03
Aberdeen	2471,75	2352,16	0	3157,84	2939,22	1264,36	1527,41	2583,71	1384,47	1576,78	2962,71	1541,18	4186,90	2015,18	3031,56
Alba Iulia	2164,46	2044,87	3157,84	0	2856,29	1974,04	1859,49	1446,40	1814,68	1856,14	199,60	1766,17	1611,40	1173,80	3423,85
Alicante	2841,97	2722,38	2939,22	2856,29	0	1679,48	2060,57	1840,03	1913,69	2094,56	2661,15	2033,30	3666,09	1912,94	1085,16
Amiens	1358,20	1238,61	1264,36	1974,04	1679,48	0	413,87	1328,78	270,92	463,24	1778,90	427,63	3003,10	800,66	1771,82
Amsterdam	986,93	867,34	1527,41	1859,49	2060,57	413,87	0	1465,03	170,52	84,95	1664,35	93,32	2888,55	747,72	2152,91
Ancona	2011,36	1891,77	2583,71	1446,40	1840,03	1328,78	1465,03	0	1358,94	1492,01	1251,26	1371,71	2256,20	782,50	2407,60
Antwerp	1101,33	981,74	1384,47	1814,68	1913,69	270,92	170,52	1358,94	0	206,37	1619,55	170,76	2843,74	702,92	2006,03
Apeldoorn	923,89	804,30	1576,78	1856,14	2094,56	463,24	84,95	1492,01	206,37	0	1661,00	120,30	2885,20	774,70	2202,28
Arad	1969,32	1849,73	2962,71	199,60	2661,15	1778,90	1664,35	1251,26	1619,55	1661,00	0	1571,03	1652,22	978,67	3228,71
Arnhem	930,57	810,98	1541,18	1766,17	2033,30	427,63	93,32	1371,71	170,76	120,30	1571,03	0	2795,23	654,40	2166,68
Athens	3193,51	3073,92	4186,90	1611,40	3666,09	3003,10	2888,55	2256,20	2843,74	2885,20	1652,22	2795,23	0	2202,86	4233,65
Augsburg	1242,59	1123,00	2015,18	1173,80	1912,94	800,66	747,72	782,50	702,92	774,70	978,67	654,40	2202,86	0	2417,44
Aveiro	3064,62	2945,03	3031,56	3423,85	1085,16	1771,82	2152,91	2407,60	2006,03	2202,28	3228,71	2166,68	4233,65	2417,44	0

Appendix-4

Fragment of $f(c_{ij})$ input values for gravity model computation, TEN-T rail

	Aalborg	Aarhus	Aberdeen	Alba Iulia	Alicante	Amiens	Amsterdam	Ancona	Antwerp	Apeldoorn	Arad	Arnhem	Athens	Augsburg	Aveiro
Aalborg	0	6,9921E-05	1,6368E-07	2,1345E-07	1,2381E-07	5,4209E-07	1,02666E-06	2,4718E-07	8,2446E-07	1,17155E-06	2,5785E-07	1,15479E-06	9,8053E-08	6,4766E-07	1,0647E-07
Aarhus	6,9921E-05	0	1,8075E-07	2,3915E-07	1,3493E-07	6,5182E-07	1,32929E-06	2,7942E-07	1,0376E-06	1,54585E-06	2,9227E-07	1,52049E-06	1,0583E-07	7,9294E-07	1,153E-07
Aberdeen	1,6368E-07	1,8075E-07	0	1,0028E-07	1,1575E-07	6,2554E-07	4,28635E-07	1,498E-07	5,2172E-07	4,02212E-07	1,1393E-07	4,21012E-07	5,7045E-08	2,4625E-07	1,0881E-07
Alba Iulia	2,1345E-07	2,3915E-07	1,0028E-07	0	1,2257E-07	2,5662E-07	2,8921E-07	4,78E-07	3,0367E-07	2,90254E-07	2,51E-05	3,20579E-07	3,8512E-07	7,2579E-07	8,5304E-08
Alicante	1,2381E-07	1,3493E-07	1,1575E-07	1,2257E-07	0	3,5453E-07	2,35518E-07	2,9536E-07	2,7306E-07	2,27936E-07	1,4121E-07	2,41879E-07	7,4404E-08	2,7327E-07	8,4921E-07
Amiens	5,4209E-07	6,5182E-07	6,2554E-07	2,5662E-07	3,5453E-07	0	5,83819E-06	5,6636E-07	1,3624E-05	4,66001E-06	3,1601E-07	5,46833E-06	1,1088E-07	1,5599E-06	3,1854E-07
Amsterdam	1,0267E-06	1,3293E-06	4,2864E-07	2,8921E-07	2,3552E-07	5,8382E-06	0	4,6591E-07	3,4391E-05	0,000138579	3,61E-07	0,000114828	1,1985E-07	1,7886E-06	2,1575E-07
Ancona	2,4718E-07	2,7942E-07	1,498E-07	4,78E-07	2,9536E-07	5,6636E-07	4,65914E-07	0	5,415E-07	4,49216E-07	6,3871E-07	5,31465E-07	1,9645E-07	1,6332E-06	1,7252E-07
Antwerp	8,2446E-07	1,0376E-06	5,2172E-07	3,0367E-07	2,7306E-07	1,3624E-05	3,43908E-05	5,415E-07	0	2,34814E-05	3,8125E-07	3,42949E-05	1,2366E-07	2,0239E-06	2,485E-07
Apeldoorn	1,1716E-06	1,5459E-06	4,0221E-07	2,9025E-07	2,2794E-07	4,66E-06	0,000138579	4,4922E-07	2,3481E-05	0	3,6246E-07	6,90978E-05	1,2013E-07	1,6662E-06	2,0618E-07
Arad	2,5785E-07	2,9227E-07	1,1393E-07	2,51E-05	1,4121E-07	3,1601E-07	3,61002E-07	6,3871E-07	3,8125E-07	3,62459E-07	0	4,05164E-07	3,6632E-07	1,0441E-06	9,5927E-08
Arnhem	1,1548E-06	1,5205E-06	4,2101E-07	3,2058E-07	2,4188E-07	5,4683E-06	0,000114828	5,3146E-07	3,4295E-05	6,90978E-05	4,0516E-07	0	1,2799E-07	2,3351E-06	2,1302E-07
Athens	9,8053E-08	1,0583E-07	5,7045E-08	3,8512E-07	7,4404E-08	1,1088E-07	1,19851E-07	1,9645E-07	1,2366E-07	1,20129E-07	3,6632E-07	1,27987E-07	0	2,0608E-07	5,5792E-08
Augsburg	6,4766E-07	7,9294E-07	2,4625E-07	7,2579E-07	2,7327E-07	1,5599E-06	1,78862E-06	1,6332E-06	2,0239E-06	1,66621E-06	1,0441E-06	2,33513E-06	2,0608E-07	0	1,7111E-07
Aveiro	1,0647E-07	1,153E-07	1,0881E-07	8,5304E-08	8,4921E-07	3,1854E-07	2,15749E-07	1,7252E-07	2,485E-07	2,06183E-07	9,5927E-08	2,13016E-07	5,5792E-08	1,7111E-07	0