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Study on Urban Mobility – Assessing and improving the accessibility of urban areas

Annexe 2: Task 2 Report – Estimation of European Urban Road Congestion Costs

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Executive summary

This report documents the outcomes of Task 2 of the study MOVE/C1/SER/2014-368/SI2.696637, "Assessing and improving urban accessibility". The specific objectives of Task 2 are to:

- Analyse the availability of congestion cost estimates;
- Review the methodological approaches used for generating these estimates;
- Develop estimates of urban congestion costs from the literature that are as comparable as possible; and
- Estimate congestion costs at the national level for EU Member States.

Definition of congestion costs

A variety of definitions of congestion exist (Grant-Muller and Laird, 2007). Broadly speaking, definitions treat congestion like an objective event while others introduce subjective considerations. For the purpose of this task, congestion is defined as a condition where vehicles travelling on road links are delayed.

Congestion costs can also be considered under different perspectives (CE Delft et. al., 2011; DIW econ et. al., 2014). The most common stylisation of congestion considers vehicles using a link of a given capacity. As the number of vehicles increases the speed deteriorates and all users will experience a delay with respect to free-flow conditions. The monetary value of this delay is one intuitive measure of the economic value of congestion. In the remainder of this report we will make reference to this measure as **"Delay cost"**.

The attractive feature of this measure is that it is based on an objective reference, i.e. the free-flow conditions. However the implicit logic behind delay cost is that congestion cost will be always positive unless everyone can travel in free-flow conditions, which is quite unrealistic especially in urban areas where the capacity required to deliver undisturbed travels could not be provided.

The economic view of congestion, based on the principles of welfare economics, incorporates this aspect. Under the economic approach, it is assumed that the level of demand on links is the result of individual choices based on minimisation of costs. Motorists' choices are based on the perceived average costs. When a new vehicle enters a link, it increases the cost for all the vehicles already using the network. However the driver of the marginal vehicle neither perceives this additional cost nor pay for its impact on other drivers. Therefore an external cost arise. According to the welfare economics principle, the cost of congestion is an externality at the extent it exceeds the willingness to pay of road users.

Figure A below helps to illustrate the concept of external costs of congestion. The level of demand on a given link tends to the equilibrium at the value D_0, where the average cost curve crosses the demand curve. The demand curve shows the willingness to pay of different levels of demand for travelling on the link. However, the social cost SC_0 for the demand level D_0 is larger than the private cost PC_0. Efficient equilibrium is at the level of demand D_1 where the demand curve crosses the marginal cost curve, which includes the extra costs generated by additional vehicles which enter the link. The external costs of congestion are those generated by demand in excess of D_1. The area between the demand curve and the social cost curve (area CBA) is the measure of the external cost of congestion. This measure is often termed as **"Deadweight loss"** and we will use this definition in the remainder of this report.

Figure A: Different definitions of congestion costs
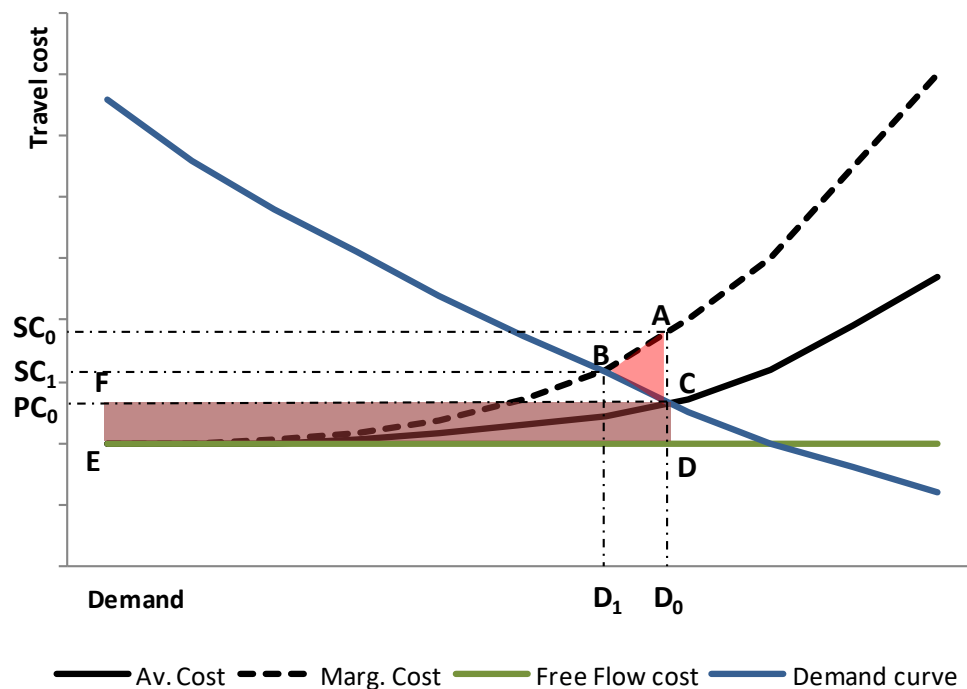
Deadweight loss is therefore the external cost of congestion while delay cost is the internal cost. In principle deadweight loss (i.e. external cost) is more representative of realistic conditions than delay cost (i.e. internal cost) (OECD/ECMT, 2007). However, behind the economic approach there are also some implicit assumptions that can make comparisons difficult, namely:

- On a given road, as demand varies, the desirable level of traffic - and of speed – also varies.

- In particular, as demand increases, the optimal level of traffic on a road will increase, i.e. the level of congestion that is acceptable varies according to the level of demand.

There are pros and cons regarding both delay cost and deadweight loss. We believe that there are no strong reasons to decide that only one of the two is a useful concept. Therefore, for the purpose of this task, both the definition of congestion costs based on the delay with respect to the free-flow conditions and the economic definition of external cost are used and two separate estimations of congestion costs are provided.

Sometimes cost of congestion is extended to other effects beyond time losses, e.g. additional energy consumption, additional polluting emissions. While we acknowledge that congestion may cause these additional effects, the scope of this study is to estimate only the cost generated by congestion in terms of longer travel time. Other sources of costs are not considered.

Methodology for estimating congestion costs

The existing literature on the estimates of urban congestion costs is not abundant and does not provide any robust ground to generalise the analysis at the European level. Given the purposes of this study an independent estimation has been arranged. The usefulness of the existing studies lies especially in their methodological approaches can be inspiring for the independent application required.
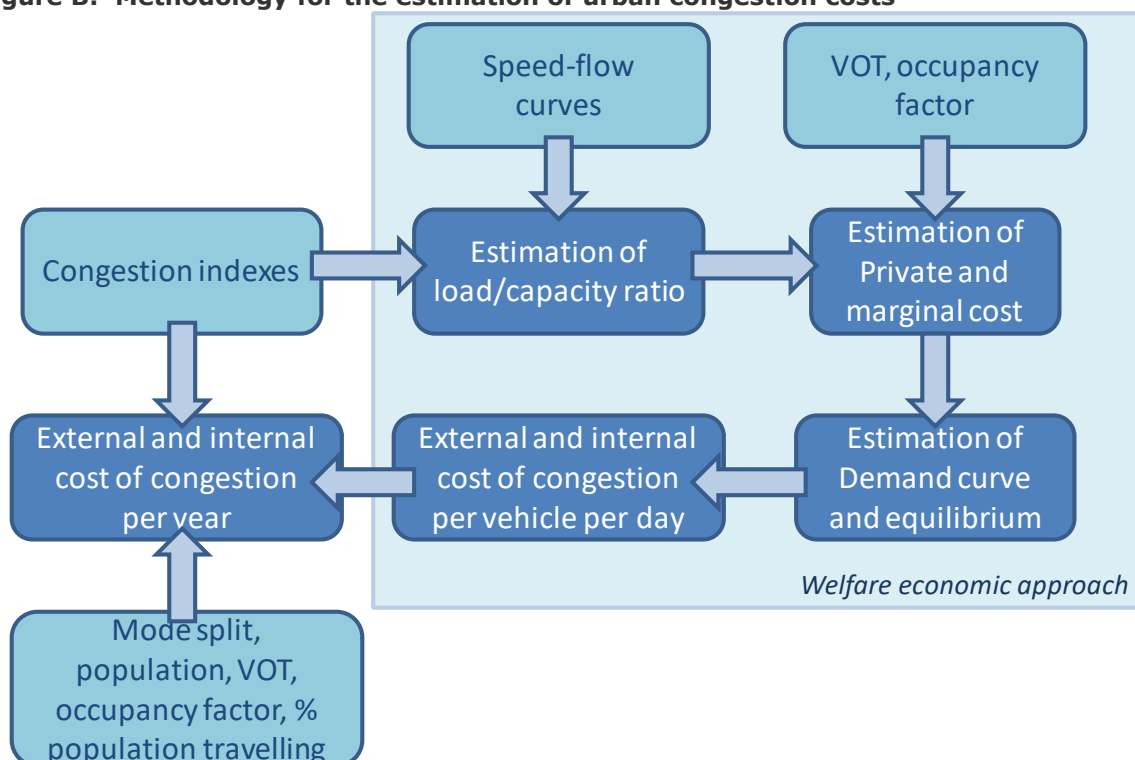
Urban congestion

At urban level, congestion costs have been estimated for passenger cars only as available information does not allow to provide a reliable estimation of congestion costs for other type of traffic (e.g. freight vehicles or public transport users). As mentioned above, estimations take into account only time losses, other costs, e.g. cost of fuel, environmental externalities, indirect costs on consumers, etc. are outside the scope of this study.

Based on observed traffic data, TomTom and INRIX provide indexes reporting the total average percentage increase in travel time with respect to Free Flow conditions as well as other indicators, e.g. the delay with a 30 min commute during peak periods (within a day and/or a year).

In order to derive the monetary values of delay costs and deadweight loss of urban congestion related to passenger cars, data from TomTom and INRIX indexes has been analysed and elaborated to obtain a set of estimations for several European cities. An overview of the methodology is presented in Figure B.

The welfare economic approach is used to define a measure of delay cost and deadweight loss of congestion of each city, which is used together with the congestion indexes and other relevant information (population, value of time, share of car mode split, car occupancy factor) to estimate the congestion cost per year (per capita and at urban level). In principle this model applies to single links, but we apply the same concept at the level of whole urban areas. We are aware that this generalisation raises methodological issues but at the scale of our study working at link levels would not be feasible.

Figure B: Methodology for the estimation of urban congestion costs

With this methodology we have estimated urban congestion costs related to passenger cars for several European cities. This set of costs has been used for a statistical analysis aimed at identifying correlations between the size of congestion cost and some known features of the cities such as size, or mode split of trips. However, the statistical analysis

has suggested that congestion is mainly dependent on local conditions, i.e. on elements that cannot be readily recognised using simple indicators like the mode shares or the population size. The only minor correlation found was between deadweight loss per capita and population of the cities by classes: the higher the population size the lower the average congestion cost per capita. In terms of delay cost per capita, simple average was estimated to generalise congestion cost estimations to the whole universe of cities.

Using these results, the costs estimated on the sample of cities have been applied country by country to all cities with at least 50,000 inhabitants. A simplified approach was adopted to generalise urban congestion costs also to cities below the threshold of 50,000 inhabitants. The simplified approach consisted in estimating the number of additional urban areas to consider in each NUTS3 zone according to two elements: the total population in the NUTS3 zone compared to the population in the cities with more than 50,000 inhabitants located in the same zone and, the typology of NUTS3 according of the classification urban / mixed / rural. Values of travel time for short distance trip (HEATCO project, 2006) by NUTS3 region have been used for the estimation of deadweight loss and, respectively, delay costs.

Inter-urban congestion

At the inter-urban level, congestion costs have been estimated for both passenger cars and trucks (the methodology applied allowed to quantify costs for road freight traffic as well). The estimation covers delays occurring on the main European network, i.e. the TEN-T Comprehensive network (motorways, primary roads) as well as other roads of regional and sub-regional interest. Again, the estimations refer only to time losses and do not include other costs.

The value of congestion costs on inter-urban roads in Europe has been estimated according to a different methodology compared to the one used for the urban costs. The reason has been that the available information regarding the delay generated by traffic was of a different nature. Rather than congestion indexes and amounts of time wasted in jams for a sample of cities, the available information consisted of the localisation of congested spots on the European road network and of the amount of delay on each spot. Building on this information, the methodology applied for the estimation of costs included two main steps. In the first step the amount of passenger and freight vehicles-km in congested spots was quantified. In the second step, unitary costs (Euro/vehicle-km) provided by CE Delft and others[1] as well as passenger and freight country-based Values of travel Time for long distance trip (HEATCO project, 2006) have been used for the estimation of deadweight loss and, respectively, delay costs.

The quantification of traffic experiencing congestion on inter-urban roads has been carried out using two main sources. One source was a map of the congested spots on the European inter-urban road network provided by JRC-IPTS. This map identified spots where road traffic is delayed in the most congested peak hour because of traffic and, for each spot, provided the amount of delay (in terms of additional time per km). The map was helpful in identifying where congestion occurs and the range of its severity. However, this source alone did not allow the quantification of the amount of demand involved in congestion. This further element could be estimated by means of parameters used in the TRUST model (TRUST is a transport network model covering the whole Europe developed by TRT).

Using the range of delay reported on the map of the congested spots and the speed-flow function associated to the links in the model it was possible to estimate the level of road occupancy in peak time. Then using daily traffic profiles the load in each hour was estimated for both passenger cars and trucks.

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[1] CE Delft, INFRAS, Fraunhofer ISI (2011): External Costs of Transport in Europe. Update Study for 2008. Delft

Results of the estimation of congestion costs

Urban congestion

According to our estimates, at European level (EU28), urban congestion costs related to passenger cars account for more than 110 billion Euros/year in terms of delay cost and about 10.9 billion Euros/year in terms of deadweight loss, These two figures are equivalent to about 0.8% and, respectively, 0.1% of GDP. These estimates are sensitive to different assumptions regarding some parameters and some input data used for the estimations. Namely, if demand is assumed to be more elastic and if steeper speed-flow curves are used, deadweight loss (external cost) could be significantly higher, up to twice the reference estimate. At the same time, if average delays proposed by INRIX are used instead of TomTom data, delay congestion costs could result lower.

In absolute terms, bigger countries explain the largest part of this cost, while in terms of cost per unit of GDP Eastern European countries are above the EU average (see table A). Given the methodology applied, an estimation is available for each NUTS3 zone. The cost per capita is different zone by zone (see Figure C) depending on the level of congestion, but also on the population of the area and its distribution between urban and rural areas.

Figure C: Yearly urban delay cost per capita by NUTS3 region in 2014
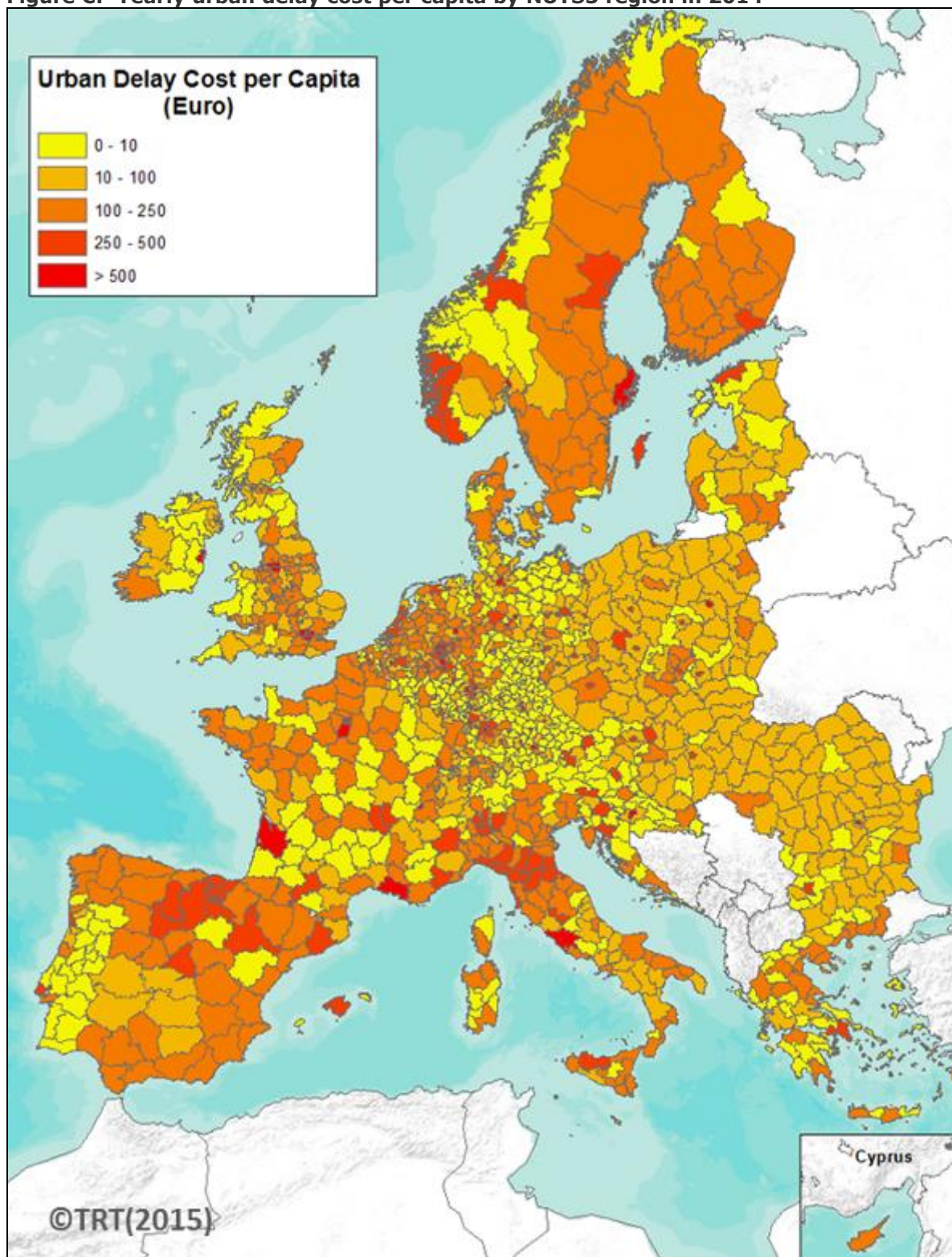
Source: TRT estimation

Table A: Yearly urban congestion cost by country

Country	Yearly urban delay cost (million Euro/year)	Urban delay cost: share of GDP (%)	Yearly urban deadweight loss (million Euro/year)	Urban deadweight loss: share of GDP (%)
Austria	1,179	0.39%	125	0.04%
Belgium	2,208	0.60%	220	0.06%
Bulgaria	697	1.81%	71	0.18%
Croatia	766	1.73%	79	0.18%
Cyprus	143	0.80%	15	0.08%
Czech Republic	1,387	0.89%	149	0.10%
Denmark	865	0.37%	91	0.04%
Estonia	181	1.12%	19	0.12%
Finland	932	0.49%	104	0.05%
France	14,210	0.71%	1,447	0.07%
Germany	18,400	0.71%	2,045	0.08%
Greece	2,547	1.22%	253	0.12%
Hungary	1,098	1.11%	81	0.08%
Ireland	1,281	0.79%	107	0.07%
Italy	14,921	0.95%	1,444	0.09%
Latvia	291	1.44%	30	0.15%
Lithuania	340	1.10%	35	0.11%
Luxembourg	109	0.25%	10	0.02%
Malta	33	0.50%	3	0.05%
Netherlands	3,391	0.57%	362	0.06%
Norway	1,375	0.51%	136	0.05%
Poland	4,457	1.20%	455	0.12%
Portugal	1,703	1.00%	171	0.10%
Romania	1,837	1.40%	157	0.12%
Slovakia	404	0.59%	39	0.06%
Slovenia	220	0.61%	23	0.06%
Spain	10,049	0.96%	1,092	0.10%
Sweden	2,610	0.68%	274	0.07%
Switzerland	1,108	0.23%	107	0.02%
United Kingdom	23,862	0.71%	2,071	0.06%
EU28	110,120	0.77%	10,972	0.08%

Source: TRT estimation

Inter-urban congestion

As far as delay cost is concerned, at European level (EU28), inter-urban congestion costs related to passenger cars account for about 31, billion euro/year, i.e. about 0.2% of GDP. If cost per unit of GDP is considered the top values are found in Poland (0.52% of GDP), Belgium (0.48%) and Bulgaria (0.45%) whereas for a large country like Germany the estimated cost is 0.10% of GDP. There are not large differences between Eastern and Western European countries. In the former group cost ranges from 0.07% of Croatia to 0.52% of Poland, while in the latter group the range is from 0.08% of Sweden to 0.48% of Belgium.

Table B: Estimated road passenger inter-urban congestion cost in EU by country (million Euros/year)

Country	Inter-urban delay congestion cost	Delay costs % share of GDP	Inter-urban deadweight loss	Deadweight loss % share of GDP
Austria	350	0.12%	56	0.02%
Belgium	1,777	0.48%	284	0.08%
Bulgaria	174	0.45%	28	0.07%
Croatia	32	0.07%	5	0.01%
Cyprus	n.a.		n.a.	
Czech Republic	284	0.18%	45	0.03%
Denmark	462	0.20%	74	0.03%
Estonia	15	0.09%	2	0.01%
Finland	154	0.08%	25	0.01%
France	7,084	0.35%	1,133	0.06%
Germany	2,504	0.10%	401	0.02%
Greece	270	0.13%	43	0.02%
Hungary	156	0.16%	25	0.03%
Ireland	367	0.23%	59	0.04%
Italy	4,379	0.28%	701	0.04%
Latvia	27	0.13%	4	0.02%
Lithuania	61	0.20%	10	0.03%
Luxembourg	81	0.19%	13	0.03%
Malta	n.a.		n.a.	
Netherlands	1,545	0.26%	247	0.04%
Norway	98	0.04%	16	0.01%
Poland	1,945	0.52%	311	0.08%
Portugal	633	0.37%	101	0.06%
Romania	350	0.27%	56	0.04%
Slovakia	158	0.23%	25	0.04%
Slovenia	42	0.12%	7	0.02%
Spain	2,450	0.23%	392	0.04%
Sweden	315	0.08%	50	0.01%
Switzerland	597	0.13%	95	0.02%
United Kingdom	4,239	0.13%	678	0.02%
EU28	30,957	0.22%	4,953	0.03%

Source: TRT estimation

With reference to freight road transport, inter-urban delay cost are estimated as much as 2,4 billion euro/year at European level (EU28), i.e. less than 0.02% of GDP (Table 5-3), while deadweight loss is about 385 million euro. Not surprisingly, the countries where the freight congestion cost (per unit of GDP) is highest are the same countries where also passenger congestion cost is large. Spain has a relatively higher cost for freight than for passengers: freight congestion cost as share of GDP is almost as twice as the EU average whereas passengers congestion cost is close to the European average, Instead, in Portugal and Sweden the freight congestion cost is relatively lower than the passenger congestion cost if compared to the average EU value.

Total congestion

At the European level (EU28), delay congestion cost (internal cost) for passenger accounts to nearly 140 billion euro/year. Estimated deadweight loss (external congestion cost) amounts to some 15,7 billion euro/year. The value of delay cost corresponds to about 1% of EU GDP. This is a not negligible cost for European drivers even though one should always keep in mind that it is an estimation of the monetary equivalent of additional travel time rather than a financial cost actually borne by individuals,

Table C: Yearly total delay congestion cost per country (passengers)

Country	Yearly total congestion cost (million Euro/year)	Share of GDP (%)	Yearly inter-urban delay cost (million Euro/year)	Yearly urban delay cost (million Euro/year)
Austria	1,529	0.51%	350	1,179
Belgium	3,985	1.08%	1777	2,208
Bulgaria	871	2.26%	174	697
Croatia	798	1.80%	32	766
Cyprus	143	0.80%	n.a.	143
Czech Republic	1,671	1.07%	284	1,387
Denmark	1,327	0.57%	462	865
Estonia	196	1.21%	15	181
Finland	1,086	0.58%	154	932
France	21,294	1.06%	7084	14,210
Germany	20,904	0.80%	2504	18,400
Greece	2,817	1.35%	270	2,547
Hungary	1,254	1.27%	156	1,098
Ireland	1,648	1.01%	367	1,281
Italy	19,300	1.22%	4379	14,921
Latvia	318	1.58%	27	291
Lithuania	401	1.30%	61	340
Luxembourg	190	0.44%	81	109
Malta	33	0.50%	n.a.	33
Netherlands	4,936	0.83%	1545	3,391
Norway	1,473	0.55%	98	1,375
Poland	6,402	1.73%	1945	4,457
Portugal	2,336	1.37%	633	1,703
Romania	2,187	1.66%	350	1,837
Slovakia	562	0.81%	158	404
Slovenia	262	0.72%	42	220
Spain	12,499	1.20%	2450	10,049
Sweden	2,925	0.76%	315	2,610
Switzerland	1,705	0.36%	597	1,108
United Kingdom	28,101	0.83%	4239	23,862
EU28	139,974,	0.98%	29,854,	110,120,

* only urban cost for Cyprus and Malta
Source: TRT estimation

The order of magnitude of our estimates compares well with other studies providing figures for European wide cost of road congestion such as CE Delft et al. (2011) and the JRC study (Christidis and Ibáñez, 2012). This latter study was based on the same data regarding observed delays, but this data has been used in our methodology in quite a different way and only for inter-urban costs. Therefore the good match between the two sources is not an artefact.

Table D: Yearly total deadweight loss (external congestion cost) per country (passengers)

| Country	Yearly total deadweight loss (million Euro/year)	Share of GDP (%)	Yearly inter-urban deadweight loss (million Euro/year)	Yearly urban deadweight loss (million Euro/year)
Austria	181	0.06%	56	125
Belgium	504	0.14%	284	220
Bulgaria	99	0.26%	28	71
Croatia	84	0.19%	5	79
Cyprus	15	0.08%	n.a.	15
Czech Republic	194	0.12%	45	149
Denmark	165	0.07%	74	91
Estonia	21	0.13%	2	19
Finland	129	0.07%	25	104
France	2,580	0.13%	1133	1,447
Germany	2,446	0.09%	401	2,045
Greece	296	0.14%	43	253
Hungary	106	0.11%	25	81
Ireland	166	0.10%	59	107
Italy	2,145	0.14%	701	1,444
Latvia	34	0.17%	4	30
Lithuania	45	0.15%	10	35
Luxembourg	23	0.05%	13	10
Malta	3	0.05%	n.a.	3
Netherlands	609	0.10%	247	362
Norway	152	0.06%	16	136
Poland	766	0.21%	311	455
Portugal	272	0.16%	101	171
Romania	213	0.16%	56	157
Slovakia	64	0.09%	25	39
Slovenia	30	0.08%	7	23
Spain	1,484	0.14%	392	1,092
Sweden	324	0.08%	50	274
Switzerland	202	0.04%	95	107
United Kingdom	2,749	0.08%	678	2,071
EU28	15,747	0.11%	4,775	10,972

* only urban cost for Cyprus and Malta
Source: TRT estimation

Of course, the absolute value of congestion cost is higher in larger Western countries (e.g. United Kingdom, France, Germany and Italy). However, when analysed as percentage of GDP, Eastern countries are more often above the EU average, with Bulgaria at the top of the ranking (more than 2% of GDP) and also Poland and Romania above 1.5%of GDP. On the other end of the ranking there are countries like Austria and Luxembourg where passengers delay cost is estimated to half percentage point of GDP or even less. This does not necessarily mean that in these countries congestion is very limited: at least in part the result depends on the high GDP level.

The contribution of urban and inter-urban congestion varies from country to country (see Figure D). On average urban congestion explains some 80% of total delay cost. The share is even higher in many Eastern European countries, especially in Croatia (96%), Estonia and Latvia (92% in both countries). Also in some Western European countries congestion costs are predominantly due to urban areas: e.g. in United Kingdom (85%), Germany (88%), Greece (90%). Inter-urban congestion costs are more significant in the geographical heart of Europe: Belgium, Luxembourg, France, and the Netherlands. In these countries inter-urban costs explain between one third and almost one half of total delay cost.

Figure D: Urban and inter-urban delay cost for passenger cars by country (Million Euro/year)
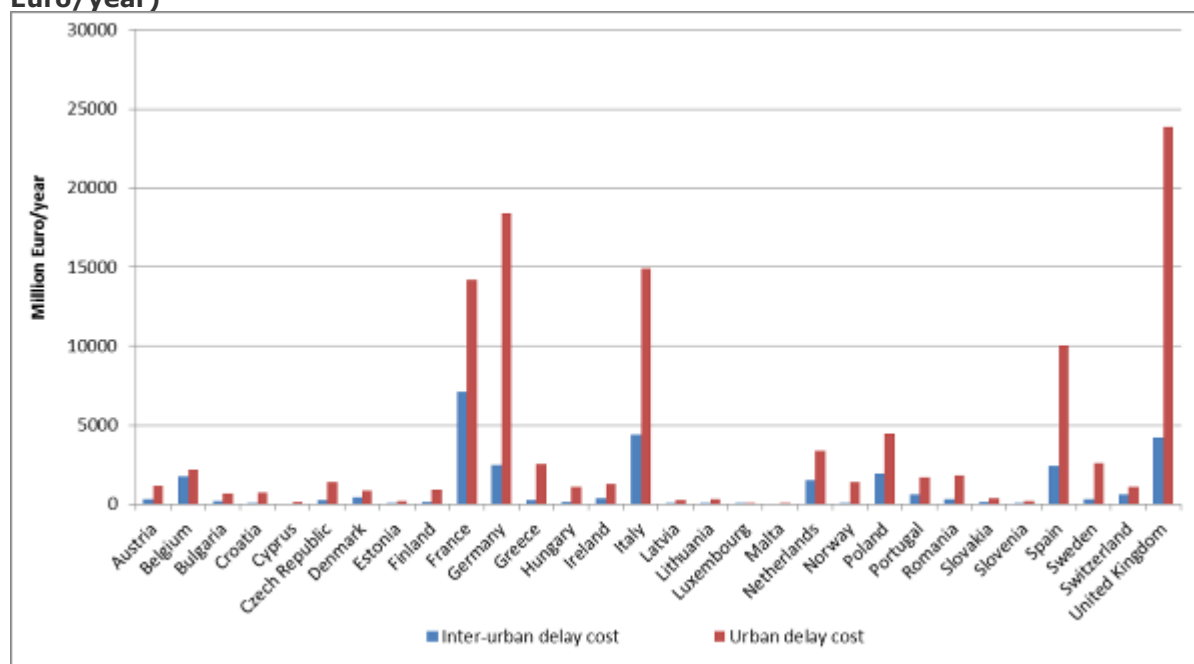
Conclusions

Making reference to impact of congestion on time losses (therefore not considering other costs such as additional fuel consumption or additional environmental externalities) and building on a theoretical discussion we have identified two different definitions of congestion cost based on alternative interpretations of impacts that traffic generates: delay cost and deadweight loss. Using a range of available information and tools we have developed a methodology to provide a quantification of congestion costs under both definitions. The methodology is sometimes complex, the estimations of urban and inter-urban costs are based on different procedures and data and several assumptions have been needed to obtain results. Results are related to congestion experienced by passenger cars at both urban and inter-urban level, while for freight, only the inter-urban dimension has been considered (due to lack of data). At urban level it has been assumed that the opportunity cost of time depends on local features and particularly economic activity, therefore applying values of time parameters by NUTS3 region, while

at inter-urban level the national value of time has been applied. We have demonstrated with some sensitivity analysis that different assumptions on key parameters can lead to significantly different values at least for urban congestion cost measured in terms of deadweight loss.

However, even considering these sources of uncertainty, the order of magnitude of the estimates is basically confirmed. Measured in terms of delay cost, the monetary value of congestion in EU is slightly more than 140 billion Euro per year, equivalent to some 1% of the GDP in the same area. Deadweight loss amounts to some 10% - 15% of this figure. In the theoretical analysis we have underlined that this is a monetary equivalent of time wasted rather than an actual expenditure.

Delay cost and deadweight loss provide two alternative measures of congestion costs. Using one or the other of the two estimations is a matter of perspective. If one wants to answer the questions "what is the cost of road congestion?" we think that one should make reference to the delay costs. However, if one wants to compare the costs of policy interventions aimed at alleviate congestion (e.g. infrastructure investments) with the potential benefit achievable, deadweight loss is a more meaningful measure because it takes into account of willingness to pay of individuals.

Congestion affects all European countries with some differences. In absolute terms congestion costs are higher in larger countries in Western Europe, but if compared to GDP most Eastern Europe countries suffer for higher costs. A large proportion of these costs depend on urban congestion, which explains on average some 80% of total costs (but more in many Eastern Europe countries). Inter-urban costs are more relevant especially in rich countries in the middle of Europe where probably the inhabitants of cities can use more efficient urban transport systems.

Our analysis has not unveiled any significant correlation between the estimated passenger congestion cost (delay cost and deadweight loss) and variables representing the features of the cities (e.g. population size, car mode share, public transport mode share). The only minor correlation found was between deadweight loss per capita and population of the cities: the higher the population size the lower the average congestion cost per capita. Therefore, congestion costs at urban level seems strictly related to local conditions of each specific city.

The methodology used for the estimation makes use of real traffic data in various forms. As the availability of this data is expected to grow in the future, the methodology could be replicated and refined (e.g. with larger sets of delay data) to update the estimates and monitor the trend of congestion costs over time.

Table of contents

1 Introduction

This report documents the outcomes of Task 2 of the study MOVE/C1/SER/2014-368/SI2.696637 "Assessing and improving urban accessibility". The general objective of the study is *"to improve understanding of urban accessibility and road congestion, and support a debate on understanding and improving urban accessibility in order to improve the functioning of urban areas and make the transport system more resource efficient".* The specific objectives of Task 2 are to:

▪ Analyse the availability of congestion cost estimates

▪ Review the methodological approaches used for generating these estimates

▪ Develop estimates of urban congestion costs from the literature that are as comparable as possible; and

▪ Estimate congestion costs at the national level for EU Member States.

As mentioned in the inception report, the content of Task 2 has been enriched with respect to what was initially proposed, namely:

▪ The role of urban public transport has been one of the criteria considered for the classification of congested European cities.

▪ We have extended the analysis to cities below the threshold of 50,000 inhabitants, although in a simplified way.

▪ Congestion costs have been compared to the size of GDP of regions and countries.

▪ The analysis of non-urban congestion costs has been discussed with JRC-IPTS in order to draw on their expertise.

With respect to the methodology set out in the inception report, there has been some deviation as a result of the initial results of the literature review. The original plan for the estimation of urban congestion costs was to collect studies from several different cities, analyse the results to understand what elements induce differences across cities and then use these elements to generalise the estimates to all urban areas in Europe. However, the survey of literature revealed that only a very limited number of studies providing estimates of urban congestion costs exist. Also, where they do exist, they are difficult to compare due to the large differences in methodologies used.

The methodology for the estimation of inter-urban costs has also been slightly adapted even though it has been based on the same elements, i.e. the information on congested spot based on real traffic data and the European transport network model.
Due to the lack of available relevant studies it was decided to revise the methodology for the estimation of urban congestion cost. The new methodology is based on the analysis and the generalisation of data on congestion levels in a wide sample of European cities as provided by the TomTom congestion index and the Inrix traffic scoreboard. This change was discussed with the stakeholders and with JRC IPTS also at the Brussels Workshop in mid-September 2015.

Finally, the scope of the analysis is focused on congestion costs in terms of time losses. Other costs, e.g. cost of additional fuel consumption, additional emissions, indirect costs on consumers were not in the scope of this study. At urban level,

congestion costs have been estimated for passenger cars only, while at inter-urban level, the estimation covered both passenger cars and trucks. Also, regarding inter-urban costs delays on the main European network, i.e. the TEN-T Comprehensive network (motorways, primary roads) as well as other roads of regional and sub-regional interest, are considered. .

This report is structured as follows:

- Section 2: General concepts about congestion and congestion costs are introduced and discussed to provide a background and set the scope of the analysis

- Section 3: Introduces the literature found on urban congestion cost estimates.

- Section 4 is devoted to the estimation of urban congestion cost. The methodology applied is explained in detail and the results for the sample of cities considered are presented and commented.

- Section 5: Estimation of non-urban congestion costs.

- Section 6: The generalisation of the estimates and the calculation of an overall congestion cost in EU.

- Section 7: Conclusions.

2 General aspects on congestion and congestion cost

This section sets out the background information on key terms, definitions and assumptions related to congestion and congestion cost, resulting from literature review.

2.1 Definition of congestion

A variety of definitions of congestion exist (Grant-Muller and Laird, 2007). Broadly speaking, definitions treat congestion like an objective event while others introduce subjective considerations. From an objective perspective congestion can be defined as the impedance vehicles impose on each other due to this relationship as the traffic flow approaches the maximum capacity of the network (adapted from Goodwin, 1997). The US Federal Highway Administration uses a definition where subjective elements are present: congestion is a relative phenomenon that is linked to the difference between the roadway system performance that users expect and how the system actually performs (quoted in OECD/ECMT, 2007).

For the purpose of this task, congestion is a defined as a condition where vehicles travelling on road links are delayed. The difference between objective and subjective elements of congestion will be at least partially reflected in the estimation of delay cost and deadweight loss (see section 2.4).

2.2 Forms of congestion

A relevant categorisation of congestion distinguishes between recurrent or non-recurrent. Recurrent congestion is the result of factors that act regularly on the transportation system. Basically recurrent congestion depends on a structural imbalance between demand and supply or, in other words, on "macro" factors such as the amount of generated trips, travel patterns, infrastructures capacity. Instead, non-recurrent congestion is caused by "micro" events (e.g. road works, crashes, weather conditions) that affect the transportation system on a random basis in space and time. It can be noted that some non-recurrent sources of congestion show a sort of regularity[2]. For instance accidents are a non-recurrent source of congestion in the sense that usually accidents do not happen every day, in the same spot and with a similar impact on traffic. However when a sufficiently long period of time (e.g. one year) and a sufficiently long part of the network are considered, it is statistically expected that a certain number of accidents will occur. In that sense accidents can be considered a more recurrent source of congestion in comparison to e.g. adverse meteorological conditions even if only in statistical terms.

The share of non-recurrent congestion varies from network to network. According to OECD/ECMT (2007), there are estimates that non-recurrent congestion can explain nearly half of total congestion, although management policies can significantly reduce this figure.

For the purpose of this task, we focus on recurrent congestion rather than on congestion generated by special circumstances. The reason for concentrating on recurrent congestion is that we aim to estimate representative figures for yearly congestion costs in the EU countries. In order to account for non-recurrent congestion

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[2] While at the same time, recurrent congestion can present large random variations (OECD, 2007).

a much more detailed representation of space and time would be needed. Even "statistically recurrent" congestion sources, for example accidents, are too complex to be considered in the context of this study. For instance, the number of accidents can be statistically estimated according to accident rates, but the impact on traffic of accidents is extremely variable depending on the exact location, time of day, number of vehicles involved, etc.

2.3 Impacts of congestion

The detrimental effect of congestion is usually thought of in terms of difficulty imposed on mobility. Indeed, the primary impact of congestion is increased travel time and/or its variability. Yet, congestion can also have a wide range of secondary effects (see for instance Figure 2-1). Reduced speed and especially "stop and go" traffic conditions can increase fuel consumption and pollution emissions. Congestion can reduce the accessibility of opportunities/activities and can negatively affect competitiveness.

For the purpose of this task we focus on the primary impact of congestion, namely the increase in travel time. Fuel consumption and pollutant emissions can be classed as different categories of costs and are estimated separately (within this study operating costs, energy consumption and emissions will be dealt with in Task 3) with parameters and functional forms that take congestion into account (e.g. representative energy consumption factors for urban areas consider that cars do not travel in free-flow conditions). Indirect impacts such as those on the competitiveness of business are highly dependent on local conditions and are difficult to quantify, especially at the strategic level of analysis of this study.

Unreliability of travel time is a primary effect of congestion. However, its quantification is much more complex and dependent on specific circumstances than increase in travel time. Actually, while there is much literature and recommended values for travel time savings, value of travel time reliability is much less investigated and standard values do not exist (OECD/ECMT, 2007). Given the difficulty of quantifying impacts on reliability and the lack of robust estimations of its value, this element is not considered in this task.

Figure 2-1: Direct and indirect impacts of congestion

			Vehicle related impacts			Persons related impacts							Business related impacts	
			\- CONGESTION IMPACTS -											
Level of impact: Null / Low / Medium / High / Very high. Tipus of impact: D = Direct, I = Indirect. (*) impact that only appears if they use own vehicles			Increase of fuel consumption	Increase of maintenance of the vehicle	Vehicle damages (due to the increase of accident)	Personal damages (due to the increase of accident)	Increase of environmental pollution	Increase of noise pollution	Stress	Increase of travel time (persons)	Lack of punctuality	Journey reliability (increase of scheduled time)	Increase of travel time (goods)	Loss of profitability of employees
INSIDE THE TRAFFIC FLUX	Private vehicles	Car drivers	D	D	D	D	D	D	D	D	D	D		
		Car passengers				D	D	D	D	D	D	D		
		Motorcycle drivers	D	D	D	D	D	D	D	D	D	D		
		Motorcycle passengers				D	D	D	D	D	D	D		
		Non-motorized users (bicycles)		D	D	D	D	D	D	D	D	D		
	Public transportation	Public transport drivers				D	D	D	D					
		Public transport passengers				D	D	D	D	D	D	D		
		Taxi drivers		D *	D *	D	D	D	D					
		Taxi passengers				D	D	D	D	D	D	D		
	Business activities	Employees that earn a salary				D	D	D	D					
		Employees that are paid for journey				D	D	D	D	D	D			
		Autonomous workers	D	D	D	D	D	D	D	D	D	D	D	D*
		Drivers of emergency services				D	D	D	D			D		
OUTSIDE THE TRAFFIC FLUX	Personal activities	Roadside residents					I	I	I		I			
		Sidewalk users					I	I						
		Rest of residents of the city					I				I			
	Business activities	Roadside businesses	I*	I*	I*						I	I	I*
		Roadside offices									I		I
		All businesses outside the congested area	I*	I*	I*						I	I*	I
Categories used to evaluate congestion costs			Operation costs			Other costs (in most cases considered as transport externalities)				Costs of time loss				

Source: OECD/ECMT, 2007.

2.4 Costs of congestion

The purpose of this task is to estimate congestion costs in the EU countries based on existing reports and studies in the literature. Taking into account the specifications made above, we consider the costs attached only to additional travel time resulting

from congestion, excluding a series of other costs, e.g. cost of fuel, environmental externalities, indirect costs on consumers, etc.

It should be noted that this cost is an estimation of the monetary equivalent of additional travel time rather than a true financial cost borne by individuals or companies. With a few exceptions (e.g. clients of taxicabs paying a higher charge because of longer travel time due to congestion, companies delivering freight that have to use more vehicles – and therefore drivers – to complete consignment in due time) travel time wasted in congestion does not entail any monetary expenditure or missing revenues.

Also, interpreting the estimation in monetary terms of congestion cost as an economic benefit that individuals could enjoy if congestion were removed is actually incorrect. As pointed out by Goodwin (2004): "The implied annual dividend [...] to be distributed to each family is a fiction. It is calculated by comparing the time spent in traffic now, with the reduced time that would apply if the same volume of traffic was all travelling at free flow speed, and then giving all these notional time savings the same cash value that we currently apply to the odd minutes saved by transport improvements. But this could never exist in the real world – not for reasons of practical difficulty, but because it is internally inconsistent. If all traffic flowed at free flow speed, we can be quite certain there would be more of it, at least part of the time saved would be spent on further travel, and further changes would be triggered whose value is an unexplored quality. It is apparently a precise answer to a phantom question".

Congestion costs can be considered under different perspectives (CE Delft et. al., 2011; DIW econ et. al., 2014). The most common stylisation of congestion considers vehicles using a link of a given capacity. As the number of vehicles increases the speed deteriorates and all users will experience a delay with respect to free-flow conditions. The monetary value of this delay is one intuitive measure of the economic value of congestion (the measure mentioned in Goodwin's quote above). In the remainder of this report we will make reference to this measure as **"Delay cost"**.

The attractive feature of this measure is that it is based on an objective reference, i.e. the free-flow conditions. However the implicit logic behind delay cost is that congestion cost will be always positive unless everyone can travel in free-flow conditions, which is quite unrealistic especially in urban areas where the capacity required to deliver undisturbed travels could not be provided.

As mentioned above, the definition of congestion can also be based on some subjective elements. One subjective element is users' willingness to pay to travel in less congested conditions. The economic view of congestion, based on the principles of welfare economics, incorporates this aspect. Under the economic approach, it is assumed that the level of demand on links is the results of individual choices based on minimisation of costs. Motorists' choices are based on perceived average costs. When a new vehicle enters a link, it increases the cost for all the vehicles already using the network. However the driver of the marginal vehicle neither perceives this additional cost nor pays for its impact on other drivers. Therefore an external cost arises. According to the welfare economics principle, the cost of congestion is an externality at the extent it exceeds the willingness to pay of road users.

Figure 2-2 helps to illustrate the concept of external costs of congestion. The level of demand on a given link tends to be the equilibrium at the value D_0, where the average cost curve crosses the demand curve. The demand curve shows the willingness to pay of different levels of demand for travelling on the link. However, the social cost SC_0 for the demand level D_0 is larger than the private cost PC_0. Efficient equilibrium is at the

level of demand D_1 where the demand curve crosses the marginal cost curve, which includes the extra costs generated by additional vehicles which enter the link. The external costs of congestion are those generated by demand in excess of D_1. The area between the demand curve and the social cost curve (area CBA in Figure 2-2) is the measure of the external cost of congestion. This measure is often termed as **"Deadweight loss"** and we will use this definition in the remainder of this report.

Figure 2-2: Different definitions of congestion costs
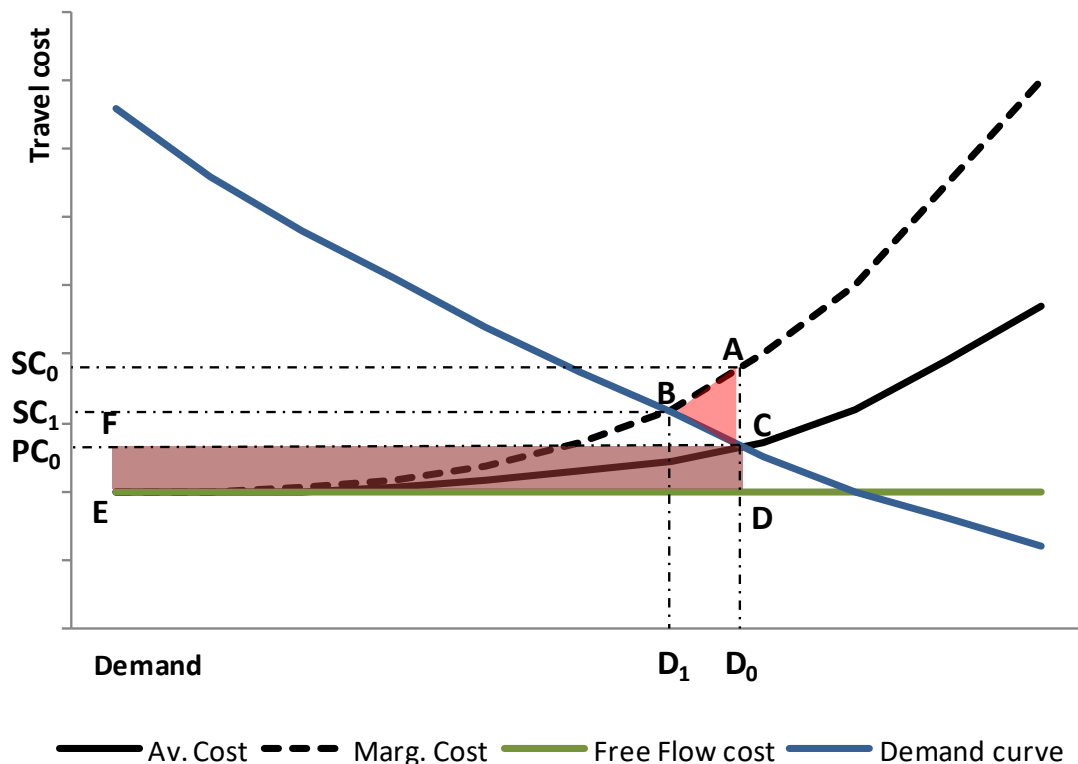
It can be noted that according to this approach, demand levels lower than D_1 are not desirable despite that they impose a delay to the free-flow travel time, and even a social cost larger than private cost. When demand is below D_1 the link is inefficiently used because the willingness to pay is higher than the actual marginal cost. In other words, the social cost for reducing congestion exceeds the benefit of such a reduction.

Deadweight loss is therefore the external cost of congestion while delay cost is the internal cost. For the purpose of this task, both the approach based on the delay with respect to the free-flow conditions and the economic approach based on external cost will be used and two separate estimations of congestion costs will be provided. In principle external costs are more representative of realistic conditions than delay costs. OECD/ECMT (2007) even strongly recommend to avoid estimating congestion costs based on delay to free-flow conditions. However we do not support such a radical view. Provided that the assumptions behind the estimations are understood, the quantification of congestion costs based on the absolute benchmark of free-flow conditions can provide some useful information especially when different situations are compared.

Indeed, behind the economic approach there are some implicit assumptions that can make comparisons difficult, namely:

- On a given road, as demand varies, the desirable level of traffic - and of speed – also varies.

- In particular, as demand increases, the optimal level of traffic on a road will increase, i.e. the level of congestion that is acceptable varies according to the level of demand.

These aspects are depicted in Figure 2-3. When demand curve 1 applies, market equilibrium demand based on private costs is D_{01} and social optimal equilibrium demand is D_{11}. If demand curve 2 applies the market equilibrium demand D_{02} is higher but also social equilibrium demand D_{12} is higher, even larger than the market equilibrium demand with demand curve 1. So, observing two roads where the normal levels of congestion are different, one cannot immediately conclude that external congestions costs are higher on the most congested road because the demand curve on the two links can be different.

Figure 2-3: External costs for different initial demand levels
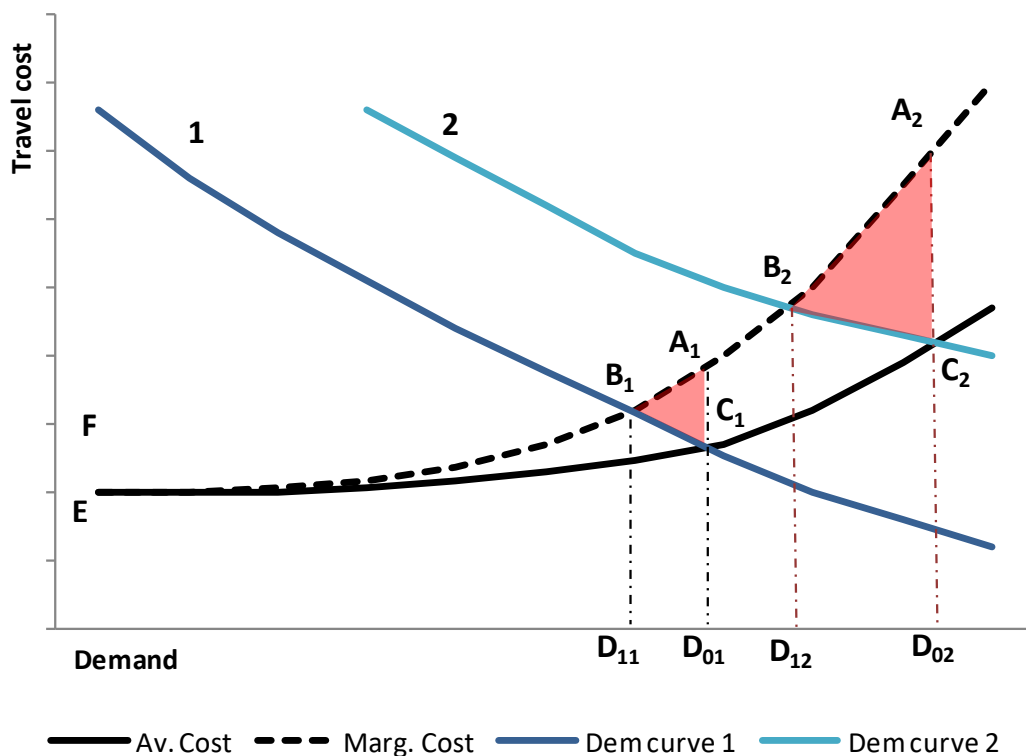
Instead, the cost of delays with respect to the free-flow conditions would be clearly higher on the most congested road. This indicator would provide a more understandable comparison between the roads unlike the absolute cost values are less significant. That's why we will provide both measures of congestion costs.

It should also be considered that the analysis of congestion according to the simple model summarised in the figures above is a simplification. First, the model refers to a single link to which a specific speed-flow relationship applies whereas in the real world links belong to networks made of links with different features. Second, in the model there is one demand function whereas in the real world there are several user categories with different preferences and willingness to pay. Since the different categories share the use of the network, the definition of the socially optimum

demand level is not straightforward. Therefore costs estimates are necessarily approximations.

Further approximation is generated by the aggregated level of analysis. In this task we aim at estimating costs for urban and inter-urban congestion for the EU28 countries, rather than for a single link or a small network. Then, we'll use the concepts introduced above in a form adapted to the requirements of the strategic level of analysis of this study (details are provided in sections 4 and 5).

2.5 Summary

Road congestion is quite a common experience but its definition involves some complexity. Different perspectives can be adopted and different types of impacts can be considered, so the estimation of congestion and of its cost is methodologically challenging.

Considering that the focus is narrowed on recurrent congestion (that only time losses of private cars drivers are accounted for) one should consider that total congestion costs are probably higher than the estimates provided below.

3 A review of urban congestion costs estimates

This section reports on the studies identified in the literature providing estimations of congestion costs at the urban level. Indeed, we have found very few examples of such estimations. Lately, especially since data from mobile sources has become available, there has been an increase in the number of sources delivering information on the level of congestion (this information is used in section 4 for our estimations of urban congestion costs). However, very little comparable on the estimation of congestion costs has been identified, since different approaches are used and not many studies report this type of analysis.

For each study we present a brief summary of the city under investigation, the scope of the analysis, the definitions applied for the cost of congestion, the methodology used, and relevant assumptions used in the analysis. The outcome of the review is discussed at the end.

3.1 Metropolitan area of Vancouver

This report (TransLink, 2015) contains the results of a study undertaken to assess the effect of congestion on the economy and residents of the metropolitan area of Vancouver (Canada) in addition to measuring the extent of congestion in terms of traffic, speed, and other indicators. These costs are estimated for Metro Vancouver currently and in 2045 under various strategic transportation alternatives considered for the Metro Vancouver Region.

The City of Vancouver is a coastal seaport city on the mainland of British Columbia, Canada. Approximately 600,000 people live in the city, while the Metro Vancouver Region is home to around 2.4 million inhabitants. In 2011, Vancouver was the most densely populated city in Canada. Urban planning in Vancouver is characterised by high-rise residential and mixed-use development in urban centres, as an alternative to sprawl.

In 2014, Vancouver was the third city with worst traffic congestion in North America after Los Angeles and Mexico City[3]. Nevertheless, although the car mode serves as the primary mode of transportation (similar to most other cities), Vancouver does have alternatives such as the SkyTrain system (the longest fully automated light metro system in North America), the West Coast Express train, an extensive public transport network (including buses, trolleys, community shuttles and a SeaBus) as well as an extensive network of bike routes.

The study adopts an economic approach to measure external congestion costs according to the principles explained in section 2. The approach is applied independently to three types of roadways in the region: Low, Medium and High Volume Capacity. In other words, the approach, which is theoretically defined for a single link is applied in an aggregated form, considering more links together.

The private cost function is estimated considering time costs as well as operating costs. Time costs are estimated using a speed-flow relationship and a value of time.

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[3] TomTom congestion index, 2014 data

Operating costs include fuel and maintenance. Demand function is estimated using a demand elasticity.

The data for applying the approach included observed elements provided by Metro Vancouver, as well as various modelled (estimated) parameters taken from the Regional Transportation Model. Table 3-1 summarises the input used and the results of the estimations.

Table 3-1: Summary of Key Input Data for Calculation of Deadweight Loss and Results in Metro Vancouver

Data	Low capacity roads	Medium capacity roads	High capacity roads	
Peak period vehicle-km (millions)	1325	2116	3716	Based on the Regional Transportation Model
Baseline congested speed (km/h)	35.3	42.2	64.1	Model output: average speed
Average free-flow speed (km/h)	50	56	67	Based on data provided by TransLink
VOT (weighted truck and car, $/h)	16.69			Calculated by HDR based on the value of time of $13.02 per person per hour, average auto occupancy of 1.46 and truck traffic share of 9.8%.
BPR curve: ▪ Coefficient ▪ Exponent	0.05 10			Congested Speed = (Free-Flow Speed)/(1+0.05[volume/capacity]^10)[4]
Flow-capacity ratio	1.24	1.21	0.99	Calculated from the BPR curve.
Elasticity of travel demand	-0.5			Reasoned assumption
Average cost of driving (AC): initial conditions, $/km	0.683	0.605	0.470	Calculated from cost model inputs
Average cost of driving (AC): optimal conditions, $/km	0.570	0.530	0.460	Calculated from cost model inputs
Excess travel time of current traffic (millions $)	142.69	154.83	19.61	Calculated from cost model inputs
Excess traffic (millions Veh-km)	186	275	224	Calculated from cost model inputs
Optimal traffic (millions Veh-km)	1141	1841	3492	Calculated from cost model inputs
Proportion of peak Vehicle-km in excess	14%	13%	6%	Calculated from cost model inputs. Used to estimate non-recurrent congestion.
Deadweight loss (millions $)	101.2	108.1	11.5	
Excess accident costs (millions $)	32.8	49.1	40.0	
Excess emission	4.2	6.4	5.2	

[4] From 'Updated BPR Curve' (www.mtc.ca.gov/maps_and_data/datamart/research/boston1.htm)

costs (millions $)				
Transit excess travel time (millions $)	21.8	23.7	3.0	
Total cost of congestion (millions $)	160.06	187.29	59.67	Sum of the cost components above.
	407.02			

Source: Current and Projected Costs of Congestion in Metro Vancouver (2015).

As shown in Table 3-1 congestion costs for transit users (namely bus users) were also estimated as well as the costs of emissions and accidents generated by the amount of traffic exceeding the optimal volume of travel (i.e. the one where demand function crosses the social cost curve). The time component of congestion cost for transit riders was estimated under the assumption that the difference in implied vehicle hours that result under actual speed and the optimal speed represent the excess delay to transit users. This is then multiplied by the value of time and bus occupancy rate to obtain total value of excess delay to transit riders. The emissions and accidents component of congestion cost were estimated on the basis of unit emissions and unit accident costs multiplied by excess traffic (in vehicle-km) estimated at earlier steps.

In addition to the impacts of recurrent congestion (occurring regularly as a result of normal travel levels), estimates of non-recurrent costs of congestion (due to random events, e.g. incidents such as stalled vehicles, spills, construction, or inclement weather) were also made based on a 2006 study by Transport Canada[5].

Furthermore, the study develops a framework for quantification of the macro-economic costs of congestion in the form of business costs and lost business activity.
Taking into account deadweight loss only, the congestion cost for Metro Vancouver is 220.8 million Canadian dollars$_{2011}$[6] (about 92 $ per capita, i.e. about 72 Euro$_{2011}$ per capita).

3.2 Ile-de-France Region (and France)

This paper (Koning, 2010) addresses the problem of road congestion accessing the French city of Paris. More specifically the evolution of the congestion cost for the Paris Ring-Road (PRR), the major urban motorway surrounding the French capital, is evaluated during the period from 2000-2007. Building on this estimation a generalisation is made at regional and national scale to provide an order of magnitude of the value of time losses. The results are also used to propose marginal pricing schemes which could potentially be used in order to correct road congestion externality on the PRR.

Paris is the capital of France and the centre of the Ile-de-France Region; the City of Paris has a population of about 2.2 million inhabitants, while around 12 million live in the Ile-de-France Region.

The city is a major rail, motorway, and air-transport hub. The city is also the most important hub of France's motorway network and is surrounded by three orbital freeways: the Périphérique (PRR), the A86 motorway in the inner suburbs, and finally the Francilienne motorway in the outer suburbs. The use of car mode is lower than in

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[5] "Costs of Non-Recurrent Congestion in Canada", 11 December 2006, Transport Canada, Economic Analysis, TP14664E
[6] Canadian dollars$_{2011}$ and Euro$_{2011}$ refer to exchange rate at the year 2011

other cities, thanks to an extensive network of public transport services. Furthermore, there are about 440 km of cycle paths and routes (pistes and bandes cyclable) in Paris.

External congestion costs are estimated according to the economic concepts introduced in section 2. The estimation of optimal traffic levels on the PRR (and therefore the specification of cost and demand curves) was repeated for different speed-classes of 5 km/h: for each class of speed (from an average of 2.5 km/h to 85.5 km/h), vehicle density and flow are available and the optimal road use and the corresponding indicators are estimated. Unit costs are then obtained by estimating the variation of economic surplus corresponding to each speed-class and applied to the correspondent number of vehicles-km observed on the PRR (e.g. in 2007 about 15.6% of traffic was travelling with an average speed of 67.5 km/h, for a total amount of 358.09 million veh-km, with an estimated unit congestion cost of 0.002 euro/veh-km). Temporal and geographic segmentations were introduced: peak and off-peak time periods were considered separately and the PRR was segmented into four sections (north, south, west, and east).

The estimation framework was populated with input data on traffic from empirical traffic counts on the road sections of PRR, providing average speeds, density and hourly and daily traffic. Assumptions on driving costs, value of time and demand elasticity have been taken from other official references.

The study provides estimates for the years 2000 and 2007, which are reported in Table 3-2 below. Results for 2007 are generalised at urban, regional and national scale to provide an order of magnitude of the value of time losses. In order to expand the result, it is considered that central Paris and the PRR were, in 2006, responsible for 26 % of queues recorded at the national level (and 33 % at the regional level). Furthermore, it is known that vehicle-km driven on the PRR correspond to 33.5 % of those driven in Paris. Two alternative assumptions are then used: the first is that road congestion cost per vehicle-km in France is the same as in Paris (values labelled as Paris (P) = PRR in Table 3-2). The alternative assumption stipulates that traffic difficulties in Paris are on average two times worse than elsewhere in France (see Table 3-2).

Table 3-2: Summary of Key Input Data for Calculation of congestion costs and Results on Paris Ring Road (PRR)

Data	2000	2007	Notes
Daily traffic in vkm (millions)	7830	7661	Based on traffic counts
Average speed (km/h)	45.9	43.5	Based on traffic counts
Average speed during peak periods (km/h)	30.4	28.6	
Average speed during off-peak periods (km/h)	57.3	54.4	
Average free-flow speed (km/h)	90		
VOT (weighted truck and car, Euro/h)	16.69 Euro		Boiteux report (actualized): the value of time of 10.2 Euro per person per hour in 2007, 13.4 for Home-Work displacements. Average auto occupancy of 1.3 and truck traffic share of 23% (with VOT of 31.4 euro/h).
Speed-flow function	f(s) = 356.86*s – 3.95*s2		Empirical evidence from traffic counts
Elasticity of travel demand	-0.4 peak period -0.8 off-peak period		Reasoned assumption
Average cost of driving (AC): initial conditions, Euro/km	0.26 euro/km	0.3 euro/km	Calculated from cost above and assuming the increase by 14.5% of price index of motorised displacements between 2000 and 2006
Total cost of congestion on PRR (millions Euro)	117.2	130.1	Aggregated approach
Cost of congestion during peaks on PRR (millions Euro)	85.9	100.5	
Cost of congestion during off-peaks v (millions Euro)	40.2	44.9	Disaggregated approach by time period
Total cost of congestion on PRR (millions Euro)	126.1	145.4	
Total cost of congestion in Paris+ PRR (millions Euro)	-	518 906	Aggregated approach (Paris unit congestion cost= PRR unit congestion cost) (Paris unit congestion cost= twice PRR unit congestion cost)
Total cost of congestion in Ile-de-France (millions Euro)	-	1,571 2,748	Aggregated approach (Paris unit congestion cost= PRR unit congestion cost) (Paris unit congestion cost= twice PRR

			unit congestion cost)
Total cost of congestion in France (millions Euro)	-	1,994 3,487	Aggregated approach (Paris unit congestion cost= PRR unit congestion cost) (Paris unit congestion cost= twice PRR unit congestion cost)

Source: Koning (2010)

Taking into account deadweight loss of the aggregate approach, the congestion cost for Ile-de-France ranges from 1,571 to 2,748 million Euro (about 130 to 230 euro per capita).

3.3 Congestion costs in six Italian cities

This study (Fondazione Caracciolo, 2013) analyses various aspects related to urban transport and mobility in Italy. Among the various themes considered, a chapter is focused on congestion costs. Estimates are provided for six Italian cities: Palermo, Rome, Milan, Naples, Genoa, and Turin. Table 3-3 provides some information on the six cities under analysis.

Table 3-3: overview on the Italian cities under analysis

City	Population 2014	Car share	PT share	TomTom congestion index 2014*
Palermo	678,492	44%	16%	42%
Rome	2,863,322	66%	28%	38%
Milan	1,324,169	41%	49%	30%
Naples	989,111	48%	24%	29%
Genoa	596,958	49%	26%	22%
Turin	902,137	64%	28%	22%

* increase in overall travel times when compared to a Free Flow situation
Sources: elaborations on data from ISTAT, EPOMM, TomTom

The estimates concern the monetary value of time wasted due to congestion, i.e. the cost of delay as defined in section 2.1 above. As for the case of Vancouver, a whole network is considered rather than just a link. The starting point of the process is the TomTom congestion index for the year 2012. The congestion index is a measure of the increase in overall travel times when compared to a Free Flow situation[7]. An absolute value of delay was obtained by making reference to the average travel time per trip provided by the survey on mobility in Italy carried out yearly by ISFORT[8] (on average about 57.9 minutes in 2011). The monetary value of the time wasted in congestion per capita for car users and PT users was estimated applying value of time drawn from the HEATCO project. The total congestion cost for each city was finally calculated taking into account the amount of population travelling and the share of trips by mode of transport used (car and PT).

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[7] More details on the TomTom index data are provided in section 4.

[8] http://www.isfort.it/sito/statistiche/Audimob.htm

Table 3-4: Summary of Key Input Data for Calculation of congestion costs and results in selected Italian cities

| Data	Palermo	Rome	Milan	Naples	Genoa	Turin
2012 TomTom congestion index (%)	39%	34%	26%	24%	23%	23%
Time wasted in congestion per year (h)	98.83	87.39	70.45	70.45	58.70	58.70
Average yearly congestion cost per capita: car users (euro/year)	1,137.48	1,005.91	810.82	810.82	675.68	675.68
Average yearly congestion cost per capita: PT users (euro/year)	817.29	722.75	582.58	582.58	485.48	485.48
Total cost of congestion (millions Euro)	542.661	2306.846	794.053	593.206	280.436	495.673
2012 Population	656,829	2,614,263	1,240,173	961,106	584,644	869,312
Cost of congestion per capita (Euro/year)	826.2	882.4	640.3	617.2	479.7	570.2

Source: Fondazione Caracciolo (2013)

The estimated delay congestion cost for the six Italian cities above ranges from 280 to 2,300 million Euro (about 480 to 880 euro per capita). Values per capita are much larger than the figures reported for the previous studies in Vancouver and Paris, but this is in line with the expectations because those studies deals with external costs rather than delay costs.

3.4 The economic costs of gridlock in the UK, France and Germany

This study (Cebr-INRIX, 2012) has addressed the estimation of direct and indirect economic costs placed upon households due to workers and businesses experiencing heavy road traffic congestion during peak periods. The study analyses the amount of time spent idling in traffic jams by commuters, business travellers and freight vehicles in large urban zones (LUZs) of the UK, France and Germany (see Figure 3-1) with special focus on London, Paris and Stuttgart.

Figure 3-1: Large Urban Zones (LUZs) in UK, France and Germany
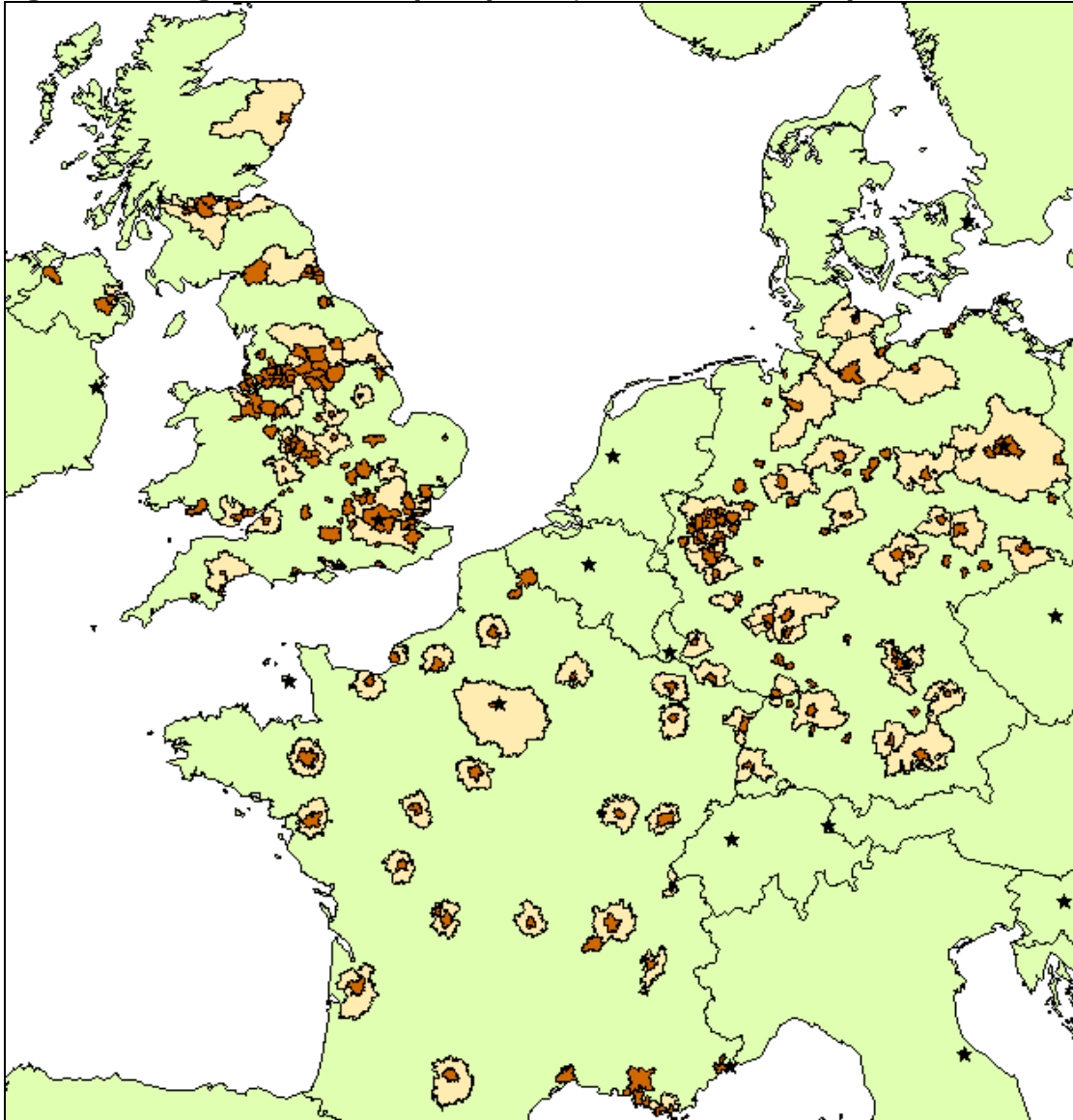
Source: Cebr-INRIX (2012)

Building on the amount of idle time, three sources of congestion costs are considered in the study:

- Value of lost working hours for commuters

- Cost of fuel consumed during idle time

- Indirect costs to households in terms of higher consumer prices. Higher prices are explained by higher production costs because of delays imposed by congestion to business travellers which lowers productivity. Furthermore, time spent idling by both light goods vehicles (LGVs) and heavy goods vehicles (HGVs) imposes higher freight costs on businesses, which are in turn passed on to the consumer.

The first source of congestion costs is a sort of delay cost, although restricted to a specific category of road user. While delay costs consider the reduced speed in comparison to free-flow condition, here only the idling time is considered. The other two sources of costs associated with congestion are instead not related to increased travel time and therefore are beyond the specific scope of this report.

The methodology applied in the study followed a three-stage approach:

First, the average number of annual 'wasted hours' per vehicle spent idling during peak periods was estimated based on INRIX data[9].

Second, the direct costs to car-commuting households for workers' time spent idling in traffic was quantified as well as the cost related to higher fuel consumption. The value of commuter wasted time was estimated by applying a value of time to the amount of wasted hours (therefore the delay cost principle was applied). The value of time was assumed to be as much as 50% of the hourly wage[10]. In order to calculate direct fuel costs, fuel price averages for regular unleaded petrol were used together with an average fuel consumed per vehicle when idling.

Third, the indirect costs imposed to all households as result of business travellers and road freight idling in traffic was estimated. The estimate is based on the principle that employees spend more time stuck in traffic and less productive time in the workplace. This loss of productivity raises the unit costs of production i.e. the cost of producing a unit of economic output. Unit costs are also pushed up by higher fuel and labour costs faced by freight companies. The study assumes that 80%-90% of these additional costs are passed on to consumers in the form of higher prices for goods and services that are produced. Higher prices reduce the quantities of goods and services purchased by households which results in a loss of consumer welfare, according to economic welfare approach.

The main inputs used for the estimations as well as the results for three Large Urban Zones and aggregated at the national level are shown in Table 3-5. Taking into account the estimation of direct and indirect costs, the total congestion cost for the LUZs above ranges from 960 to 2600 million Euro, while direct costs account for about 700 to 1800 million Euro (about 110 to 260 euro per capita).

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[9] Similarly to TomTom, INRIX provides indicators of congestion in several urban areas worldwide, see http://inrix.com/scorecard/

[10] Only a share of hourly wage was considered under the assumption that part of productivity lost in traffic is recovered during the working week

Table 3-5: Summary of Key Input Data for Calculation of congestion costs in peak hours and Results in LUZs of UK, France, and Germany

Data	London	UK*	Paris	France*	Stuttgart	Germany
INRIX annual wasted time per vehicle (h)	66.1	39.2	57.8	45.4	57.9	40.8
VOT commuting (euro/h)	13.5	9.7	11.7	9.5	10.8	8.9
VOT business (euro/h)	28.6	18.5	36.2	26.6	25.9	23.2
Share of traffic during peak periods (AM and PM)	Commuting 82% Business12% Trucks 6%					
Direct costs (higher fuel and value of time costs) (Million euro/year)	1358	3620	1817	3883	701	5647
Indirect costs (higher costs of goods & services) (Million euro/year)	539	1320	858	1674	261	2183
Total cost of congestion (millions Euro/year)	1896	4940	2675	5557	962	7830
LUZs Population (from Urban Audit)	12 208 100		11 755 918		2 691 666	
Direct Cost of congestion per capita (Euro/year)	111.2		154.6		260.4	

national value refers to LUZs only

3.5 Comments on the review of urban congestion cost estimates

In this section we presented four different studies addressing the estimation of urban congestion costs. We do not claim that these four studies are the only existing examples of estimations of urban congestion costs, nevertheless despite a thorough search in the public domain (and having also questioned stakeholders whether they were aware of applications where congestion costs have estimated without receiving any positive response) we have not been able to find additional documented estimates. Therefore we think that our desk survey of literature has demonstrated that there are very few studies on this matter.

The four studies are based on different methodologies and assumptions (see Table 3-6 for a summary). Two studies out of four adopt a definition of costs based on the economic principle of externalities (deadweight loss) while the other two consider delay costs. Two studies focus on the effect of congestion on travel time whereas other two include also other aspects. One study considers the overall city road

network (although segmented in different road types) as the basic element of the analysis (i.e. the theoretical framework introduced in section 2.4 concerning the cost curves and the demand curve is applied the overall road capacity of the city), another study starts from a trunk road infrastructure and generalise results while two studies considers cities as a whole. Simulated results from a model is used in one studies, speeds and road occupancy based on traffic counts are used in another while GPS based delay data feeds other two studies. Given these methodological differences the costs estimated are unsurprisingly different. Studies estimating deadweight loss come up with somewhat lower values (per capita) as expected but in general terms costs are hardly comparable even if restricted to the time component.

In summary, the existing literature on the estimates of urban congestion costs is not abundant and does not provide any robust ground to generalise the analysis at the European level. Given the purposes of this study an independent estimation is required. The usefulness of the existing studies lies especially in their methodological approaches and can be inspiring for the independent application required.

Table 3-6: Comparison of the four studies reporting estimations of urban congestion costs

Element	Vancouver	Paris	Italian cities	LUZs in FR, DE, UK
Target	Car users; Truck drivers; Transit users	Car users	Car users; Transit users	Car users; Truck drivers
Cost elements	Time losses; Additional emissions; Additional accidents	Time losses	Time losses	Time losses; Additional fuel consumption; Higher consumers prices
Type of time component cost	Deadweight loss (delay cost for transit users)	Deadweight loss	Delay cost	Delay cost
Source of congestion data	Observed + modelled (regional transport model)	Traffic counts	TomTom data	Inrix data
Base unit of analysis	Whole city network segmented in three road types	One major road infrastructure	Whole city	Whole city
Average cost estimated§	72 €/capita-year	130-230 €/capita-year	480-880 €/capita-year	100-260 €/capita-year

§ Only time component of congestion cost

4 Estimation of urban congestion costs

In this section we present our estimation of urban congestion costs. At the urban level, congestion costs have been estimated for passenger cars only as available information does not allow to provide a reliable estimation of congestion costs for other type of traffic (e.g. freight vehicles or public transport users). As mentioned above, estimations take into account only time losses, other costs, e.g. cost of fuel, environmental externalities, indirect costs on consumers, etc. are not in the scope of this study. The methodology followed for the estimation is explained in detail and results are shown.

Given the purpose of Task 2, both the delay cost with respect to the free-flow conditions and deadweight loss based on external cost have been estimated using two separate methodologies.

## 4.1 Methodology for estimating costs of urban congestion

The most common information on urban congestion is estimations of time wasted in traffic jams. TomTom and INRIX indexes are elaborations of this information, providing the total average percentage increase in travel time with respect to Free Flow conditions[11] for passenger cars as well as other indicators, e.g. the delay within a 30 minute commute during peak periods (within a day and/or a year).

In order to derive the monetary values of delay costs and deadweight loss of urban congestion related to passenger cars, data from TomTom and INRIX indexes has been analysed and elaborated to obtain a set of estimations for several European cities. This set of estimations has been used for statistical analysis and to extrapolate as a further step a generalised function for European cities, to be applied also where congestion indexes are not available (see chapter 6).

The overview of the methodology is presented in the following figure.
The welfare economic approach is used to define a measure of delay cost and external costs of congestion of each city, which is used together with the congestion indexes and other relevant information (population, value of time, share of car mode split, car occupancy factor) to estimate the congestion cost per year (per capita and at urban level).

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[11] A Congestion Level of 12% corresponds to 12% longer travel times compared to a Free Flow situation

Figure 4-1: Methodology for the estimation of urban congestion costs
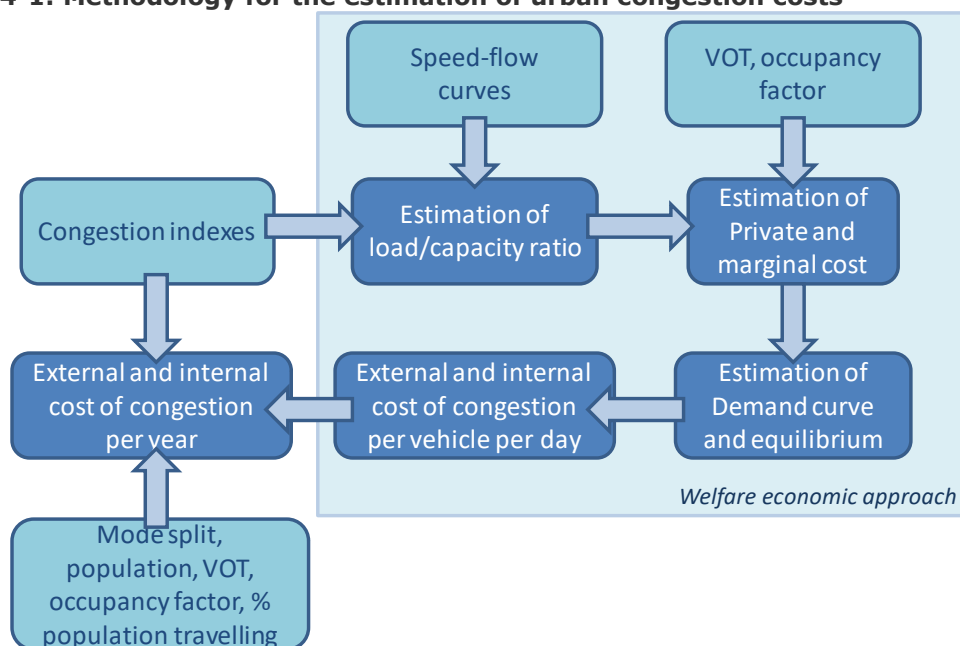
The welfare economic concept of **external costs of congestion** was described in chapter 2.4. Accordingly, for the purpose of this task, the external costs of congestion are those generated by demand in excess with respect to the efficient equilibrium, where the demand curve crosses the marginal cost curve (deadweight loss). In quantitative terms, the area between the demand curve and the social cost curve (area CBA in Figure 2-2) is the measure of the external cost of congestion.

In principle this model applies to single links, but we apply the same concept at the level of whole urban areas (similarly to what has been done in the study for the city of Vancouver reported in the previous section). We are aware that this generalisation raises methodological issues but at the scale of our study working at link levels would not be feasible.

4.1.1 Data provided by TomTom and INRIX

The methodology applied for the estimation of deadweight loss and delay cost of urban congestion builds on the congestion indexes provided by TomTom (and INRIX) in aggregate terms by city. TomTom provides online data for 101 European cities (including Norway and Switzerland), while INRIX provides online data for about 94 Larger Urban Zones (LUZs). Table 4-1 – 4-4 report the indicators available from TomTom and INRIX.

Table 4-1: TomTom indicators

Indicator	Definition
Congestion level	Increase in overall travel times when compared to a Free Flow situation (i.e. a traffic situation in which travel times are not worsened by traffic congestion, most typically during the night). For example, a Congestion Level of 12% corresponds to 12% longer travel times compared to a Free Flow situation.
	The Traffic Index figures are based on speed measurements from TomTom's historical traffic database. These speed measurements are used to calculate the travel times on individual road segments and entire networks. By weighting based on the number of measurements, busier and more important roads in the network have more influence than quieter, less important roads. This makes the statistics match the user experience of people driving in the cities.
Delay per day with a 30 min commute	Part of the commuting time caused by delay. Based on two 30 minute peak period journeys per day. Only measurements during peak periods are taken into account.
Delay per year with a 30 min commute	Total accumulated delay per year with a 30 minute commute. Based on 230 work days per year and two peak period journeys per day. Only measurements during peak periods are taken into account.
Congestion Level on highways	Congestion level taking into account only measurements on highways. This is based on Functional Road Classes, an industry standard that defines different road categories
Congestion Level on non-highways	Congestion level taking into account only measurements on non-highways. This is based on Functional Road Classes, an industry standard that defines different road categories
Morning peak Congestion Level	Congestion level during the busiest one-hour-long period in the morning, based on real traffic measurements
Evening peak Congestion Level	Congestion level during the busiest one-hour-long period in the evening, based on real traffic measurements.

Source: TomTom (data and definitions 2014)

Table 4-2: INRIX indicators

Indicator	Definition
INRIX index	It represents a percentage point increase in the average travel time of a commute above free-flow conditions during peak hours. An INRIX Index of 30, for example, indicates a 20-minute free-flow trip will take 26 minutes during the peak travel time periods with a 6-minute (30 percent) increase over free-flow.
	For each road segment, an INRIX Index is calculated for each 15 minute period of the week, using the formula
	INRIX Index = (RS/CS) – 1
	where
	▪ Reference Speed (RS): An uncongested "free flow" speed is determined for each road segment using the INRIX Traffic Archive.
	▪ Calculated Speed (CS): All archived speeds for each 15 minute period each day for each road segment is calculated for each month (e.g. Monday from 06:00 to 06:15 for April 2012) and a "calculated speed" for each time slot is established for each road segment. Thus, each segment has 672 corresponding calculated speed values – representing four 15 minute time windows for all 24 hours of each day times the seven days in a week.
Wasted Time (Hours/Minutes) in Congestion per year	To convert delay from a typical commute trip into monthly and annual delay totals – "Hours Wasted in Congestion" – requires an estimate of typical commute trip length (in time) and the number commute trips the typical commuter takes in a month/year.
	The assumed number of annual commute trips is assumed at 440 – equivalent to travelling to and from work 5 days a week for 44 weeks. "Wasted Hour" Estimates are annualized and to create a monthly estimate of wasted hours, the annual result is divided by 12.
	In Europe, government published trip time estimates are used where credible and aligning with the metropolitan areas being analysed. Otherwise a 30 minute trip time is used.

Source: INRIX (data and definitions 2014)

The indicators reported by the two sources for the cities covered in both databases are often different. There are about 62 cities/large urban zones included in both databases. Figure 4-2 shows how the congestion indexes for these cities compare between the two databases, while Figure 4-3 shows the comparison for the estimated yearly wasted time in congestion.

It is apparent that, apart from a few exceptions, both the congestion index and the wasted time per year present lower values in the INRIX database.

There can be various reasons for these differences. Firstly, although the name of the cities is the same, the actual study area might not be identical. For example, TomTom congestion index seems to make reference to 'cities' while INRIX explicitly refers to Large Urban Zones (LUZs). This difference can play a significant role because LUZs probably include areas where congestion is less significant than in the urban core, therefore on average the congestion index might be reduced. Secondly, the methodology applied for the estimation of the indices is probably different since the technology behind the two sources is not the same. Also, with reference to the indicator of wasted time in congestion per year, a further difference is related to the amount of working days considered, i.e. 220 by INRIX and 230 by TomTom. This can explain some 5% difference between the estimates.

Figure 4-2: Comparison of congestion index based on TomTom and INRIX data

Congestion index (%)
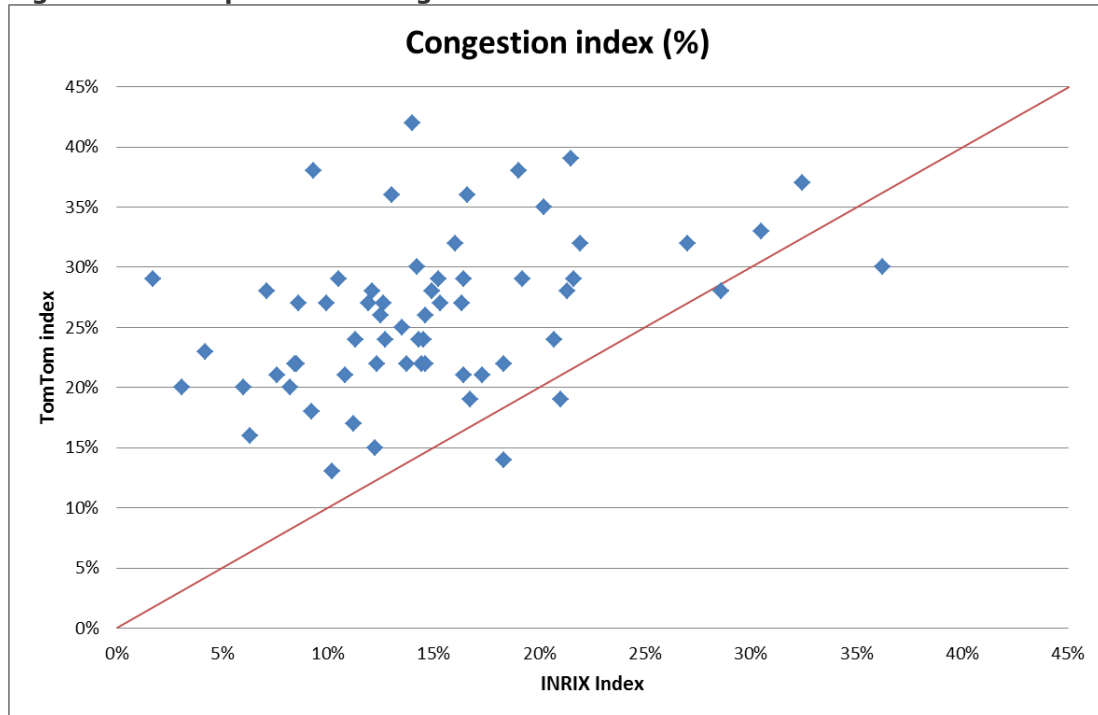
Figure 4-3: Comparison of wasted time in congestion per year based on TomTom and INRIX data

Wasted time in congestion per year (hours)
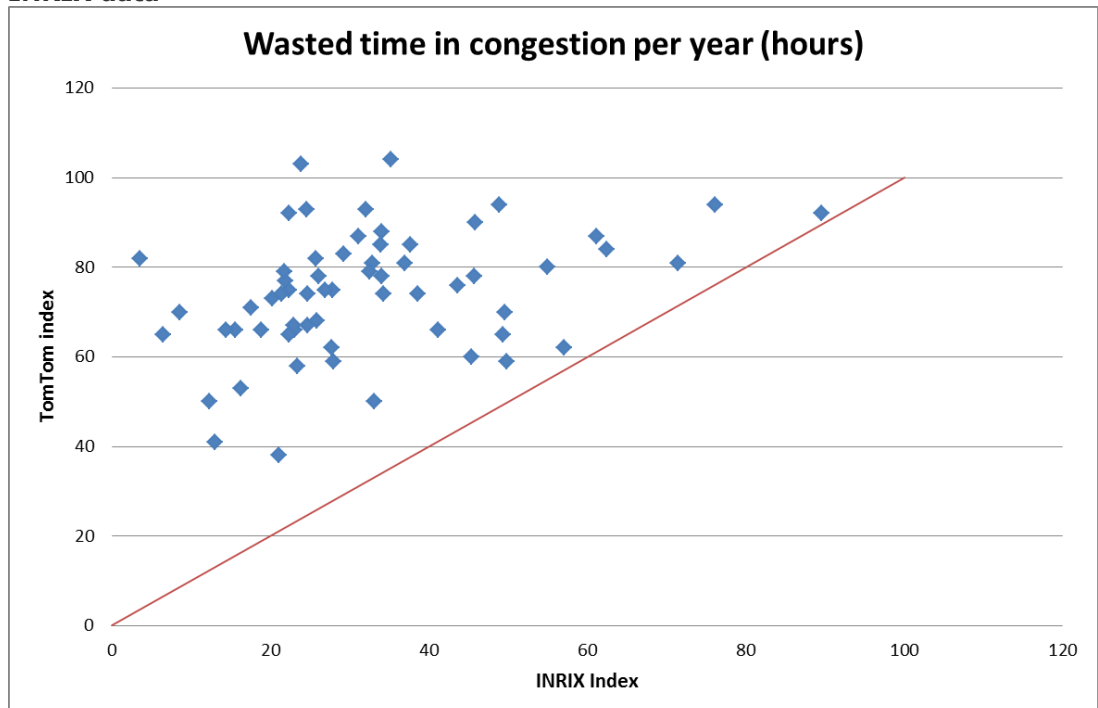
Given these differences the two source are not directly comparable. Thus, although merging the two database could enrich the number of cities, we decided to base the estimation of urban congestion costs only on the data provided by one source only. We decided to use TomTom for two major reasons. Firstly, the number of European cities available from the TomTom database is larger. Secondly, there are more

indicators available from the TomTom database. The Inrix data was used to make comparisons (see section 4.3.3 below).

4.1.2 Estimation of delay costs (internal cost of congestion)

Delay congestion costs are estimated by applying values of travel time (VOT) for passenger cars to the amount of delays provided by TomTom or estimated on the TomTom data. Four different segments have been considered:

▪ Motorway traffic during peak period

▪ Motorway traffic during off-peak period

▪ Non-motorway traffic during peak period

▪ Non-motorway traffic during off-peak period

The two road types (motorways, non- motorways) are differentiated according to the data already available from the TomTom dataset: the purpose of this differentiation is especially to use different speed-flow functions. Instead, peak and off-peak periods are separated to take into account that trip purposes are not the same during different periods of the day and therefore that values of time and elasticities of demand are also variable. This segmentation is not directly available in the TomTom dataset so the data has been elaborated to derive wasted time in congestion separated for peak/off peak crossed with motorways/other roads.

The amount of delay on motorways (non-motorways) during peak periods has been estimated by applying the ratio between the congestion index on motorways (non-motorways) and the average congestion index to the amount of delay during peak periods.

The amount of delay on motorways (non-motorways) during off-peak periods has been estimated in two steps. First, given the ratio between the congestion index and the average congestion index during peak periods the daily amount of delay on motorways (non-motorways) has been estimated. Second, the part of this daily delay occurring during off-peak periods has been estimated building on the shares of trips in peak and off-peak (based on travel surveys statistics). Basically, given these shares and given the amount of delay during peak periods the amount of delay in off-peak time has been computed such as the sum of two components reproduce the total daily delay (on motorway and non-motorway respectively).

Once the estimation has been made independently for motorways and non-motorways demand during peak and off-peak periods, the average value of delay cost has been estimated using the share of transport demand on motorways and non-motorways in the two periods,. The share of transport demand on motorways and non-motorways is estimated such as the average delay time during peak period is reproduced as a weighted average of delay time on motorways and non-motorways. The share is assumed to be the same during off-peak periods.

The ratio between the costs in the peak and off-period is consequently calculated and applied to the observed yearly value of delay time for peak periods in order to estimate the yearly delay time for off-peak periods.

The monetary equivalent of these indicators is the yearly delay cost of congestion per vehicle. This cost is computed using a value of time per vehicle:

$$IC_p = VOT_p * DT_p \qquad\qquad [1]$$

Where:

IC_p = delay cost by period p (peak or off-peak)

VOT_p = Value of Time by period p (peak or off-peak)
DT_p = yearly delay time by period p (peak or off-peak)

As mentioned above, in order to take into account that trip purposes are not the same during different time periods of the day, two VOTs have been considered in the calculations, one for peak and the other for off-peak. They have been estimated as weighted average of VOT for commuting/business trips and VOT for personal trips. The amount of trips by purpose generated in each period. This data has been estimated from data of the ASTRA-EC model[12], based on national travel surveys, as reported in the following table.

Table 4-3: Share of trips generated by purpose and time period

Period	Commuting - business	Personal
Peak	49%	51%
Off-peak	22%	78%

Source: TRT elaboration on ASTRA-EC model, based on national travel surveys

The values of time by purpose have been estimated on the basis of the values reported in deliverable 5 of the HEATCO project[13] for short distance trip by car. The GDP deflator has been used to update the values to Euro$_{2014}$. The value for commuting-business trips resulted from the average between commuting and business VOT weighted by the respective share of generated trips (i.e. about 95% commuting and 5% business). Values by country are reported in Table 4-4. The average EU values are about 9.7 Euro$_{2014}$/hour per person for commuting-business trips and, respectively, 7.5 Euro$_{2014}$/hour per person for personal purposes trips.

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[12] The ASTRA-EC model is an integrated assessment model at European scale (EU27 Countries plus Norway and Switzerland) applied for strategic policy assessment in the transport and energy field. For more information, see www.astra-model.eu .
[13] HEATCO Developing Harmonised European Approaches for Transport Costing and Project Assessment: Deliverable 5 - 2006.

Table 4-4: VOT for short distance trips by purpose and country (Euro $_{2014}$ / hour per person)

Country	Commuting - business	Personal
Austria	9.5	7.1
Belgium	9.1	6.8
Bulgaria	3.5	2.8
Cyprus	9	7
Czech Republic	6.5	5.1
Denmark	10.1	7.5
Estonia	5.7	4.4
Finland	9	6.7
France	12.4	9.6
Germany	9.5	7.1
Greece	7.9	6.1
Hungary	5.7	4.4
Ireland	9.9	7.4
Italy	11.5	8.9
Latvia	5.2	4
Lithuania	5	3.9
Luxembourg	13.9	10.5
Malta	7.5	5.7
Netherlands	9.2	6.8
Norway	15.3	11.6
Poland	5.6	4.3
Portugal	7.7	5.9
Romania	3.4	2.6
Slovakia	5.2	4.1
Slovenia	9	7.1
Spain	9.7	7.5
Sweden	9.8	7.2
Switzerland	12.9	9.9
United Kingdom	9.8	7.3

Source: TRT elaboration on HEATCO project

Since delays are reported for vehicles rather than for individuals, the results of equation [1] are multiplied by the average vehicle occupancy factors, in order to take into account that the delay is suffered by all individuals travelling in cars experiencing congestion and not only drivers. Occupancy factors are different by country (Table 4-5) and are estimated from the IPTS survey on transport and mobility[14]. The average EU value is about 1.7 passenger per vehicle.

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[14] EU SURVEY ON ISSUES RELATED TO TRANSPORT AND MOBILITY, JRC-IPTS (2014)

Table 4-5: Average car occupancy factor by country (in person/vehicle)

| Country	Car occupancy factor
Austria	1.5
Belgium	1.7
Bulgaria	2.2
Cyprus	1.7
Czech Republic	2.1
Denmark	1.4
Estonia	2.0
Finland	1.5
France	1.5
Germany	1.4
Greece	2.0
Hungary	2.1
Ireland	1.9
Italy	1.7
Latvia	2.2
Lithuania	2.1
Luxembourg	1.4
Malta	1.6
Netherlands	1.6
Norway	1.4
Poland	2.2
Portugal	1.9
Romania	2.7
Slovakia	2.4
Slovenia	1.7
Spain	1.8
Sweden	1.5
Switzerland	1.4
United Kingdom	1.5

Source: TRT elaboration on IPTS survey

4.1.3 Estimation of deadweight loss (external cost of congestion)

The deadweight loss have been estimated by applying the welfare economics framework introduced in section 2, i.e. the estimation of deadweight loss exemplified by triangle ACB in Figure 4-2. As mentioned above, we have worked in aggregated terms rather than on a link by link basis. A segmentation is based on the same elements used for the estimation of delay costs: period of the day and type of infrastructure. For each component (e.g. costs on highways in peak time) the process is the following:

▪ Definition of the private costs curve (i.e. speed-flow curve with VOT used to transform time in cost).

- Definition of <u>social costs curve</u> (derivative of previous curves).
- Definition of <u>demand curve</u> (based on elasticity).
- Calculation of the <u>optimal demand level</u>, where demand curve crosses social curve, by means of an iterative process.
- The <u>deadweight loss</u> are estimated as the size of the area between the two curves.
- The <u>delay costs</u> are estimated as the area between the point where the demand curve and the private cost curve cross and the free flow cost.

Figure 4-4: Welfare economic principle for the estimation of congestion costs
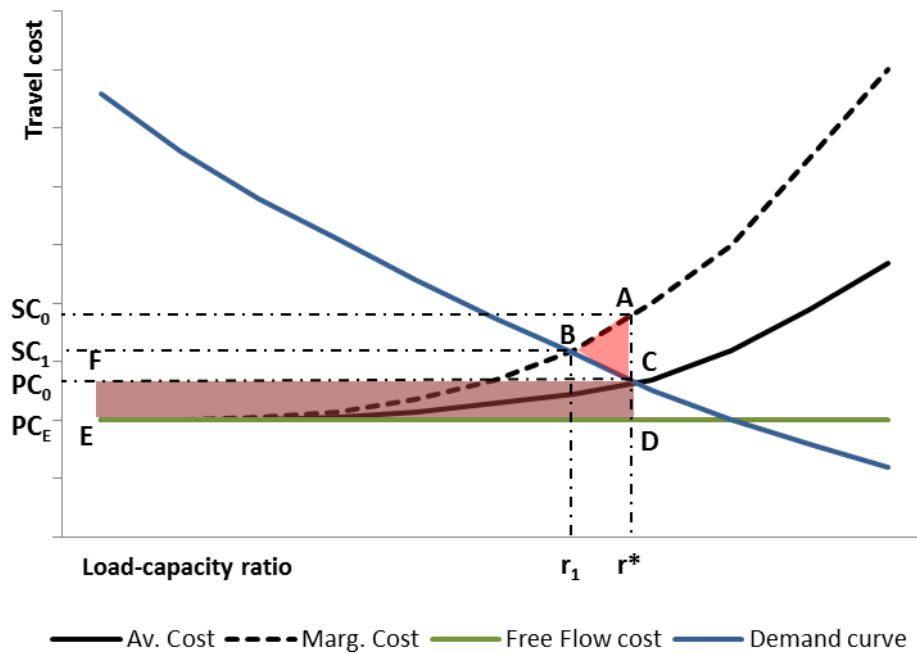
Definition of the private costs curve

The private cost curve is assumed to reflect the monetary cost of driving time. Several studies include also the out of pocket costs of driving (including fuel and maintenance), often as a constant value. However, fuel consumption and operating costs are estimated separately within this study, in Task 3. Therefore, for the purpose of this task only time related costs have been taken into account.

The time cost of driving increases as the average speed falls, i.e. as the traffic flow increases. The speed-flow function is applied to represent this relationship, namely as follows:

$$T = T_0 * (1 + ParA * r^{ParB}) \qquad [3]$$

Where

T = actual travel time
T_0 = travel time in free flow conditions
r = flow / capacity ratio
$ParA$ and $ParB$ = parameters of the function

As mentioned above, two speed-flow functions have been implemented in order to differentiate between the road types (motorways, non-motorways) for which TomTom data is available. According to the description of such data, travel time in free-flow conditions (T_0) is set to 0.5 hours because delays make reference to 30 min commute trips.
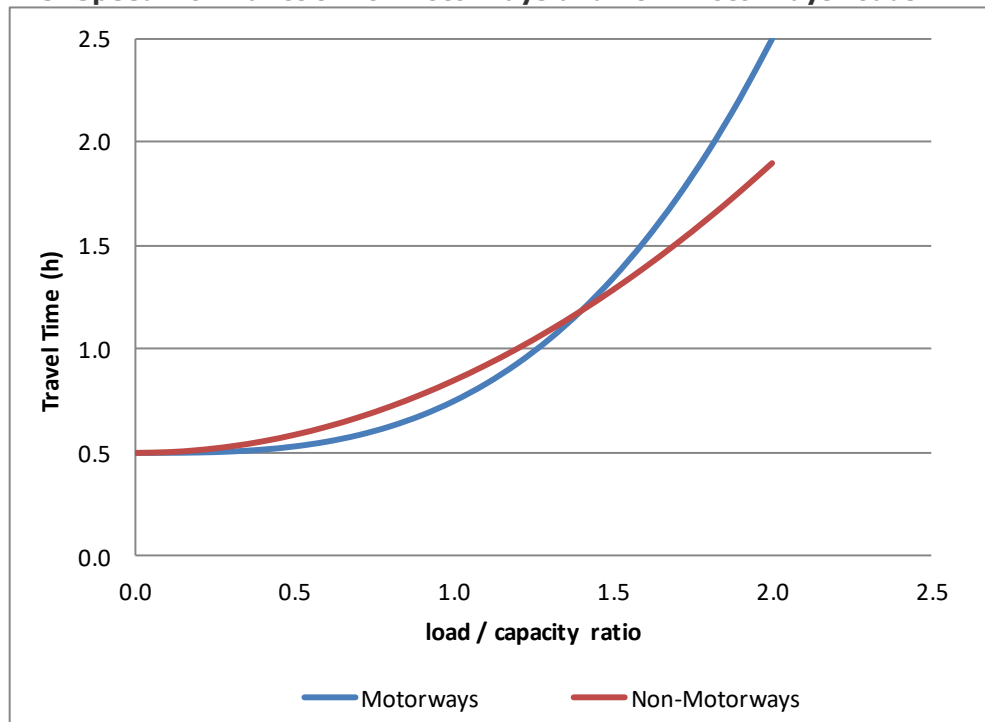
The following parameters have been used, based on applications of strategic models:

Table 4-6: Speed-flow function for Motorways and non- Motorways roads

Parameter	Non-motorways	Motorways
T_0 (in hour)	0.5	0.5
ParA	0.7	0.5
ParB	2	3

Source: TRT models

Figure 4-5: Speed-flow function for Motorways and non- Motorways roads

The time cost of driving (average cost) results from the travel time multiplied by the Value of Time in euro/hour per vehicle.

$$AC = VOT * T_0 *(1 + ParA * r^{ParB}) \qquad [4]$$

Definition of marginal cost curve

The social cost curve has been derived from the private (average) cost curve, using the first derivative of the expression [4] reported above:

$$MC = VOT * T_0 + VOT * T_0 * ParA * ParB * r^{(ParB-1)} \qquad [5]$$

Definition of demand curve

Finally, the procedure required finding the demand curve. This curve has been estimated using demand elasticity parameters[15] starting from the initial demand (i.e.

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[15] Demand elasticity parameters are defined here as a measure of the relationship between a change in the transport demand (i.e. the amount of trips by car) and a change in the related cost (in this case the private cost per trip). As an example, a value of the elasticity parameter of -0.5 means that an increase of cost by 20% is reflected in a decrease of transport demand by -10%.

the level of demand corresponding to the observed delay as reported by TomTom data).

Given the speed flow curves, the load/capacity ratio producing the reported delay could be computed (r* in the figure below) separately for motorways and non-motorways demand during peak and off-peak periods.

Figure 4-6: Identification of load-capacity ratio on the speed-flow function
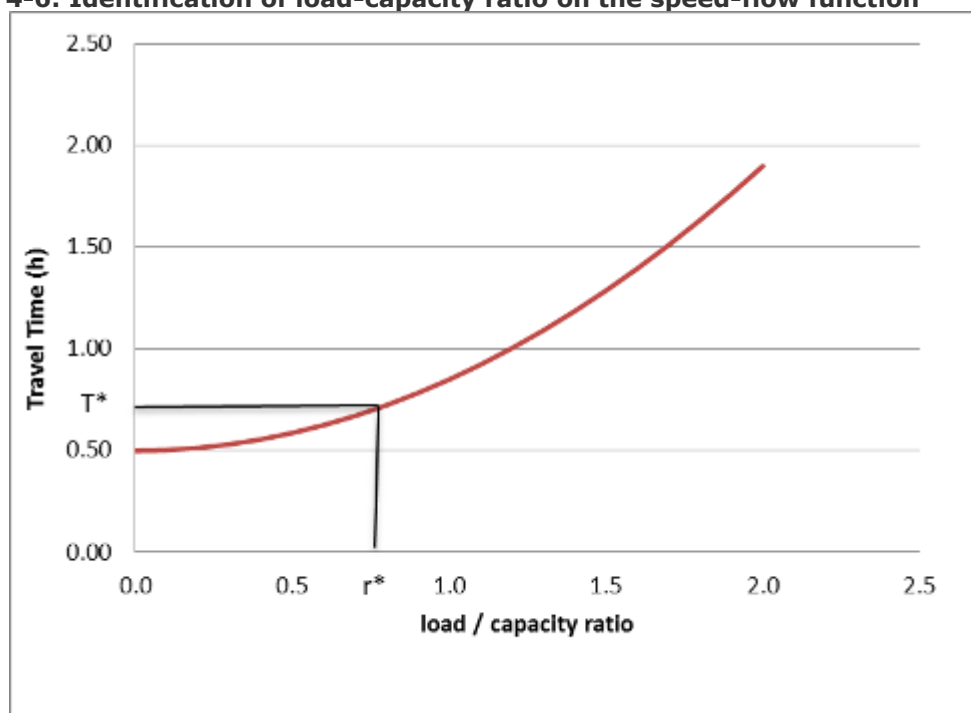
Then the following function has been used to estimate the flow/capacity ratios for alternative values of cost (i.e. of travel time):

$$r = m\ AC + k \qquad [6]$$

Where:
r = flow / capacity ratio
AC = average cost of driving (time cost of driving only)
m = cost elasticity
k = constant parameter defining the position of the demand curve

Different elasticity parameters m have been used for peak and off-peak periods. Values have been estimated as weighted average of values by trip purpose, considering the composition of trips in different periods (see Table 4-3 above). Cost elasticity parameters by purpose have been defined on literature. In particular Littman (2011) and Oum et.al. (1990). Values used are reported in Table 4-7

Table 4-7: Elasticity to cost of short distance car trips by purpose

	Commuting - business	Personal
Urban car trips	-0.49	-0.58

Source: TRT elaboration on literature data

Calculation of the optimal demand level

The demand curve has been estimated by applying elasticity parameters starting from the initial level of demand (by definition the demand curve crosses private cost curve in correspondence to the level of demand identified by the speed-flow curve for the

travel cost reported by the congestion indicator). This point corresponds to point C in Figure 4-4. In order to estimate the deadweight loss, point B of Figure 4-4 is also required. In order to identify this point where the demand curve and the social cost curve cross, an iterative process has been applied. Basically it has been searched the value of the load/capacity ratio (r_1 in Figure 4-4) for which the marginal costs curve social provides a marginal cost (SC_1 in Figure 4-4) that corresponds to the same load/capacity ratio according to the demand curve. Once again the process has been made independently for motorways and non-motorways and for peak and off-peak periods.

Estimation of deadweight loss per car and per day
Using the elements obtained in the steps described above, it has been possible to estimate the value of deadweight loss and delay cost of congestion using the following formulae.
Deadweight loss (area of the triangle ABC in Figure 4-4):

$$EC^w = (r^* - r_1) * (SC_0 - PC_0) / 2 \qquad [7]$$

Delay costs (area of the rectangle EFCD in Figure 4-4):

$$IC^w = (r^*) * (PC_0 - PC_E) \qquad [8]$$

The estimations have been made separately for each segment, i.e. motorways and non-motorways during peak and off-peak periods.

In principle, the delay cost computed with [8] should correspond to the delay cost estimated as explained above in section 0. However the two estimates are dissimilar. Since we assume that the original TomTom data is a reliable measure of the wasted time since it is computed on real-life data, we have considered that the delay congestion cost estimated by applying values of time to the delays is the most representative one. Therefore we have assumed that the procedure explained above allowed to identify the ratio between deadweight loss and delay cost (i.e. the ratio between the values obtained from [7] and [8]). Eventually the deadweight loss has been estimated by applying this ratio to the value of the delay cost defined as explained in section 0.

Total deadweight loss and delay cost of congestion per year
The yearly value of delay and deadweight loss per car has been estimated on the basis of TomTom data on yearly delays, values of time and the ratio between deadweight loss and delay cost (see equation [1]).

Building on the deadweight loss and delay cost for a single car by time period (EC_p and IC_p), total cost in the urban context has been estimated using the population size (P), the share of individuals travelling ($shTP$) and the car share ($shCar$)

$$IC = P * shTP * shCar * \textstyle\sum_p IC_p \qquad [9]$$
$$EC = P * shTP * shCar * \textstyle\sum_p EC_p \qquad [10]$$

Car share data has been defined based on information reported in the EPOMM Modal Split Tool (TEMS)[16] integrated with local sources where data from this tool was not available. The share of population travelling is estimated as 76% of population living in the city, according to AUDIMOB data for 2013.

4.2 Estimated costs of urban congestion in the sample of cities

In this section the results of the estimation of deadweight loss (external cost) and delay (internal) congestion cost related to passenger cars by city is reported. An

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[16] http://www.epomm.eu/tems/

important remark is that some parameters used for the estimations are country-specific, namely values of time and car occupancy factors. In particular, values of travel time are sometimes significantly different (see for instance Table 4-4) so the comparison of estimates should take this aspect into account.

Figure 4-7 shows the estimated delay cost per capita in each city of the sample. The estimation of delay cost per capita ranges from 144 euro per year per capita in Odense to 913 euro per year per capita in Rome; on average, delay cost account for about 431 euro per year per capita. As mentioned, these figures have to be analysed taking into account the differences in VOT and occupancy factor parameters by country. Taking into account only the capital cities the average is about 374 euro per year per capita, with two outliers cities (Rome and Luxembourg City) around 900 euro per year per capita and the other cities in general in a range between 200 and 450 euro (see Figure 4-8).

Figure 4-7: Yearly urban delay cost per capita in selected European cities (in euro per capita per year)
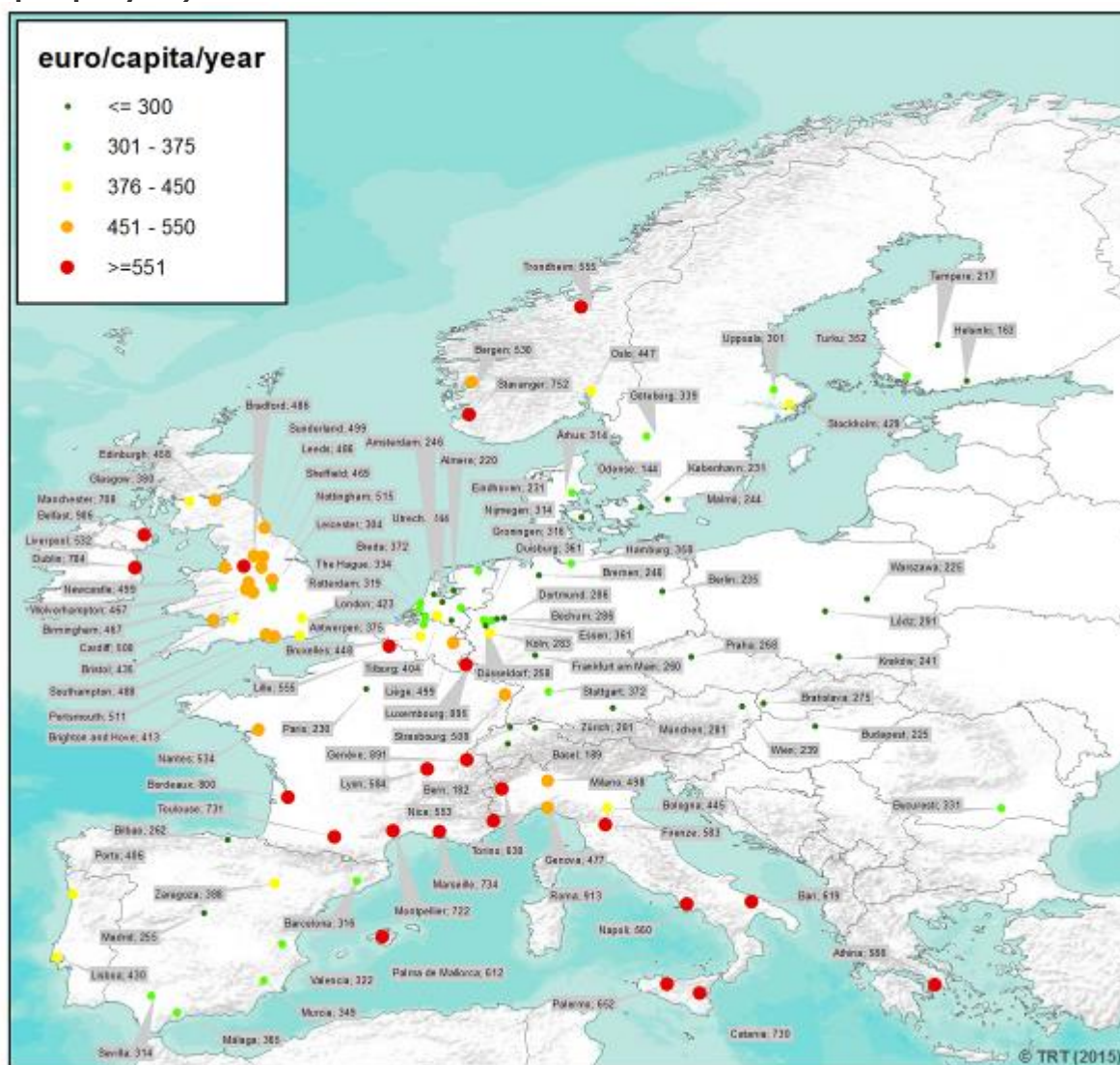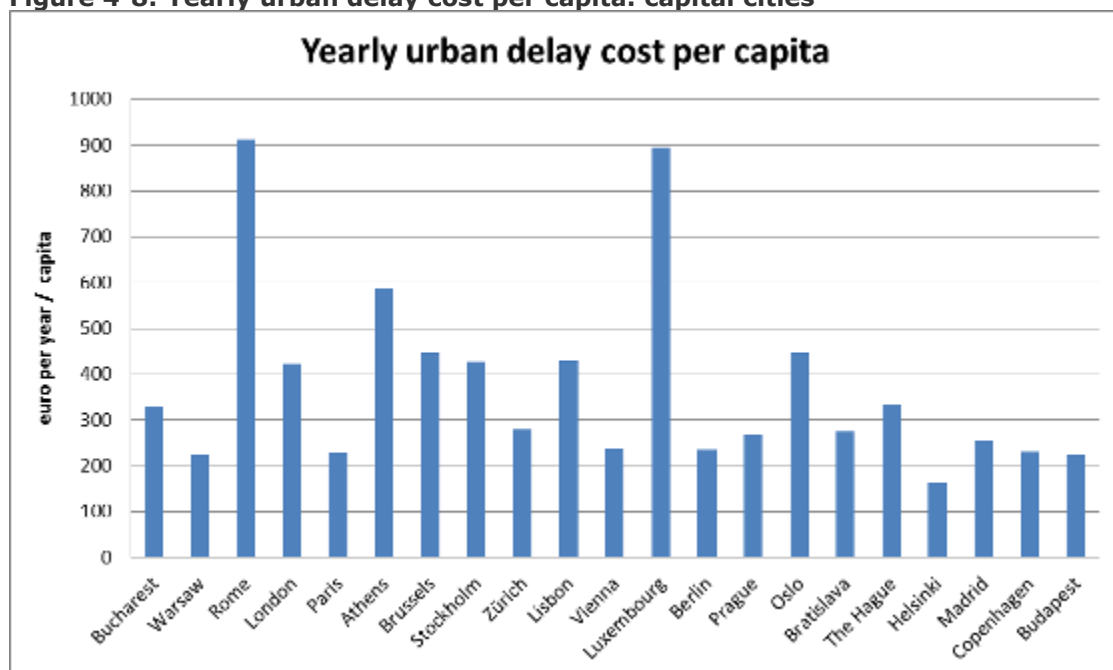

Source: TRT estimation

The twenty cities with higher delay cost per capita show values above 600 euro per year per capita, including cities of various size in terms of population (from about

103,000 inhabitants in Luxembourg City to 2.6 million in Rome). Italy, France, United Kingdom and Spain are the countries with more than one city among the twenty with higher delay cost (see Figure 4-9).

The twenty cities with lower delay cost per capita present values below 250 euro per year per capita: sixteen cities have values between 210 and 250 euro, while the last four are between 140 and 190. Also in this case, cities of various size in terms of population are included (from about 165,000 inhabitants in Basel to 3.3 million in Berlin). Several capital cities are among those with lower delay cost per capita: in some cases, a linkage with the availability and use of public transport services might be assumed (see Figure 4-10).
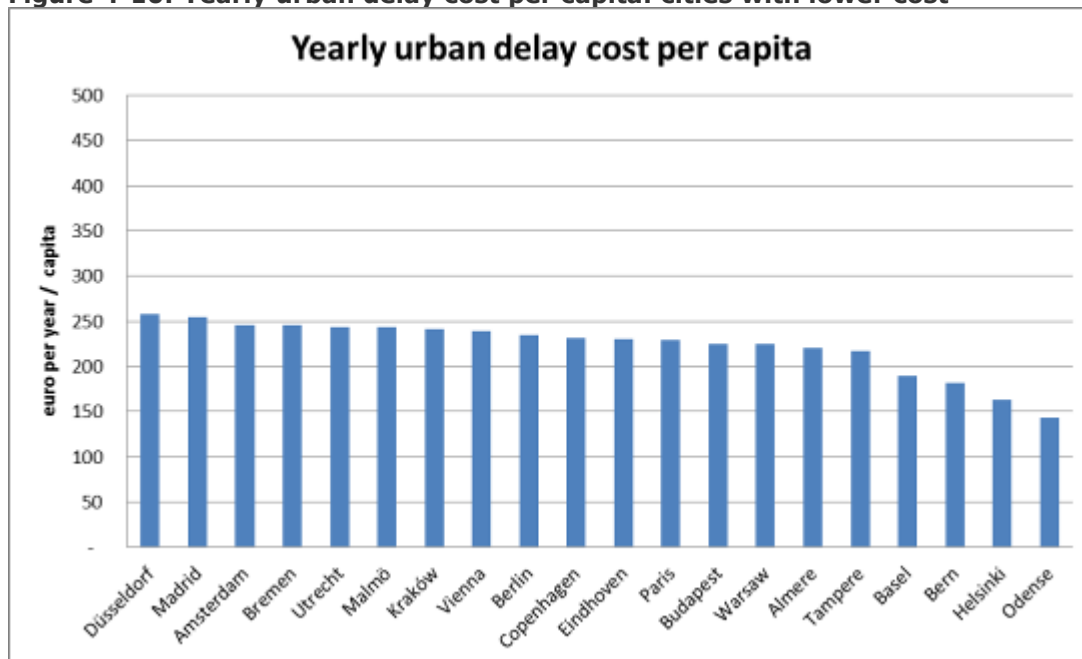
Figure 4-8: Yearly urban delay cost per capita: capital cities

Source: TRT estimation

Figure 4-9: Yearly urban delay cost per capita: cities with higher cost
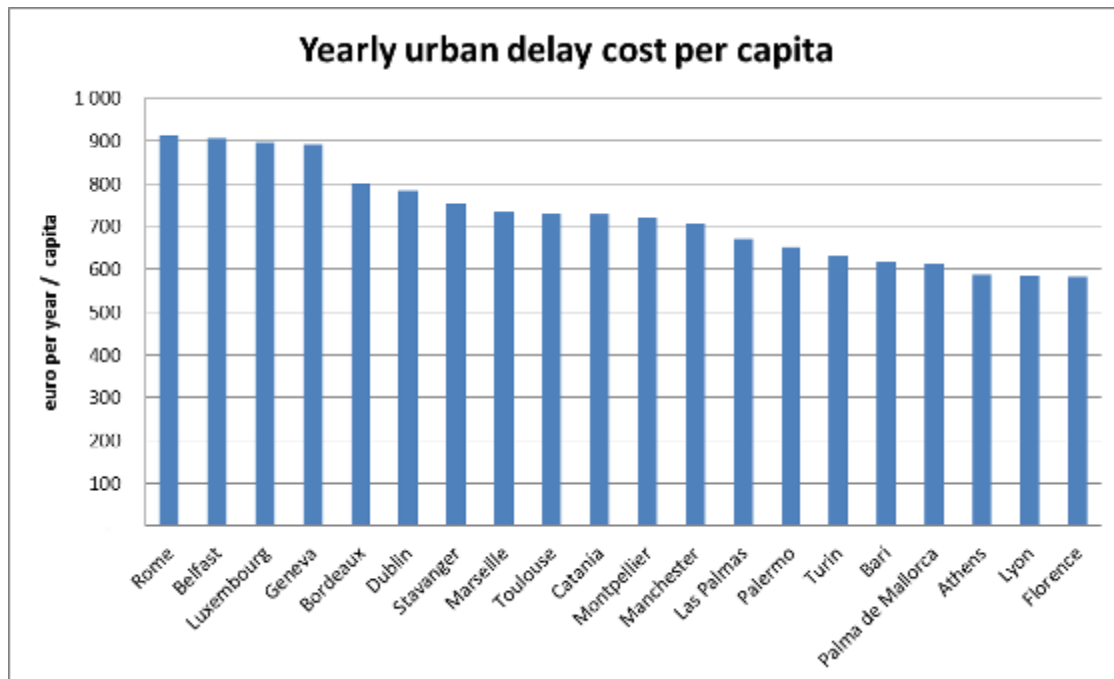
Source: TRT estimation

Figure 4-10: Yearly urban delay cost per capita: cities with lower cost

Source: TRT estimation

The deadweight loss per capita estimated for the sample of cities ranges from 11 euro per year per capita in Bern to 86 euro per year per capita in Catania; on average, delay cost account for about 45 euro per year per capita. Again differences in VOT and occupancy factor parameters by country play a role in explaining the variability. The analysis of the estimation for the capital cities shows an average value about 35 euro per year per capita, again with Rome and Luxembourg City with a much higher cost around 75-80 euro per year per capita and the other cities in general ranging between

20 and 40 euro (see Figure 4-11). Budapest presents values lower than the other capitals, i.e. about 12 euro per year per capita.

Figure 4-11: Yearly urban deadweight loss per capita: capital cities
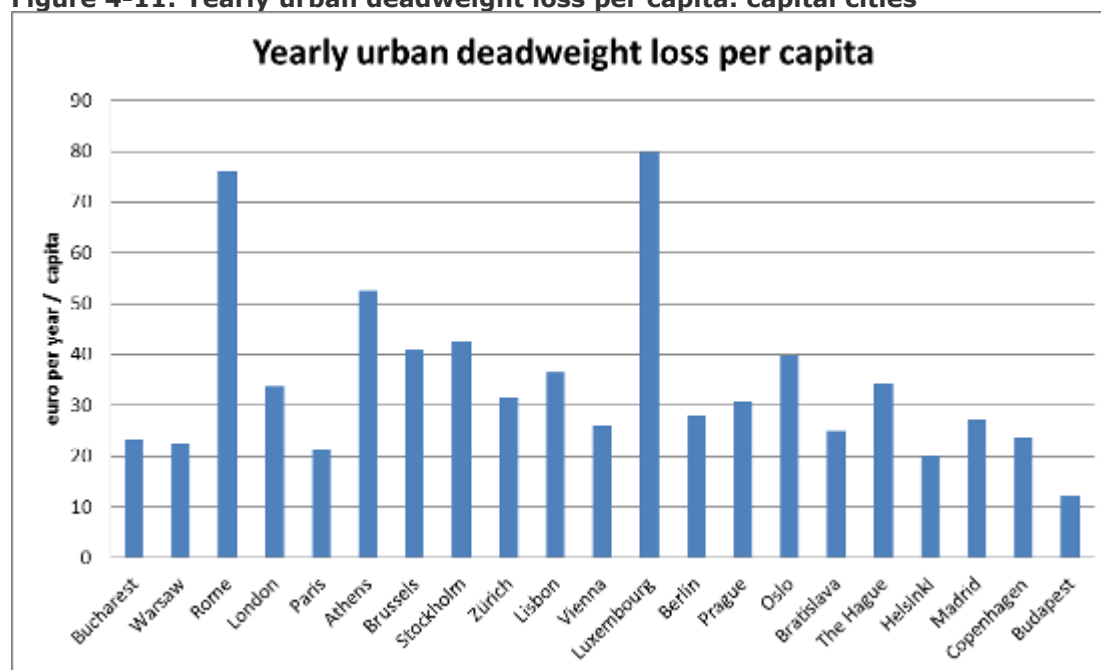
Source: TRT estimation

In general, deadweight loss is a fraction of delay cost and so the ranking of the cities remains more or less the same whatever indicator is considered. Thus, the twenty cities with higher deadweight loss per capita (Figure 4-12) are the same with higher delay cost values except for Trondheim, Lille and Nice. Deadweight loss in these cities exceeds 60 euro per year per capita.

Also the twenty cities with lower deadweight loss per capita are basically the same with lower delay cost with the exception of Bucharest, Łódź, Bratislava and Leicester (see Figure 4-13). They present values below 30 euro per year per capita with sixteen cities having values between 18 and 29 euro and two with values around 11 Euro.

Figure 4-12: Yearly urban deadweight loss per capita: cities with higher cost
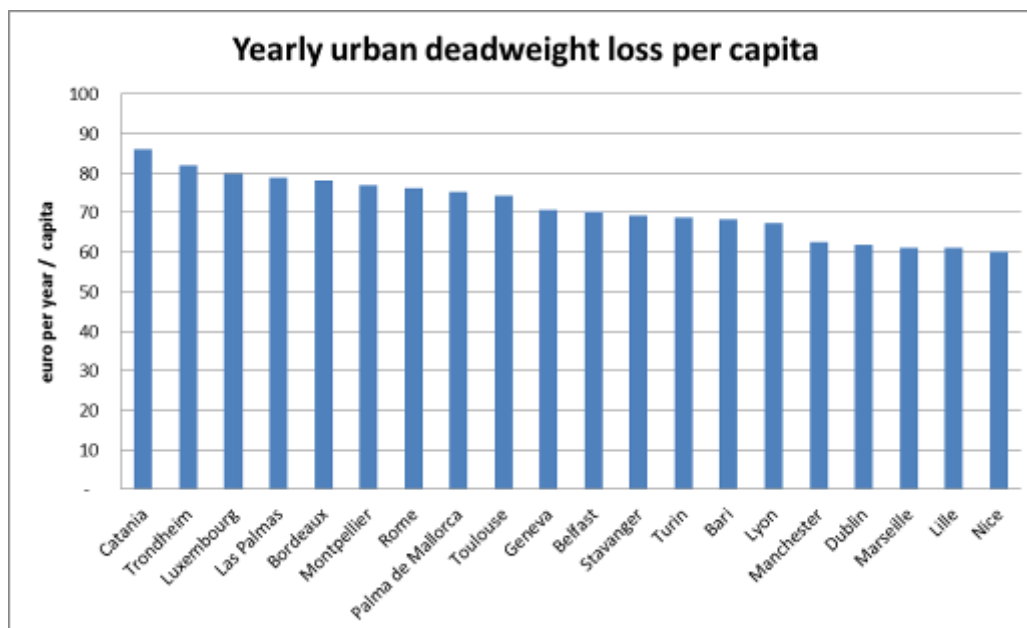
Source: TRT estimation

Figure 4-13: Yearly urban deadweight loss per capita: cities with lower cost
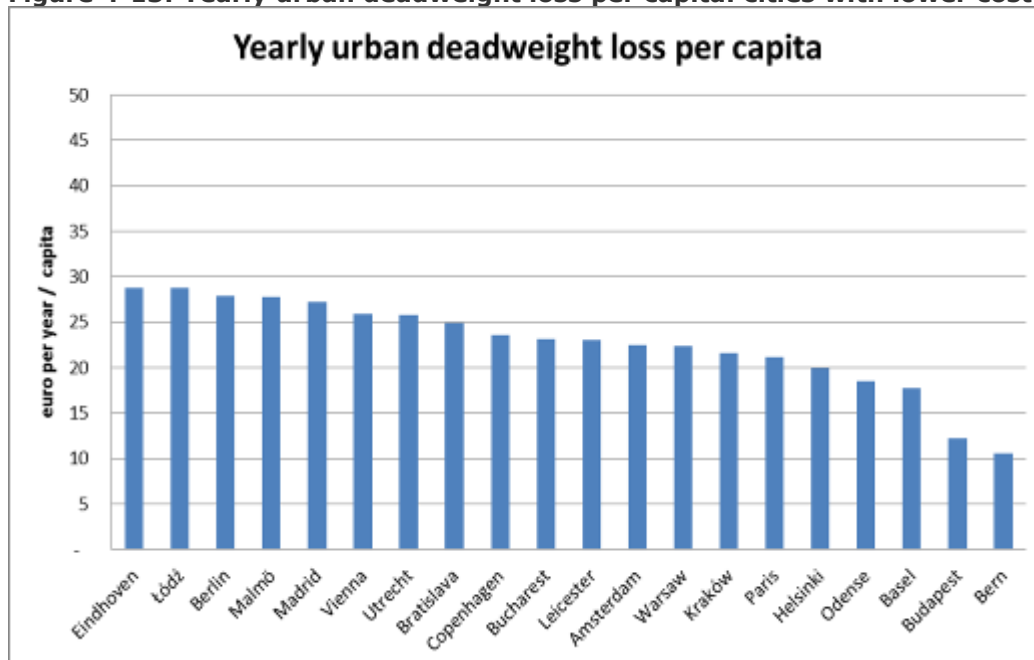
Source: TRT estimation

4.2.1 Comparisons with literature

Making reference to the literature review reported in section 3, a comparison has been made between the urban congestion costs estimated here and the values reported in the studies reviewed. As already noted, these studies adopt various definitions of congestion costs, sometimes including also elements not related to wasted time (e.g. additional fuel consumption) whereas our estimations are focused on this element. This aspect should be taken into account when the comparisons are made.

The congestion cost in **Paris** and **Ile-de-France** region is estimated in two studies: Koning (2010) and Cebr (2012). According to the former study the congestion cost for Ile-de-France ranges from about 130 to 230 Euro per capita according to the deadweight loss definition. The latter source estimated a direct cost of congestion (delay and fuel) in the Large Urban Zone of Paris of 154 Euro/year per capita. According to our methodology, delay cost per capita (related to passenger cars only) resulted as much as 230 euro/year while deadweight loss per capita was about 20 Euro/year. Therefore our estimation of delay cost seems to be in line with the comparable data.

The estimates of congestion cost in Fondazione Caracciolo (2013) for six Italian cities (Palermo, Rome, Milan, Naples, Genoa, and Turin) are compared in Table 4-8.: The estimates concern delay cost and range from about 480 to 880 euro per capita. According to our methodology, delay costs per capita (related to passenger cars only) estimated in these cities range between 414 and 793 euro per capita, which is much in line with the term of comparison.

Table 4-8: comparison of estimates of congestion for six Italian cities

Delay cost of congestion per capita (Euro/year)	Palermo	Rome	Milan	Naples	Genoa	Turin
Fondazione Caracciolo (2013)	826.2	882.4	640.3	617.2	479.7	570.2
TRT estimation (2015)	565.9	793.2	432.7	486.4	414.7	547.2

Based on data reported by Cebr (2012), direct cost (delay and fuel) of congestion per capita in the Large Urban Zones of **London** and **Stuttgart** are as much as 111 Euro/year and respectively 260 Euro/year[17]. Our estimations of delay cost per capita in these two cities (see Figure 4-7) are of 423 Euro/year and, respectively 372 Euro/year: the values estimated with our methodology are larger especially for London. There are however methodological reasons that can explain at least part of the difference. First of all the wasted time during peak time used in Cebr is lower (66 hours) than the 92 hours reported by TomTom. The reason might be related to the area of application: in Cebr the Large Urban Zone is used whereas we considered the city area. Then our methodology takes into account also off-peak congestion, (which in London and Stuttgart account for about 16% of peak wasted hours). Finally, there is also a difference when estimates based on daily wasted time are expanded to the year as the number of working days considered is not the same.

4.3 Sensitivity analysis

4.3.1 Parameters used in the methodology for estimation of congestion costs

In order to verify the robustness of the estimation, sensitivity tests related to some of the parameters implemented in the methodology have been performed. Namely, the analysis has been focused on the parameters related to exogenous assumptions:

▪ Elasticity of transport demand,

▪ Form of the speed-flow function,

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[17] Cebr (2012) reports direct cost (delay and fuel) of congestion in the Large Urban Zones of London and Stuttgart (e.g. 1,358 and 701 million Euro respectively): this value has been divided by the total population of the LUZs according to Urban Audit data for 2012 (12.2 and 2.7 million inhabitants respectively).

▪ Share of trips during peak time period.

The sensitivity analysis has been conducted on a sample of cities of different population size and congestion level, as reported in the tables below.

Demand elasticity

Based on literature, demand elasticity parameters used in the methodology are set at about -0.5 for peak periods and -0.55 for off-peak (see also Table 4-7 and paragraph 4.1.3). Two sensitivity tests have been performed to analyse the impacts of using different values. One test used lower demand elasticity of -0.20 (peak) / -0.26 (off-peak). The other test used higher values: -0.8 (peak) / -0.87 (off-peak).

The results of the test demonstrated that this parameter is quite significant for the estimation of the deadweight loss (Table 4-8). When demand elasticity is lower, the estimates of deadweight loss per capita are reduced by around 35% to 40%; when demand elasticity is higher the deadweight loss per capita is increased on average by 30% to 35%. The estimation of delay congestion cost per capita is instead not affected by different demand elasticity parameters.

Table 4-9: Summary of sensitivity tests on demand elasticity: deadweight loss per capita

City	Country	Population	Congestion index	Deadweight loss per capita (euro/capita)		
				Low elasticity	Base elasticity	High elasticity
Warsaw	Poland	1,711,000	40%	28.9	22.3	14.2
Dublin	Ireland	527,612	38%	79.9	61.8	39.2
London	United Kingdom	8,308,000	37%	44.6	33.8	21.1
Paris	France	2,244,000	35%	27.6	21.2	13.4
Brussels	Belgium	166,497	33%	53.0	40.9	25.8
Stuttgart	Germany	597,939	32%	62.6	49.1	31.8
Stockholm	Sweden	914,909	30%	55.4	42.7	26.9
Milan	Italy	1,251,000	30%	56.5	42.9	26.7
Prague	Czech Republic	1,247,000	27%	40.1	30.8	19.3
Helsinki	Finland	599,676	22%	26.5	20.0	12.3
Madrid	Spain	3,234,000	21%	36.4	27.2	16.6
Copenhagen	Denmark	562,379	21%	31.4	23.5	14.3
Budapest	Hungary	1,732,000	20%	16.7	12.3	7.3
Amsterdam	Netherlands	825,080	19%	29.9	22.5	13.7
Malmö	Sweden	278,523	16%	37.4	27.8	16.9

Form of speed-flow curve

The form of the speed-flow curve is definitely an uncertain element, especially because this function is generally an attribute of a single link while we used this concept with reference to the overall network of a city. Again, two different sensitivity tests have been performed separately for motorway and non-motorway roads: one with a steeper curve and the other with a smoother curve (Figure 4-14).

Figure 4-14: Alternative speed-flow functions for sensitivity analysis
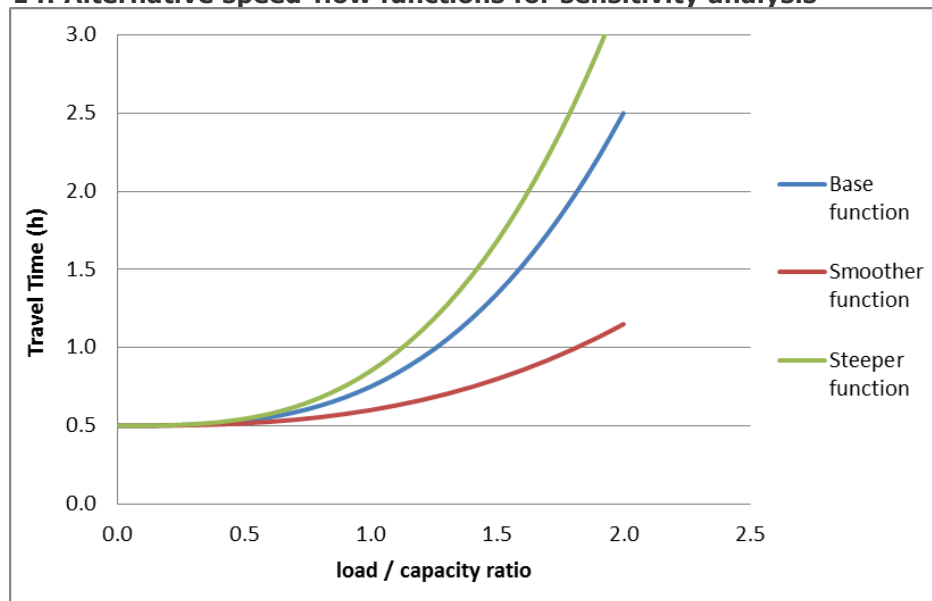
The tests confirmed that this element is also significantly influential for the estimates (Table 4-10). When a smoother speed-flow function is used, an increase of about 40% to 60% is observed in the estimates of deadweight loss per capita; when speed-flow function is steeper, the estimated size of the deadweight loss is on average 10% lower (even if with much variability among cities).

The impact of different speed-flow curves on the estimation of delay congestion cost is different. A smoother function does not change the estimates while an increase of about 3-4% of the estimated cost is obtained when applying a steeper function.

Table 4-10: Summary of sensitivity tests on speed-flow function: deadweight loss per capita

City	Country	Population	Congestion index	Deadweight loss per capita (euro/capita)		
				Smoother function	Base function	Steeper function
Warsaw	Poland	1,711,000	40%	32.0	22.3	16.7
Dublin	Ireland	527,612	38%	90.4	61.8	52.9
London	United Kingdom	8,308,000	37%	50.1	33.8	37.3
Paris	France	2,244,000	35%	30.4	21.2	17.5
Brussels	Belgium	166,497	33%	59.0	40.9	31.4
Stuttgart	Germany	597,939	32%	67.3	49.1	22.7
Stockholm	Sweden	914,909	30%	61.0	42.7	31.8
Milan	Italy	1,251,000	30%	62.6	42.9	41.5
Prague	Czech Republic	1,247,000	27%	43.2	30.8	22.7
Helsinki	Finland	599,676	22%	28.1	20.0	15.7
Madrid	Spain	3,234,000	21%	39.0	27.2	25.9
Copenhagen	Denmark	562,379	21%	33.8	23.5	22.2
Budapest	Hungary	1,732,000	20%	19.7	12.3	20.4
Amsterdam	Netherlands	825,080	19%	32.4	22.5	22.9
Malmö	Sweden	278,523	16%	39.6	27.8	26.3

Table 4-11: Summary of sensitivity tests on speed-flow function: delay cost per capita

City	Country	Population	Congestion index	Delay cost per capita (euro/capita)		
				Smoother function	Base function	Steeper function
Warsaw	Poland	1,711,000	40%	224.9	224.9	230.7
Dublin	Ireland	527,612	38%	783.9	783.9	799.7
London	United Kingdom	8,308,000	37%	422.5	422.5	438.8
Paris	France	2,244,000	35%	229.6	229.6	236.6
Brussels	Belgium	166,497	33%	448.0	448.1	457.4
Stuttgart	Germany	597,939	32%	371.9	371.9	376.5
Stockholm	Sweden	914,909	30%	428.9	428.9	438.8
Milan	Italy	1,251,000	30%	498.3	498.3	512.0
Prague	Czech Republic	1,247,000	27%	268.1	268.1	275.3
Helsinki	Finland	599,676	22%	163.0	163.0	168.8
Madrid	Spain	3,234,000	21%	255.0	255.0	264.5
Copenhagen	Denmark	562,379	21%	231.2	231.2	239.6
Budapest	Hungary	1,732,000	20%	225.4	225.4	234.4
Amsterdam	Netherlands	825,080	19%	246.4	246.4	255.4
Malmö	Sweden	278,523	16%	243.8	243.8	254.4

Share of trips in peak time
Within the methodology applied, the share of peak trips affects the value of time per vehicle by time period as well as the average congestion cost per period. According to the ASTRA-EC model, based on national travel surveys data, on average the share of trips during peak periods (7-9 and 17-19) is about 41%. Two tests have been performed to analyse the influence of different assumptions on the estimation of congestion cost. In one test a higher share of trips during peak period was assumed (about 45%), in the other tests a lower share (about 35%) was used.

As shown in Table 4-12 assuming a higher share of trips during peak period generates lower values of deadweight loss in the range of -4% / -9%. On the contrary, assuming a lower share of trips the resulting deadweight loss is increased 5% / 12% larger. The impact on the estimates of the delay cost is the same in sign but of a smaller size: differences are in the order of -3% / 5%.

Table 4-12: Summary of sensitivity tests on share of peak trips: deadweight loss per capita

City	Country	Population	Congestion index	Deadweight loss per capita (euro/capita)		
				lower share	Base share	higher share
Warsaw	Poland	1,711,000	40%	24.0	22.3	21.1
Dublin	Ireland	527,612	38%	69.3	61.8	56.9
London	United Kingdom	8,308,000	37%	36.4	33.8	31.8
Paris	France	2,244,000	35%	22.9	21.2	19.9
Brussels	Belgium	166,497	33%	45.3	40.9	38.0
Stuttgart	Germany	597,939	32%	52.3	49.1	46.7
Stockholm	Sweden	914,909	30%	46.8	42.7	39.8
Milan	Italy	1,251,000	30%	47.7	42.9	39.6
Prague	Czech Republic	1,247,000	27%	33.2	30.8	29.0
Helsinki	Finland	599,676	22%	21.4	20.0	19.0
Madrid	Spain	3,234,000	21%	29.6	27.2	25.5
Copenhagen	Denmark	562,379	21%	25.5	23.5	22.0
Budapest	Hungary	1,732,000	20%	13.8	12.3	11.2
Amsterdam	Netherlands	825,080	19%	24.2	22.5	21.2
Malmö	Sweden	278,523	16%	29.3	27.8	26.7

Table 4-13: Summary of sensitivity tests on share of peak trips: delay cost per capita

City	Country	Population	Congestion index	Delay cost per capita (euro/capita)		
				lower share	Base share	higher share
Warsaw	Poland	1,711,000	40%	235.8	224.9	217.9
Dublin	Ireland	527,612	38%	821.7	783.9	762.2
London	United Kingdom	8,308,000	37%	442.5	422.5	409.6
Paris	France	2,244,000	35%	240.8	229.6	222.4
Brussels	Belgium	166,497	33%	470.0	448.1	435.1
Stuttgart	Germany	597,939	32%	389.9	371.9	360.4
Stockholm	Sweden	914,909	30%	450.1	428.9	416.1
Milan	Italy	1,251,000	30%	522.9	498.3	483.5
Prague	Czech Republic	1,247,000	27%	281.4	268.1	259.8
Helsinki	Finland	599,676	22%	170.7	163.0	158.0
Madrid	Spain	3,234,000	21%	267.5	255.0	247.1
Copenhagen	Denmark	562,379	21%	242.6	231.2	224.1
Budapest	Hungary	1,732,000	20%	236.4	225.4	218.6

| Amsterdam | Netherlands | 825,080 | 19% | 258.3 | 246.4 | 238.9 |
| Malmö | Sweden | 278,523 | 16% | 254.0 | 243.8 | 237.0 |

Combined parameters

The series of tests presented above have demonstrated that the estimates of urban deadweight loss (external congestion cost) are sensitive to assumptions on the form of the speed-flow curve and on the demand elasticity used. Instead, the share of trips in peak time (which is intrinsically a less uncertain parameter) does not influence the estimates significantly. The quantification of delay cost is much less sensitive to the parameters tested.

A further sensitivity test has been made to explore a sort of upper ceiling for the estimation of the deadweight loss, combining a higher demand elasticity and a steeper speed-flow function. The result of this test (Table 4-14) is that under these conditions the deadweight loss per capita would result 75% to 110% larger than the base estimates, i.e. some 20% of the delay cost per capita.

Table 4-14: Summary of sensitivity tests on demand elasticity and speed-flow function: deadweight loss per capita

City	Country	Population	Congestion index	Deadweight loss per capita (euro/capita)	
				Base elasticity and speed-flow function	higher elasticity and steeper speed-flow function
Warsaw	Poland	1,711,000	40%	22.3	41.1
Dublin	Ireland	527,612	38%	61.8	116.3
London	United Kingdom	8,308,000	37%	33.8	65.6
Paris	France	2,244,000	35%	21.2	39.4
Brussels	Belgium	166,497	33%	40.9	75.9
Stuttgart	Germany	597,939	32%	49.1	85.1
Stockholm	Sweden	914,909	30%	42.7	78.7
Milan	Italy	1,251,000	30%	42.9	81.8
Prague	Czech Republic	1,247,000	27%	30.8	56.1
Helsinki	Finland	599,676	22%	20.0	36.9
Madrid	Spain	3,234,000	21%	27.2	51.6
Copenhagen	Denmark	562,379	21%	23.5	44.8
Budapest	Hungary	1,732,000	20%	12.3	26.4
Amsterdam	Netherlands	825,080	19%	22.5	43.0
Malmö	Sweden	278,523	16%	27.8	52.8

The overall result of the sensitivity tests is that the estimates of urban deadweight loss (external costs) presented in the previous pages can vary also significantly if different assumptions are made on some key parameters. Under the assumptions used in the tests, different estimates in the range of -40% up to +115% have been obtained. The key parameters are used to summarise complex circumstances (the reaction of demand when travel time increases, the deterioration of speed on the

network when demand increases) that could be described in a less uncertain fashion only under a much more detailed analysis (i.e. for single links, segmenting demand by group and so on). At the aggregate level of detail of this study the uncertainty is inherent, it is the price to be paid for producing estimates for several cities and then at the country and EU level. When the costs presented in this section will be used to generalise costs at the EU level the results of the sensitivity tests will be considered to define an interval of deadweight loss rather than a single value.

The tests also demonstrated that the estimation of delay congestion cost is less sensitive to the parameter under analysis, with an estimated variation between -3% and +5%. Nevertheless, it should be underlined the direct relationship with the value of time used to give a price to the wasted time. Value of travel time is in itself an estimation rather than an objective element, therefore different values than those derived from the HEATCO project used in our calculations might be proposed. In case these different values would have a direct impact on the estimation.

4.3.2 Estimation of delay cost under alternative reference conditions

The methodology applied for estimating delay congestion costs (internal costs) is based on the additional travel time with respect to Free Flow conditions. As already mentioned in chapter 2, OECD/ECMT (2007) recommend to avoid estimating congestion costs based on delay to free-flow conditions because such conditions are highly theoretical. We have already argued that, while it is true that free-flow conditions are non-representative of everyday mobility, the quantification of congestion costs based on the absolute benchmark of free-flow conditions can be useful especially when different situations are compared. Nevertheless, in order to add a further element to our analysis, we have estimated how delay congestion costs would change considering additional time with respect to alternative reference conditions than free-flow. The procedure used is described as follows.

The speed-flow functions related to motorway and non-motorway roads have been used to identify the travel time corresponding to different levels of load-capacity ratio (e.g. 20%, 30%, and 50%). The delay for 30 minutes provided by the TomTom data has been therefore adjusted considering the difference between the free-flow time and the various levels of traffic. This has been repeated for all cities and separately for peak / off-peak and motorways / non- motorways roads. It has then been aggregated to compute a daily and then a yearly value using the same approach described in section 4.1. Finally, VOT has been applied to estimate the delay cost per capita.

Since the procedure has been applied for different levels of load-capacity ratio (20%, 30%, 50%) a relationship could be defined between load-capacity ratio and average delay cost per capita. Using the data for all cities, the following equation has resulted:

$$ICvar = -1.0706 * r^2 - 0.0202 * r + 1.0015 \qquad [11]$$

Where:
$ICvar$ = variation of delay congestion cost (internal cost) with respect to cost estimated with reference to free flow conditions
r = Flow capacity ratio

Variation of average delay cost per capita

$$y = -1.0706x^2 - 0.0202x + 1.0015$$
$$R^2 = 0.9995$$
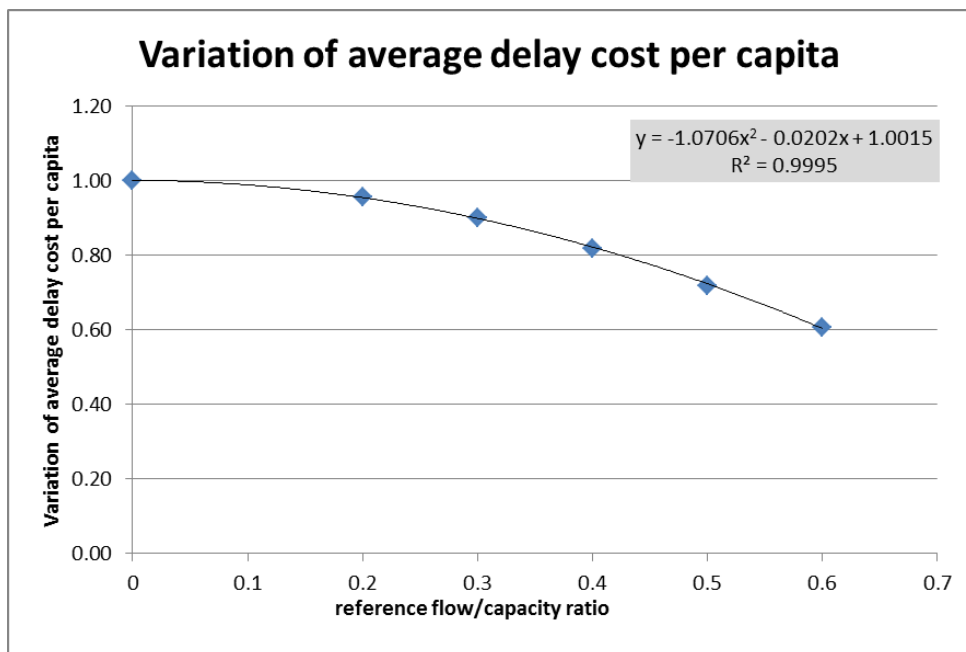
Using this equation one can scale the delay cost to more realistic traffic conditions. For instance, in the case that a load-capacity ratio of 50% is taken as a reference to measure congestion, the estimate of delay cost should be reduced on average by about 28% with respect to the value corresponding to the free-flow conditions.

4.3.3 INRIX data versus TomTom data

The estimation of urban congestion costs was based on the sample of cities in the TomTom database. The similar data provided by INRIX was not used because, as explained in 4.1.1 above, the comparisons for the cities included in both databases revealed that methodological differences make the two datasets not directly comparable. In this section we show how the estimates would change if the INRIX data were taken as a reference.

As far as delay cost is concerned the differences would be sometimes significant (see some comparisons in Figure 4-15). The costs computed with INRIX would be lower proportionally to the difference between wasted hours according to the two sources.

In case of deadweight loss[18], the reduction would be smaller (on average about 17%), although the differences would depend on the specific situation of the cities and sometimes would be quite significant (
Figure **4-16**).

In summary, the use of one source instead of another would make a difference. After the sensitivity analyses on some key parameters, this is another aspect that should be considered. Basically, the estimates of urban congestion costs should be regarded as an order of magnitude rather than as exact values.

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[18] Assumptions have been made to integrate the information provided by INRIX to the format required by the methodology (e.g., highways/non-highways and off-peak data).

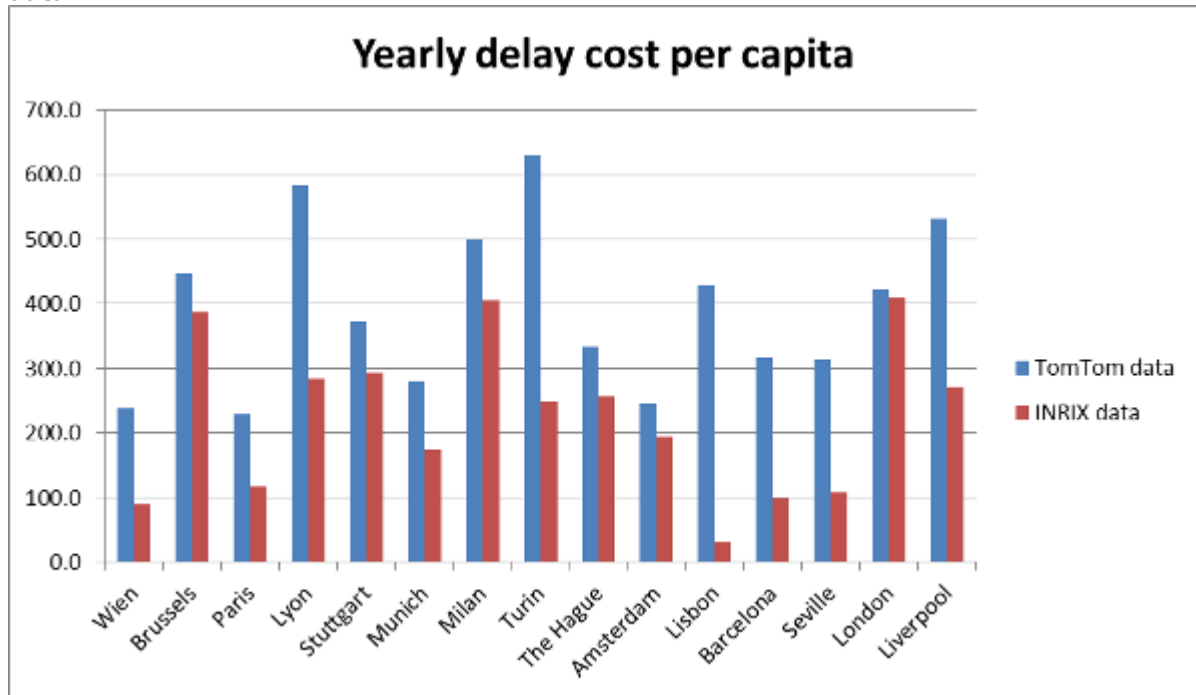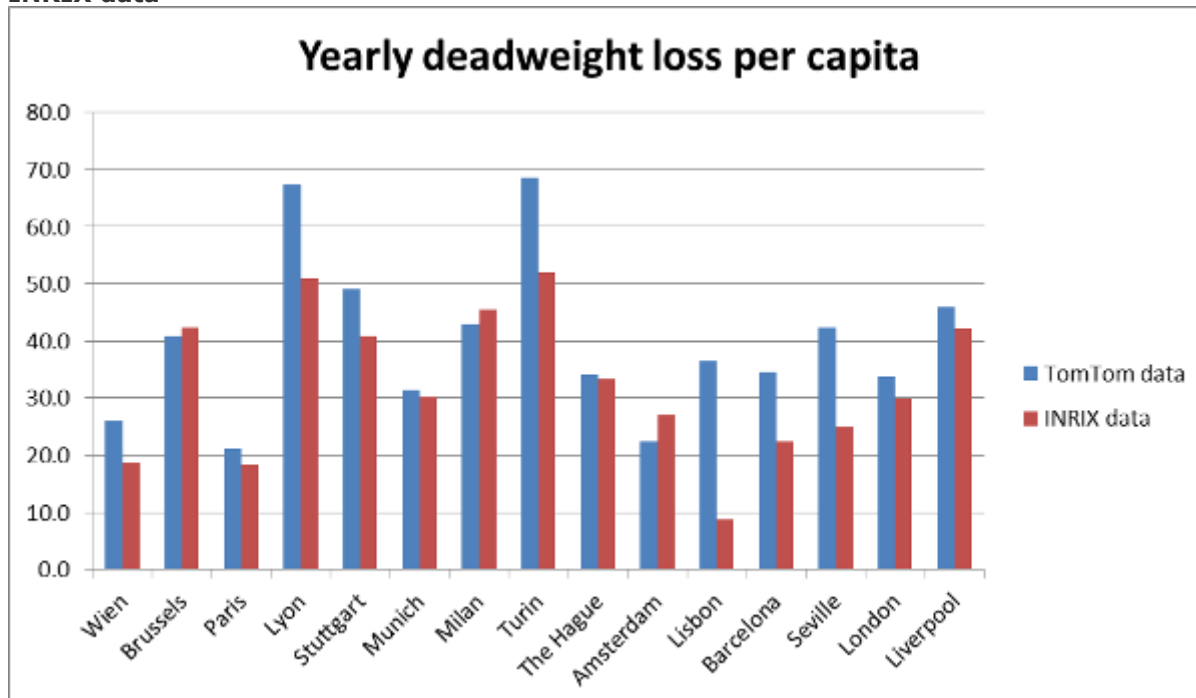**Figure 4-15: Comparison of yearly delay cost per capita based on TomTom and INRIX data**

Figure 4-16: Comparison of yearly deadweight loss per capita based on TomTom and INRIX data

5   Estimation of inter-urban congestion costs

At inter-urban level, congestion costs have been estimated for both passenger cars and trucks (the methodology applied allowed to quantify costs for road freight traffic as well). The estimation covers delays occurring on the main European network, i.e. the TEN-T Comprehensive network (motorways, primary roads) as well as other roads of regional and sub-regional interest. Again, the estimations refer only to time losses and do not include other costs.

The value of congestion costs on inter-urban roads in Europe has been estimated according to a different methodology compared to the one used for the urban costs. The reason has been that the available information regarding the delay generated by traffic was of a different nature. Rather than congestion indexes and amounts of time wasted in traffic jams for a sample of cities, the available information consisted of the localisation of congested spots on the European road network and of the amount of delay on each spot. Building on this information, the methodology applied for the estimation of costs included two main steps. In the first step the amount of passenger and freight vehicles-km in congested spots was quantified. In the second step, unitary costs (Euro/vehicle-km) provided by CE Delft and others[19] as well as the passenger and freight Value of Time for long distance trip (HEATCO project, 2006) have been used for the estimation of deadweight loss and delay costs. The paragraphs below explain how these two steps have been implemented and present the results of the methodology.

5.1   Estimation of traffic on congested inter-urban links

The quantification of traffic experiencing congestion on inter-urban roads has been carried out building on two main sources. One source was a map of the congested spots on the European inter-urban road network provided by JRC-IPTS. This map identified spots where road traffic is delayed in the most congested peak hour because of traffic and, for each spot, provided the amount of delay (in terms of additional time per km). The map was drawn using real traffic data for the year 2009[20], since the forthcoming updated version of the study wasn't available yet.

The map was very helpful to identify where congestion occurs and the range of its severity, however this source alone did not allow to quantify the amount of demand involved in congestion. This further element could be estimated by means of parameters used in the TRUST network model. TRUST is a transport network model covering the whole Europe developed by TRT (see Box 5-1 for details). In TRUST the road network is classified into different link types (e.g. motorways, dual carriageways roads, etc.). Each link type is associated to specific features; in particular speed-flow functions. Speed flow functions link traffic on one road to the time required to travel onto the road itself. They differ according to road types, for instance urban roads free flow speed is disturbed already for relatively low level of traffic whereas on motorways speed is maintained longer but is then more rapidly reduced when traffic approach the capacity.

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[19] CE Delft, INFRAS, Fraunhofer ISI (2011): External Costs of Transport in Europe. Update Study for 2008. Delft

[20] Details on the data are provided in Christidis and Ibáñez (2012).
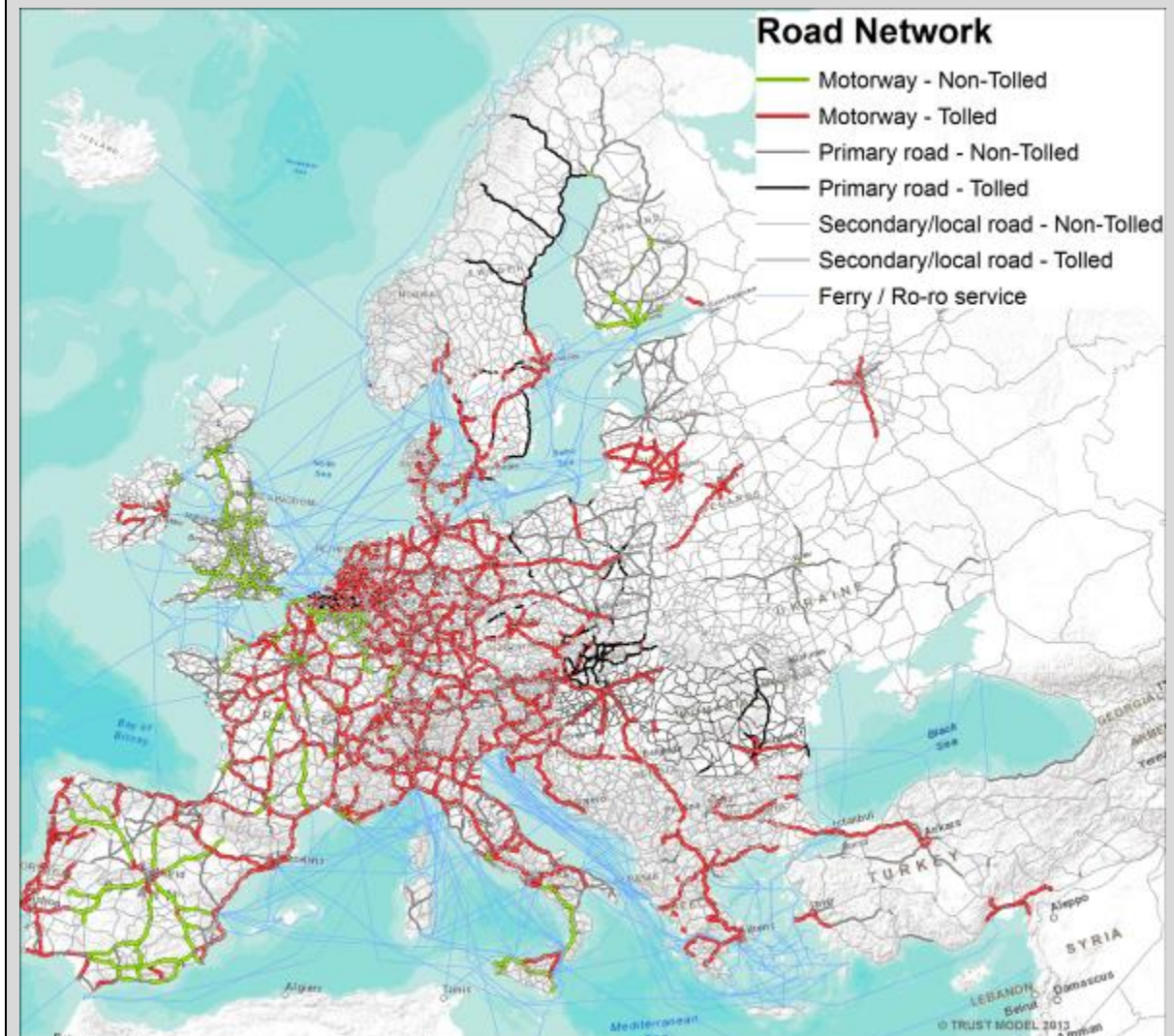
Box 5-1: The TRUST model

TRUST (TRansport eUropean Simulation Tool) is a transport network model developed by TRT in the MEPLAN software environment.

TRUST is a transport network model for the assignment of Origin-Destination matrices at the NUTS3 level of detail for passenger and freight demand. TRUST covers the whole Europe, including Accession and Neighbouring countries.

Road as well non-road transport modes are dealt with in TRUST. The road network includes all the relevant links between the NUTS3 regions, i.e. motorways, primary roads as well as roads of regional and sub-regional interest. Also ferry connections (Ro-Ro services) between European regions are explicitly modelled with their travel time and fare. Road network links are separated in different classes, each with specific features in term of capacity, free-flow speed and toll.

The main output of TRUST is the load on road network links in terms of vehicles per day and on non-road links in terms of either trips or tonnes per day. The model is calibrated to reproduce tonnes-km and passengers-km by country consistent to the statistics reported in the Eurostat Transport in Figures pocketbook net of intra-NUTS3 demand (available from ETISplus), which is not assigned to the network. Using load as an input parameter and emissions factors the model also provides emissions by link for NOx, PM and CO.

Figure 5-1: The road network in TRUST

The TRUST model uses the most recent data made available by the ETISplus[21] project. Apart the features of the network links (speed, capacity, etc.), the main parameters used in TRUST are:

- Transport costs by mode;

- Speed-flow functions;

- Values of travel time;

- Average fuel consumption and emission factors (for road modes).

The TRUST model has been successfully applied for the assessment of the Eurovignette directive on behalf of the European Commission.

Using the range of delay[22] reported on the map of the congested spots and the speed-flow function of the roads where the spots are located it was possible to estimate the level of occupancy of each spot in peak time, i.e. the amount of vehicles (in terms of Passenger Cars equivalent Units – PCUs) experiencing congestion in the most congested peak hour[23].

Figure 5-2 provides an overview of the localisation of congested links at European level, based on the elaboration of data provided by JRC and the network of the TRUST model. According to the JRC data a large number of links in the TRUST network experience some congestion. However, in several cases congestion occurs in some spots rather than along the whole link. For the purpose of drawing the map, only links where the congestion occurs for at least 30% of their length have been considered. However, the estimation of the congestion cost was based on all congested spots[24].

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[21] http://www.etisplus.eu/default.aspx. ETISplus provides a set of data including networks, matrices, etc. to serve for the development of transport modelling at the European level.

[22] Data has been used in terms of classes of delay instead of punctual values due to some discrepancies occurring when joining the TRUST network with the JRC network, which are not perfectly matching

[23] It is basically the same process already described with reference to the estimation urban congestion costs

[24] In order to avoid overlaps with the estimation of urban congestion (see chapter 4), the road links related to some zones representing large metropolitan areas have been excluded from the calculation. The metropolitan area excluded are: London, Berlin, Wien, Paris, Brussels and Amsterdam.

Figure 5-2: Map of interurban congestion in Europe* (roads with free flow speed above 50 km/h)
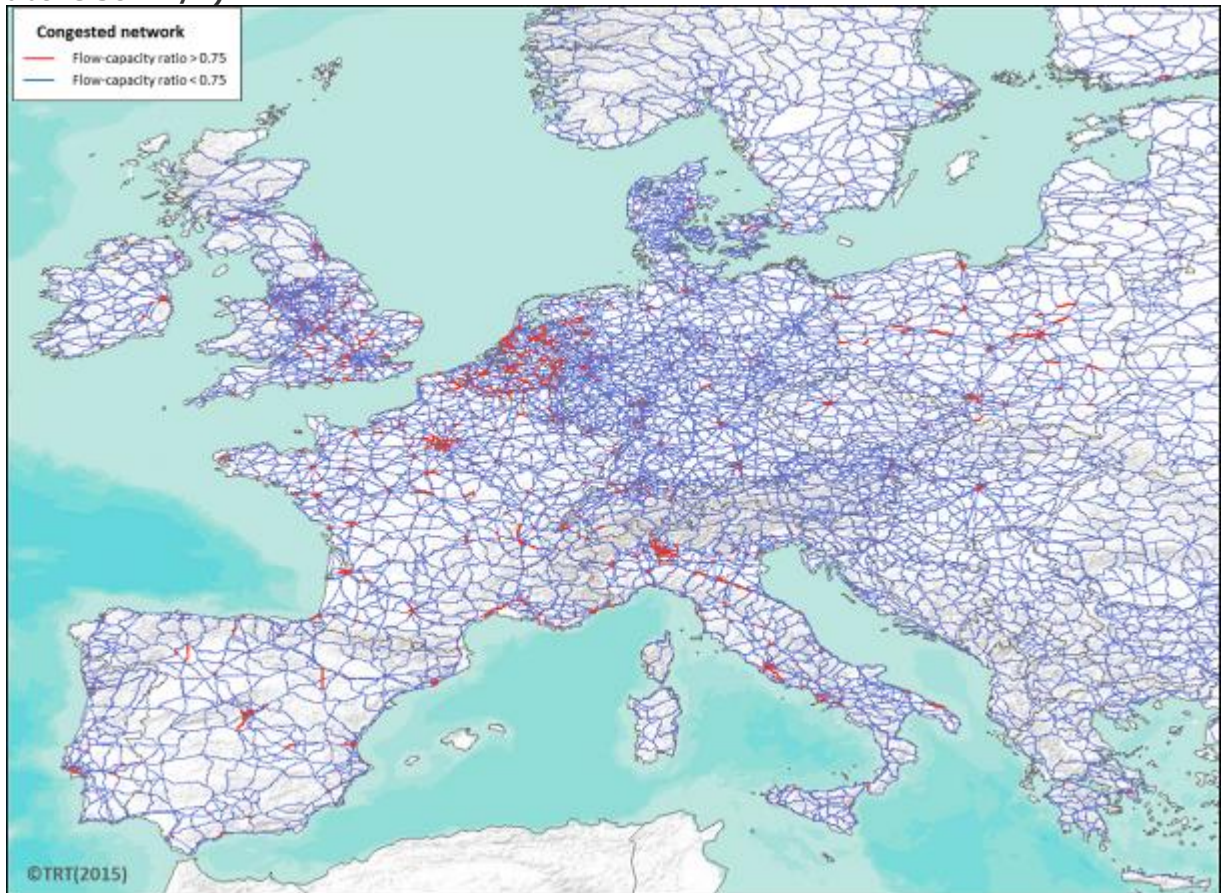
*Data not available for Bulgaria, Romania, Cyprus and Malta.
Source: TRT estimation on JRC data (2012)

Traffic on road links includes several vehicle types: cars, trucks, etc. Since the congestion cost associated with each type is different, a segmentation of the estimated loads has been estimated. Two main classes of road users have been considered: cars and trucks. The share of demand belonging to each class has been estimated making reference to the segmentation of traffic on each link assigned by the TRUST model. With reference to inter-urban traffic of buses, the analysis of traffic count data from UK suggests that it represent a small share of traffic flow (about 0.4% to 1% of traffic on motorways and principal roads): therefore, this mode of transport hasn't been taken into account for the estimation of inter-urban congestion cost.

The most congested peak hour is when motorists experience the highest delays, however there are other peak and off-peak periods when some congestion occurs. In order to estimate the overall cost of inter-urban congestion also delays outside the most congested peak hours should be estimated. This task was addressed using representative road load profiles for passenger cars and trucks during the day.

Road profiles describe how traffic changes over a 24 hour period. Of course in principle each road has its own profile but the distribution of traffic during the day is very similar for different roads and also in different countries (although peak time can be slightly different according to local habits about e.g. working time). For this exercise the load profile of a sample of roads in Italy and UK has been examined. In Italy, traffic counts related to 3 dual carriageways roads and 15 single carriageway roads

have been analysed: traffic flows data are available on an hourly basis by direction and by mode (car and trucks) and refer to the years 2012, 2014 and 2015. In UK, data from the national web portal on traffic count has been downloaded (http://www.dft.gov.uk/traffic-counts/), together with aggregated information provided in the road traffic statistical tables[25], i.e. car traffic distribution on all roads by time of day: from the web portal traffic flows data are available on an hourly basis by mode (car, bus, light trucks and heavy trucks). Data selected for the analysis are related to about 96 sections on motorways and 207 principal roads, referring to the years 2013 and 2014.
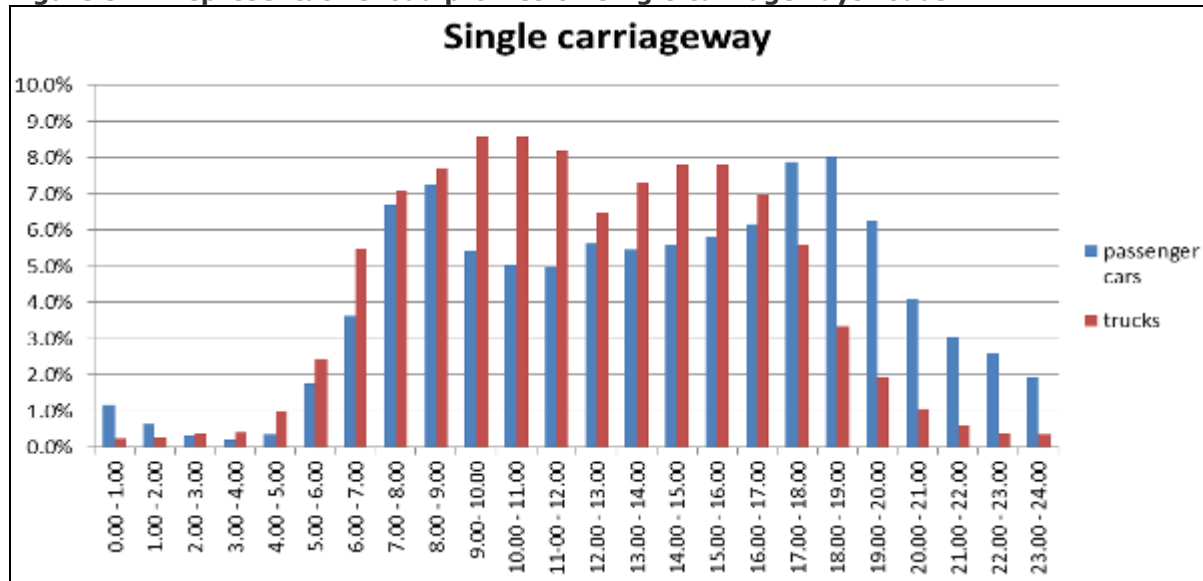
From this data a set of representative load profiles (i.e. share of demand for each hour in a day) by mode (car and trucks separately and also in terms of Passenger Cars equivalent Units – PCUs) and road type (single and dual carriageways) has been defined.

Figure 5-3: Representative load profiles on dual carriageways roads

Source: TRT estimation

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[25] https://www.gov.uk/government/statistical-data-sets/road-traffic-statistical-tables-index
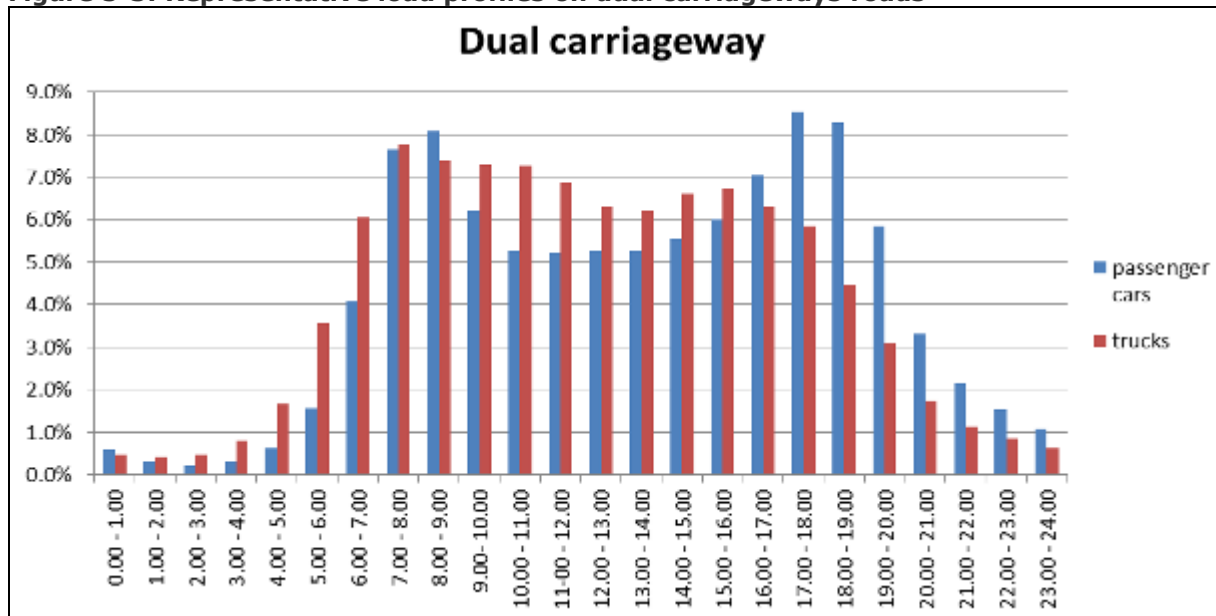
Figure 5-4: Representative load profiles on single carriageways roads

Source: TRT estimation

Using these profiles and using the estimated load in the most congested peak time it has been possible to estimate the load in each hour. Given the capacity of the road (taken from TRUST) and considering the sum of all vehicle types (in terms of Passenger Cars equivalent Units – PCUs) the load/capacity ratios have been estimated for each link and hour. All vehicles travelling in hours with a load/capacity ratio higher than 1 have been considered experiencing congestion (over capacity); furthermore, also vehicles travelling in hours with a load/capacity ratio between 0.75 and 1 have been considered experiencing congestion (near capacity), in line with definitions used for the update of the IMPACT handbook (2013) (see paragraph 5.2).

After this process, the total number of vehicles incurring congestion on the inter-urban European network in an average day has been obtained for each vehicle type (car and truck). Since the length of the congested spots was also reported in the map provided by JRC-IPTS, it has been straightforward to compute the hours spent in congestion by vehicle type. The estimation of the amount of yearly traffic is made assuming 230 work days per year.

Data for Cyprus, Malta, Bulgaria and Romania was not available from the map of congested spot. For Cyprus and Malta inter-urban congestion costs have not been estimated due to the lack of any information. For Bulgaria and Romania an estimation has been arranged using the TRUST model to compare the level of (non-urban) traffic in Bulgaria and Romania to that of other countries. More specifically, the length of congested links in Bulgaria and Romania according to TRUST has been compared to the length of congested links in other countries. The results of TRUST are modelled data coarser than the JRC information based on observed delays and therefore it is convenient to use the latter source. However TRUST results are consistent with observed traffic: countries where more congested spots are reported are also those where there are more links close or over capacity in the TRUST network. Therefore it could be reasonably assumed that if the length of congested links in one country is similar to the length in Bulgaria or Romania, also its level of congestion cost, as estimated according to the JRC data, is similar. Under this assumption, an estimation of the congestion cost in Bulgaria and Romania could be obtained even if in an approximated fashion.

5.2 Estimation of inter-urban congestion costs

With the procedure above, an estimation of the hours spent in congestion per year by country and vehicle type (car and truck) has been obtained. The original plan for estimating inter-urban congestion cost was to apply literature data of unitary cost (i.e. cost per vehicle-km) to a number of vehicles-km in congestion as drawn from the TRUST model. However, since from the JRC data we could better estimate the level of delay rather than the number of vehicles-km, a different approach has been eventually adopted.

5.2.1 Estimation of inter-urban delay congestion costs (internal costs)

Delay congestion costs at inter-urban level have been estimated by applying values of travel time by mode (VOT) to the amount of delays estimated. In order to take national differences into account, country specific values have been used. The values of time applied have been quantified building on those reported in deliverable 5 of the HEATCO project[26]. More specifically, the values for long distance trip by car have been used, weighted by the share of generated trips by purpose. For trucks, the same deliverable provides values of VOT per tonne per hour for road modes, which have been used assuming an average load of 12 tonnes/vehicle. The GDP deflator has been applied to update the values to Euro$_{2014}$. The resulting values by country are reported in Table 5-1. The average EU values are about 10.5 Euro$_{2014}$/hour per person and 2.9 Euro$_{2014}$/hour per tonnes.

Since delays are reported for vehicles rather than for individuals, the results VOT values are multiplied by the average vehicle occupancy factors, in order to take into account that the delay is suffered by all individuals travelling in cars experiencing congestion and not only by drivers (see Table 4-5).

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[26] HEATCO Developing Harmonised European Approaches for Transport Costing and Project Assessment: Deliverable 5 - 2006.

Table 5-1: VOT for long distance trips by mode and country (Euro $_{2014}$ / hour per person and per tonne)

Country	Car	Trucks
Austria	12.5	3.5
Belgium	11.7	3.5
Bulgaria	4.5	1.2
Cyprus	9.8	2.9
Czech Republic	8.1	2.2
Denmark	12.4	3.8
Estonia	7.5	2.0
Finland	10.5	3.5
France	14.9	3.5
Germany	12.0	3.5
Greece	10.6	2.7
Hungary	6.9	2.1
Ireland	12.6	3.7
Italy	14.1	3.3
Latvia	6.0	1.9
Lithuania	5.9	1.8
Luxembourg	16.0	4.3
Malta	9.9	2.6
Netherlands	11.8	3.5
Norway	18.8	5.3
Poland	6.6	2.0
Portugal	9.9	2.7
Romania	4.0	1.1
Slovakia	6.7	2.0
Slovenia	11.0	2.6
Spain	11.3	3.0
Sweden	11.9	3.7
Switzerland	15.5	3.9
United Kingdom	12.3	3.6

Source: TRT elaboration on HEATCO project

5.2.2 Estimation of inter-urban deadweight loss (external costs)

In order to estimate the deadweight loss of inter-urban congestion, data reported in the 2008 CE-Delft study on external costs (CE-Delft et. al. 2011) has been considered. As far as congestion is concerned, the study provides values of marginal costs consistent with the economic definition of external cost of congestion (deadweight loss, see paragraph 2.4), together with estimation of delay costs.

In the inception phase it was mentioned that the reference source for unitary external costs would be the update of the IMPACT handbook of external costs carried out as part of a recent study for the European Commission (DIW-Econ et. al, 2014).

However, a closer analysis of the data provided in this updated handbook has revealed that the definition applied is not consistent to the one needed for our estimation. The updated handbook reports estimates of the Efficient Marginal Congestion Cost (EMCC) which is the amount that users should pay in addition to private costs to drive the system to the socially optimal equilibrium, Making reference to the theoretical framework introduced in Section 2, the values reported are the difference between SC_1 and PC_0 in Figure 2-2[27]. Instead, the value we would need for our estimation is the ratio between deadweight loss (area of triangle BAC in Figure 2-2) and the amount of vehicles-km.

The value of deadweight loss reported by the CE-Delft study is consistent with our definition (it is the area of the triangle BAC defined between marginal cost and demand curves in Figure 2-2).

As mentioned above, the original plan was to estimate deadweight loss by applying a unitary cost (per vehicle-km and mode) to the amount of passenger and freight traffic in congested condition. However, on the one hand we could not quantify the total number of vehicles-km experiencing congestion on inter-urban roads using the JRC data (but rather the amount of delay). On the other hand, deadweight loss reported in the CE-Delft study is a total value and we could not calculate a unitary cost per vehicle-km. In fact, the average cost per vehicle-km reported by the study (see the last four columns in Figure 5-5) refers to the whole traffic, not only traffic in congestion. It is just the estimated total cost divided by total traffic. This data is not useful for us because the specific contribution of our estimation (based on JRC data) is exactly to provide an updated value for total costs.

Therefore, we used the data reported by the CE-Delft study as a measure of the ratio between deadweight loss and delay cost at inter-urban level. The deadweight loss of inter-urban congestion by country for passenger and freight has been estimated by applying this ratio to the value of the delay cost quantified as explained above.

The ratio is in the order of magnitude of 1 to 6, i.e. higher than the ratio of about 1 to 10 between deadweight loss and delay cost resulting from the estimation introduced in section 4 at urban level. This seems reasonable. The amount of deadweight loss basically depends on the form of demand curve and of marginal cost curve: the steeper these curves the higher the deadweight loss. As far as demand is concerned, a steeper curve means a larger elasticity. There is no much data on this aspect but according to some literature, elasticity of inter-urban demand can be expected to be somewhat higher than urban elasticity (Dunkerley et. al., 2014). As far as marginal cost is concerned, a steeper curve means that an additional vehicle generates a larger cost increase to all other road users. This is what usually happens on motorways and other roads with less intersections than urban roads. Therefore, both on the demand side and on the supply side, it is reasonable to expect that deadweight loss is larger for inter-urban roads than for urban roads.

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[27] Compare to figure A-3 page 87 in DIW-Econ et. al, 2014.

Figure 5-5: Total social losses and delay costs of road congestion in Europe in 2008 (mio. Euro, price level)

Transport	Transport mode	Total costs (Mio. €/year)		Average per vkm			
				€/1,000 vkm		€/1,000 pkm or tkm	
		Max.	Min.	Max.	Min.	Max.	Min.
Delay costs	Total	243,194	146,214	68.23	41.02		
Passenger	Pass. cars	161,331	98,416	57.98	35.37	33.21	20.26
	Bus/coach	7,729	4,836	145.91	91.29	13.92	8.71
	Motorcycles	3,841	2,439	29.30	18.61	26.63	16.92
	Pass. total	172,901	105,691	58.29	35.63	31.11	19.02
Freight	LDV	27,633	13,827	66.55	33.30	83.18	41.62
	HDV	42,660	26,695	233.46	146.09	22.15	13.86
	Freight Total	70,293	40,522	117.55	67.77	31.13	17.95
Deadweight Loss	Total	39,212	23,606	11.00	6.62		
Passenger	Pass. cars	26,015	15,891	9.35	5.71	5.35	3.27
	Bus/coach	1,247	781	23.53	14.74	2.24	1.41
	Motorcycles	620	394	4.73	3.01	4.30	2.73
	Pass. total	27,881	17,066	9.40	5.75	5.02	3.07
Freight	LDV	4,450	2,229	10.72	5.37	13.40	6.71
	HDV	6,880	4,311	37.65	23.59	3.57	2.24
	Freight Total	11,331	6,540	18.95	10.94	5.02	2.90

Source: CE DELFT et. al. (2011)

5.2.3 Estimated inter-urban congestion costs

Table 5-2 summarises the estimated amount of inter-urban congestion costs related to passenger cars in EU28 countries. As far as delay cost is concerned, at European level (EU28), passenger inter-urban congestion costs account for about 31 billion euro/year, i.e. about 0.2% of GDP. Countries where the absolute value of delay cost at inter-urban level is higher are the biggest ones: France, Italy, United Kingdom, Germany and Spain. Conversely, the lower values of delay cost at inter-urban level are estimated for Estonia, Latvia, Croatia, Slovenia and Lithuania.

The picture changes if cost per unit of GDP is considered. Here the top values are found in Poland (0.52% of GDP), Belgium (0.48%) and Bulgaria (0.45%) whereas for a large country like Germany the estimated cost is 0.10% of GDP. There are not large differences between Eastern and Western European countries. In the former group cost ranges from 0.07% of Croatia to 0.52% of Poland, while in the latter group the range is from 0.08% of Sweden to 0.48% of Belgium.

When comparing total congestion costs among different countries it should be considered that they depend not only on the level of congestion but also on the different country-based values of travel time (see Table 5-1). For the purpose of comparing countries without the influence of the value of travel time , following Figure 5-6 shows the inter-urban delay costs estimated with both congestion costs estimated using country-specific VOT and occupancy factor and cost estimated using an average VOT and occupancy factor for all countries. Basically, considering this second set of

estimates if the cost for country A is higher than the cost for country B this means that inter-urban congestion is more significant in country A than in country B. In other terms, while the estimates based on country-specific values of travel time provide the more representative measure of congestion costs in one country according to the national economy level, the estimates based on the average EU value of time can be used to compare countries in terms of level of inter-urban congestion.

However, looking at the figure it can be noted that the level of congestion is largely the more determinant factor of total congestion cost as the ranking of countries is not significantly changed if one consider the average value of time. Of course for lower income countries inter-urban congestion costs estimated with the average EU value result higher whereas the reverse case applies to higher income countries.

Figure 5-6: comparison of passenger inter-urban delay costs per year with country-specific VOT and average EU VOT
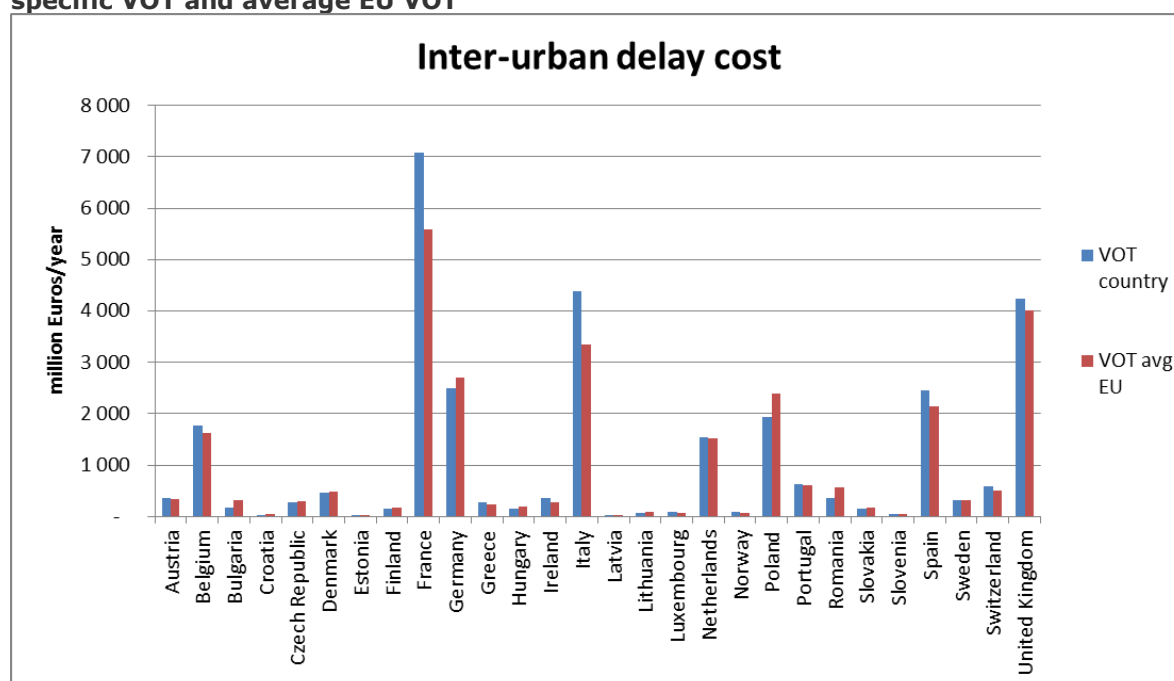
Source: TRT estimation

Regarding the deadweight loss (external cost) the estimated cost for passengers at the European level is about 5 billion euro/year, i.e. about 0.03% of GDP. The ranking is necessarily the same of delay cost, due to the procedure of estimation applied.

In terms of inter-urban delay cost per capita (see Figure 5-7) the countries with higher values are Belgium, Luxembourg, France and Netherlands, with values above 90 euro per capita per year. The lower values are estimated for Hungary, Latvia, Estonia and Croatia with values below 17 euro per capita per year. On average, at European level (EU28), inter-urban congestion costs per capita account for about 60 euro per capita per year.

Table 5-2: Estimated road passenger inter-urban congestion cost in EU by country (million Euros/year)

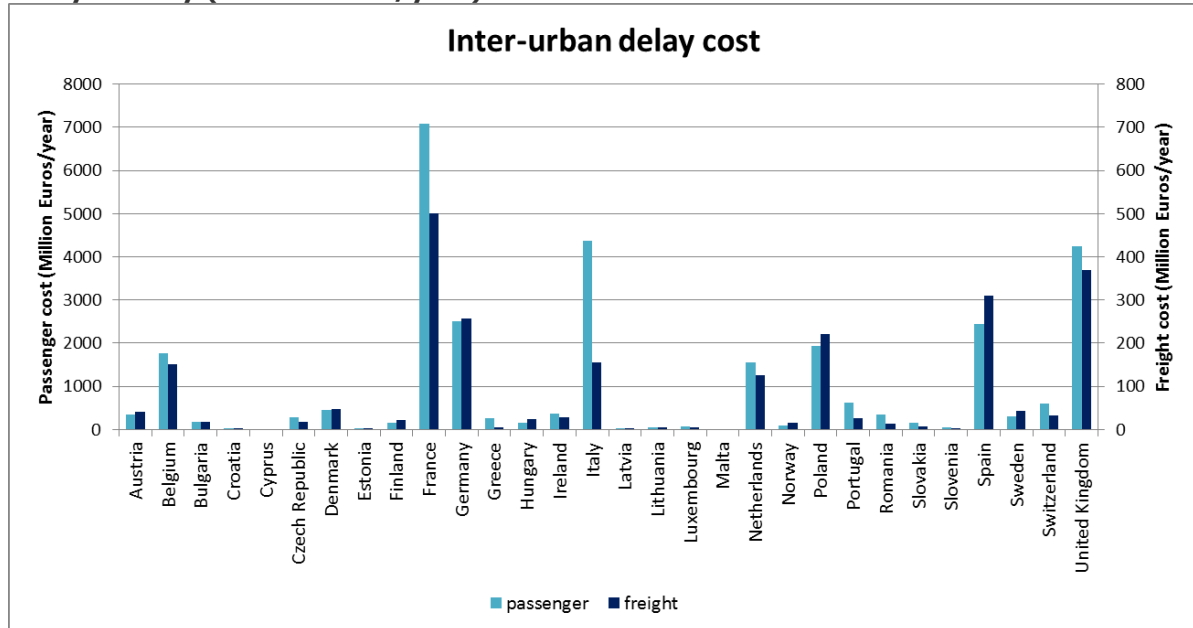| Country	Inter-urban delay congestion cost	Delay costs % share of GDP	Inter-urban deadweight loss	Deadweight loss % share of GDP
Austria	350	0.12%	56	0.02%
Belgium	1,777	0.48%	284	0.08%
Bulgaria	174	0.45%	28	0.07%
Croatia	32	0.07%	5	0.01%
Cyprus	n.a.		n.a.	
Czech Republic	284	0.18%	45	0.03%
Denmark	462	0.20%	74	0.03%
Estonia	15	0.09%	2	0.01%
Finland	154	0.08%	25	0.01%
France	7,084	0.35%	1,133	0.06%
Germany	2,504	0.10%	401	0.02%
Greece	270	0.13%	43	0.02%
Hungary	156	0.16%	25	0.03%
Ireland	367	0.23%	59	0.04%
Italy	4,379	0.28%	701	0.04%
Latvia	27	0.13%	4	0.02%
Lithuania	61	0.20%	10	0.03%
Luxembourg	81	0.19%	13	0.03%
Malta	n.a.		n.a.	
Netherlands	1,545	0.26%	247	0.04%
Norway	98	0.04%	16	0.01%
Poland	1,945	0.52%	311	0.08%
Portugal	633	0.37%	101	0.06%
Romania	350	0.27%	56	0.04%
Slovakia	158	0.23%	25	0.04%
Slovenia	42	0.12%	7	0.02%
Spain	2,450	0.23%	392	0.04%
Sweden	315	0.08%	50	0.01%
Switzerland	597	0.13%	95	0.02%
United Kingdom	4,239	0.13%	678	0.02%
EU28	30,957	0.22%	4,953	0.03%

Source: TRT estimation

Figure 5-7: Estimated passenger inter-urban congestion cost per capita in EU by country (Euros/year per capita)
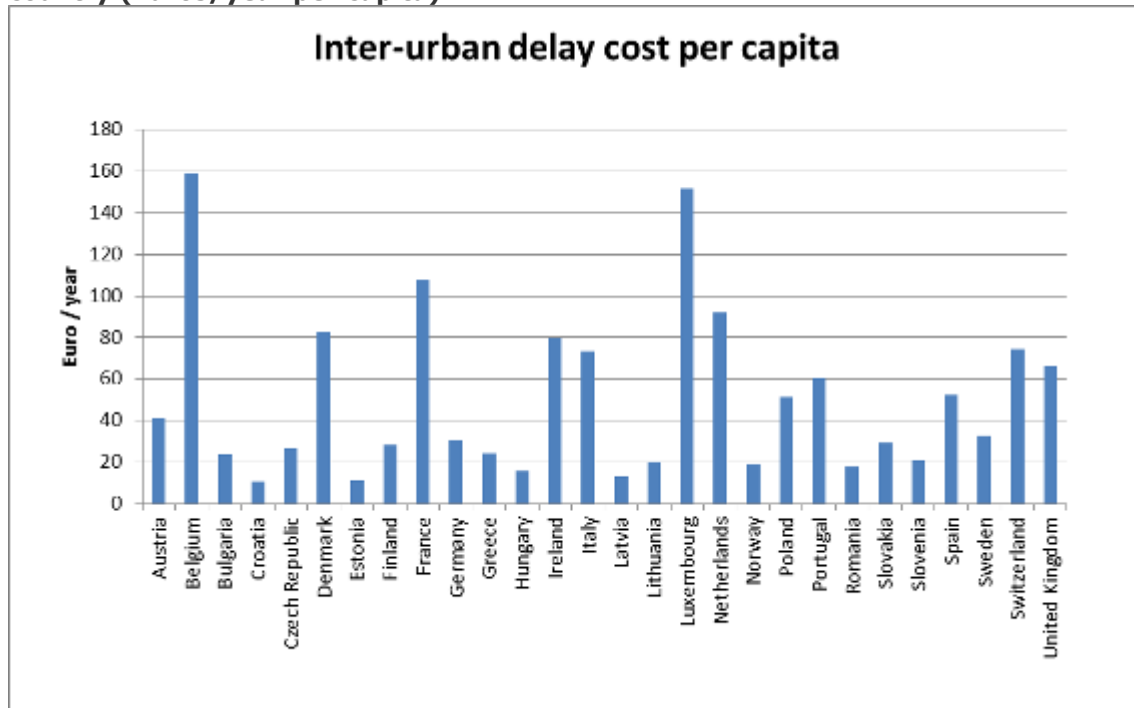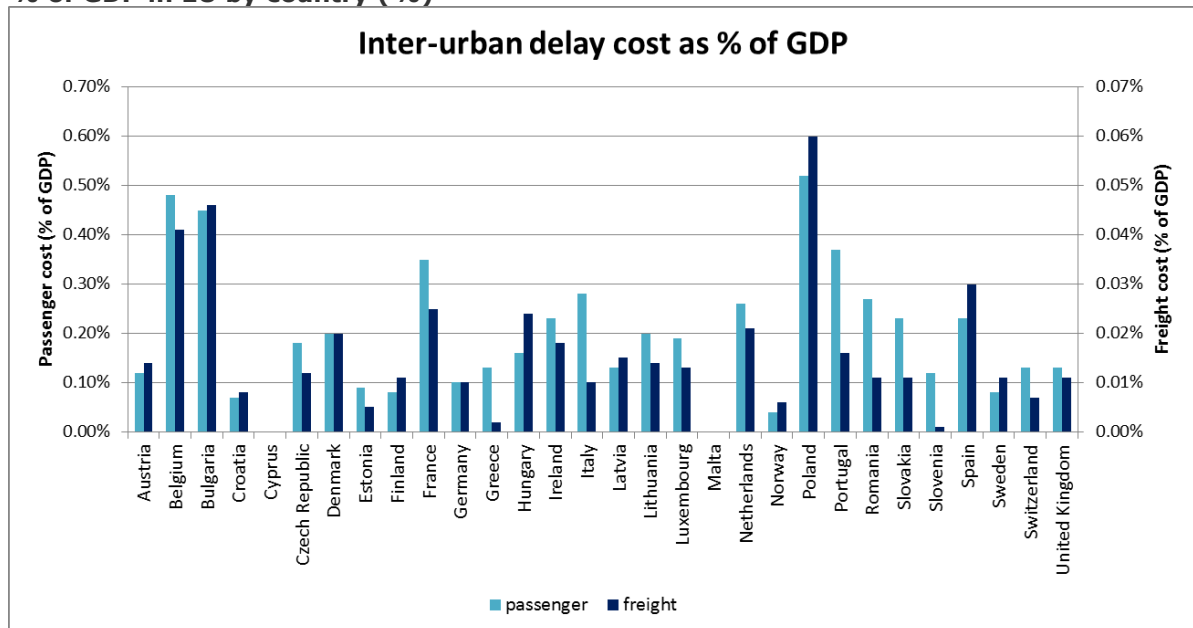

Source: TRT estimation

With reference to freight road transport, inter-urban delay cost are estimated as much as 2,4 billion euro/year at European level (EU28), i.e. less than 0.02% of GDP (Table 5-3), while deadweight loss is about 385 million euro. Not surprisingly, the countries where the freight congestion cost (per unit of GDP) is highest are the same countries where also passenger congestion cost is large. Spain has a relatively higher cost for freight than for passengers: freight congestion cost as share of GDP is almost as twice as the EU average whereas passenger congestion cost is close to the European average. The reverse case can be observed in Portugal and Sweden, where the freight congestion cost is relatively lower than the passenger congestion cost if compared to the average EU value (see Figure 5-8 and Figure 5-9).

Figure 5-8: Estimated passenger and freight inter-urban delay cost (internal cost) in EU by country (million Euros/year)

Source: TRT estimation

Figure 5-9: Estimated passenger and freight inter-urban delay cost (internal cost) as % of GDP in EU by country (%)

Source: TRT estimation

Table 5-3: Estimated road freight inter-urban congestion cost in EU by country (million Euros/year)

Country	Inter-urban delay congestion cost	Delay costs % share of GDP	Inter-urban deadweight loss	Deadweight loss % share of GDP
Austria	41.2	0.014%	6.6	0.002%
Belgium	151.7	0.041%	24.3	0.007%
Bulgaria	17.7	0.046%	2.8	0.007%
Croatia	3.7	0.008%	0.6	0.001%
Cyprus	n.a.		n.a.	
Czech Republic	18.8	0.012%	3.0	0.002%
Denmark	46.5	0.020%	7.4	0.003%
Estonia	0.9	0.005%	0.1	0.001%
Finland	21.5	0.011%	3.4	0.002%
France	501.6	0.025%	80.2	0.004%
Germany	256.9	0.010%	41.1	0.002%
Greece	4.5	0.002%	0.7	0.000%
Hungary	23.5	0.024%	3.8	0.004%
Ireland	29.3	0.018%	4.7	0.003%
Italy	155.1	0.010%	24.8	0.002%
Latvia	3.1	0.015%	0.5	0.002%
Lithuania	4.4	0.014%	0.7	0.002%
Luxembourg	5.7	0.013%	0.9	0.002%
Malta	n.a.		n.a.	
Netherlands	126.4	0.021%	20.2	0.003%
Norway	15.1	0.006%	2.4	0.001%
Poland	221.4	0.060%	35.4	0.010%
Portugal	26.9	0.016%	4.3	0.003%
Romania	14.2	0.011%	2.3	0.002%
Slovakia	7.3	0.011%	1.2	0.002%
Slovenia	0.3	0.001%	0.1	0.000%
Spain	309.5	0.030%	49.5	0.005%
Sweden	42.6	0.011%	6.8	0.002%
Switzerland	33.1	0.007%	5.3	0.001%
United Kingdom	370.1	0.011%	59.2	0.002%
EU28	2,404.6	0.017%	384.7	0.003%

Source: TRT estimation

6 Overall congestion costs in EU countries

This chapter reports on the estimation of overall congestion costs in EU countries, resulting from the association of urban and inter-urban costs. The methodology applied to estimate inter-urban congestion cost directly provided costs by country for passenger cars and trucks as described in details in section 5.

Instead, for urban congestion costs related to passenger cars the methodology presented in section 4 is concerned with only a sample of cities. Therefore a further estimation step was required in order to provide data at country level. This further step is described in the following paragraph.

6.1 Generalising urban congestion cost

With the methodology explained in section 4 we have estimated urban congestion costs related to passenger cars for several European cities. In order to add urban congestion costs to the inter-urban congestion costs at the country level estimated in section 5 a generalisation of results to other urban areas not included in the sample of cities reported by the TomTom database was needed. The procedure adopted is explained below.

6.1.1 Adding cities with less than 50,000 inhabitants

Delay congestion costs are estimated by applying values of travel time (VOT) to the amount of delays provided by TomTom or estimated on the TomTom data. First of all, in order to obtain a set of data comparable among different cities in different countries, costs have been re-estimated using an average value of time and an average occupancy factor for all EU (see Figure 6-1). This set of costs has been used for a statistical analysis aimed at identifying correlations between the size of congestion cost and some known features of the cities such as size, or mode split of trips. The idea was that if correlations are found they could be used to select the most appropriate cost from the sample cities for the other European urban areas (e.g. if congestion costs proved to be correlated to city size, once this information is known for a specific city the related urban congestion cost could be quantified using the values estimated for cities of the same size in the sample).

Unfortunately, the statistical analysis have not unveiled any significant correlation between the estimated congestion cost (delay cost and deadweight loss) and other dimensions representative of the cities (population size, car mode share, public transport mode share). For instance, in principle one might expect that the market share of cars in urban trips has something to do with the congestion. However the available information does not support this expectation. Figure 6-2 to Figure 6-5 show the distribution of the sample cities according to various indicator and urban congestion cost: car share, PT share[28], and population density of the NUTS3 region and car ownership[29]. It is apparent that the data does not form any clear pattern. Not all graphs are reported, but very similar results have been obtained using other

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[28] The car and PT share data has been drawn from the EPOMM database (http://www.epomm.eu/tems/) integrated with national sources

[29] Data on population density of the NUTS3 region where the cities are located and car ownership has been drawn from the Urban Audit database () and integrated with national sources

variables and also using the original TomTom data (congestion index, wasted time) instead of the estimated urban congestion cost.

Figure 6-1: Yearly urban delay cost per capita in selected European cities based on average European VOT and car occupancy factor (in euro per capita per year)
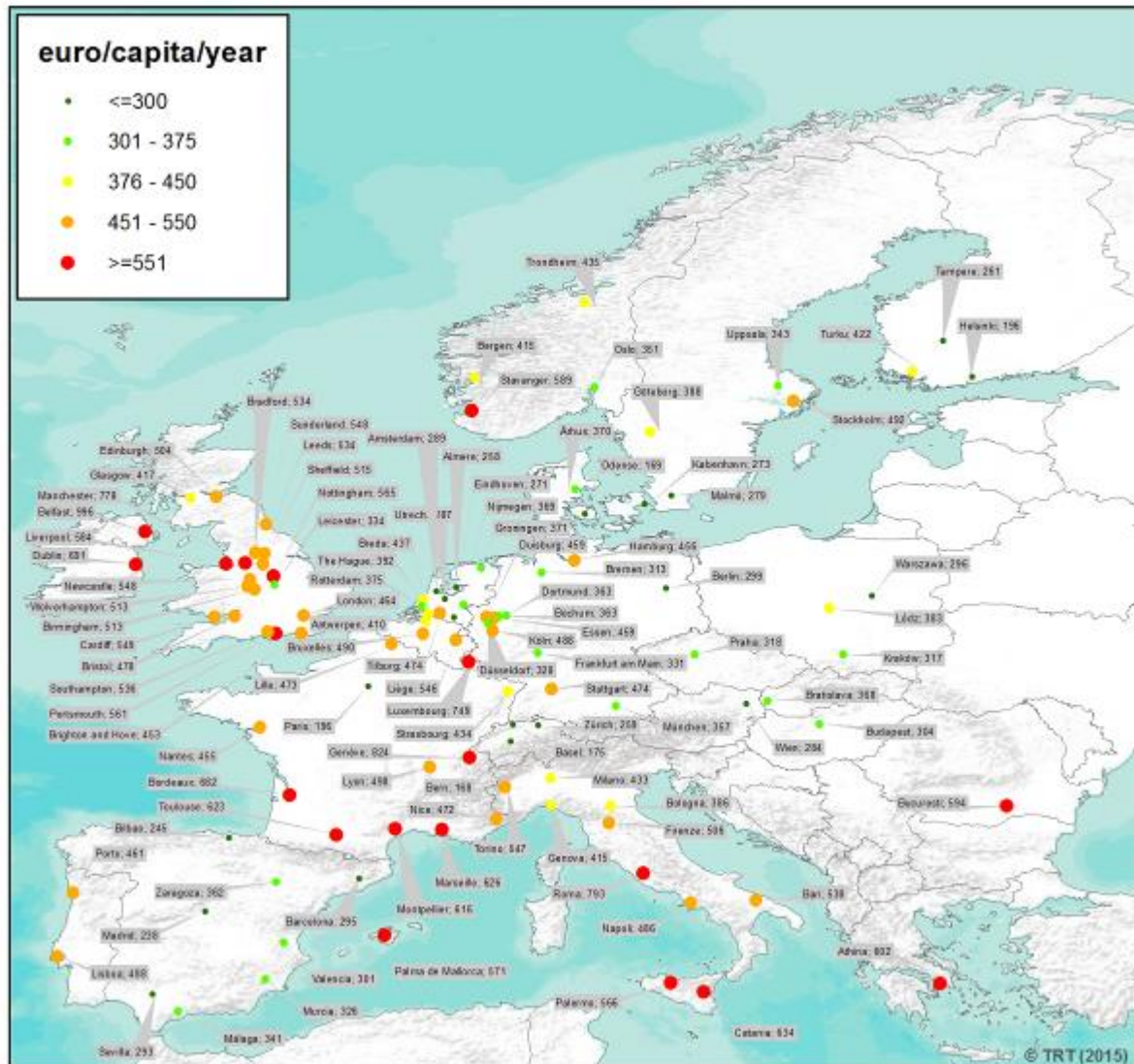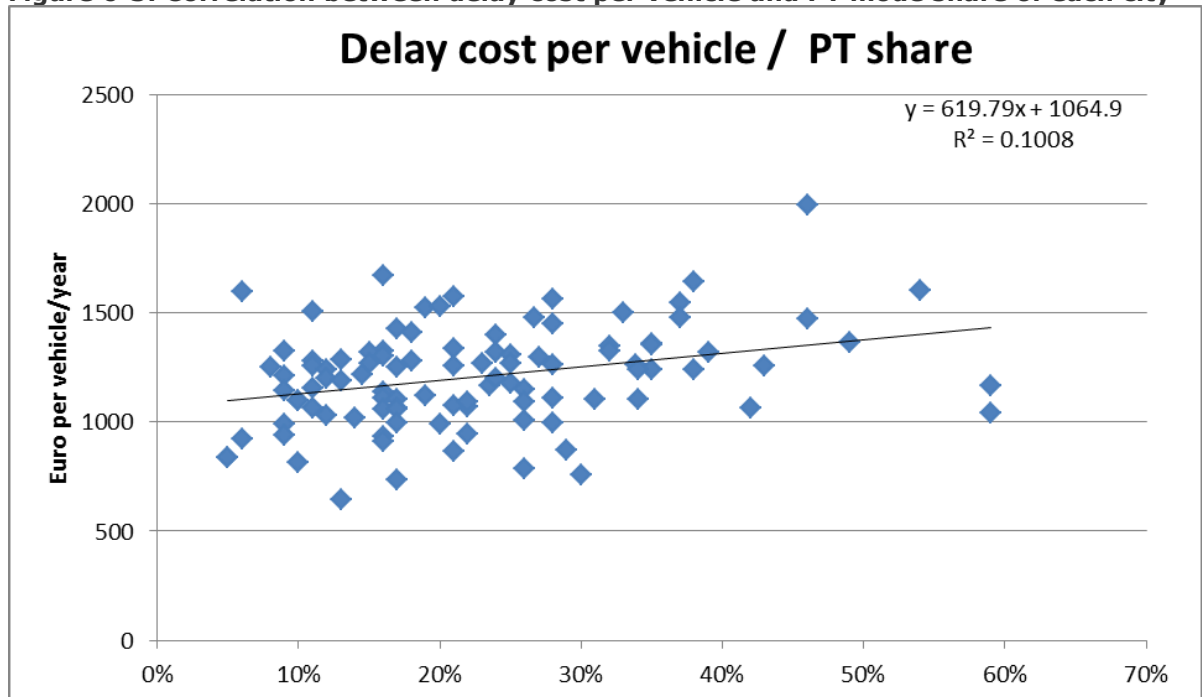

Source: TRT estimation

Figure 6-2: Correlation between deadweight loss per vehicle and car mode share of each city
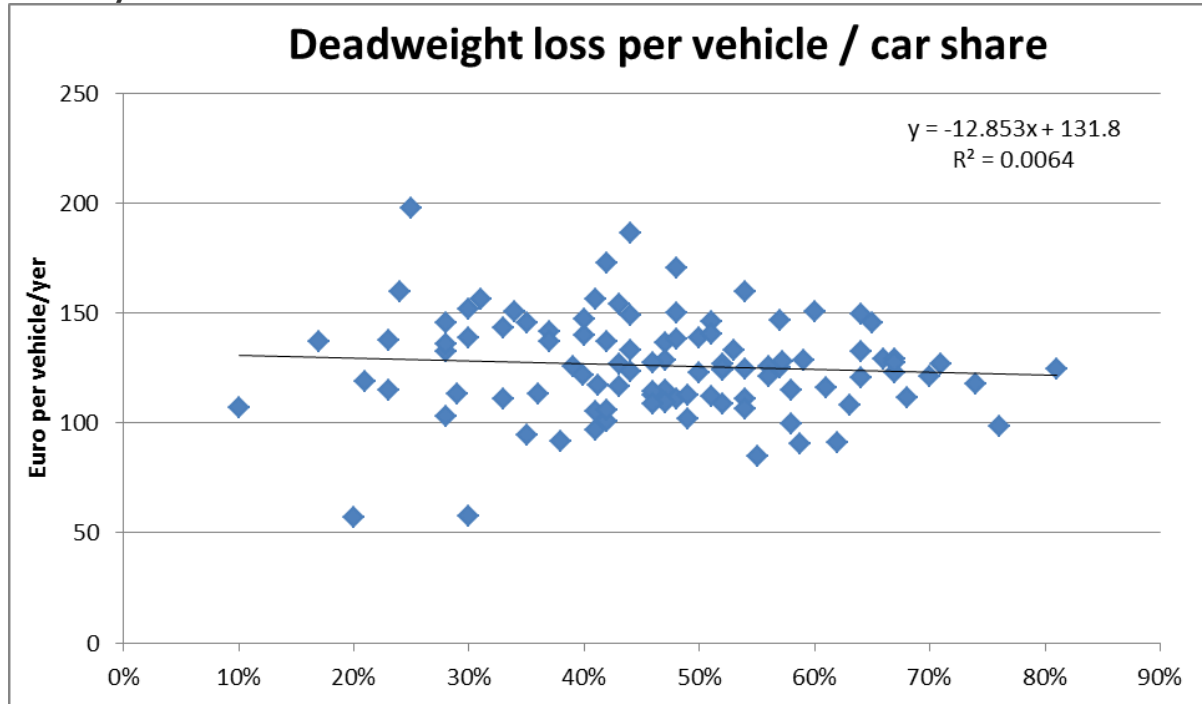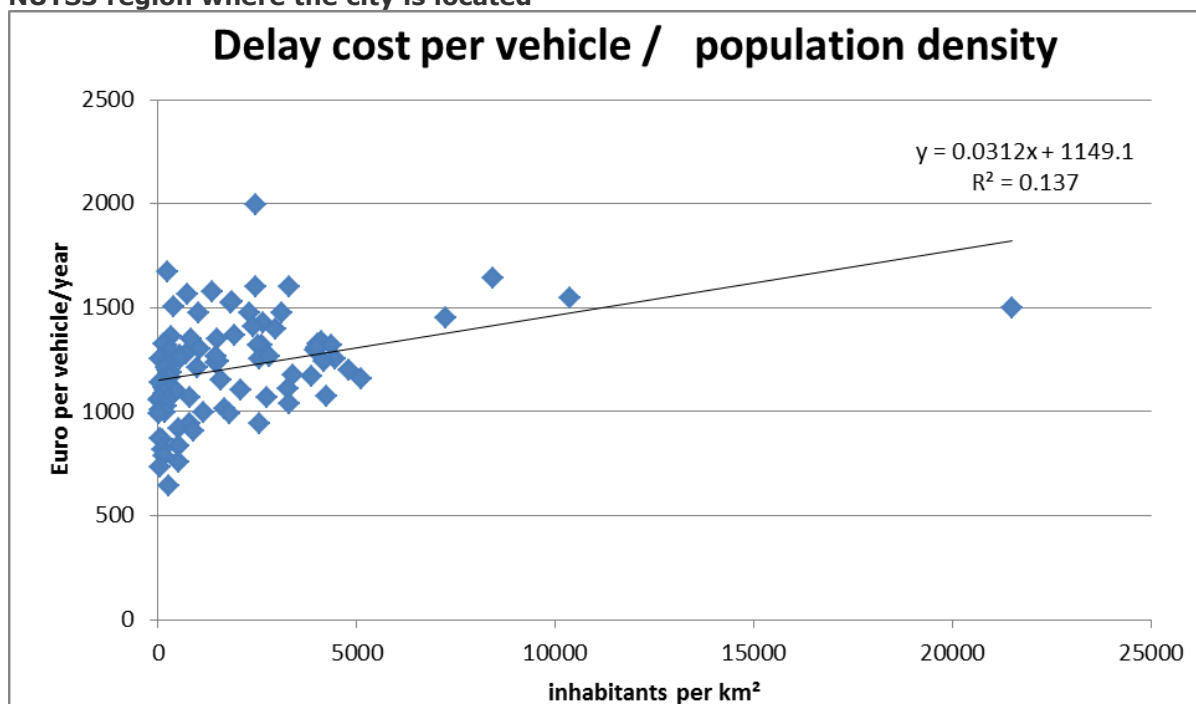

Source: TRT estimation on various data

Figure 6-3: Correlation between delay cost per vehicle and PT mode share of each city
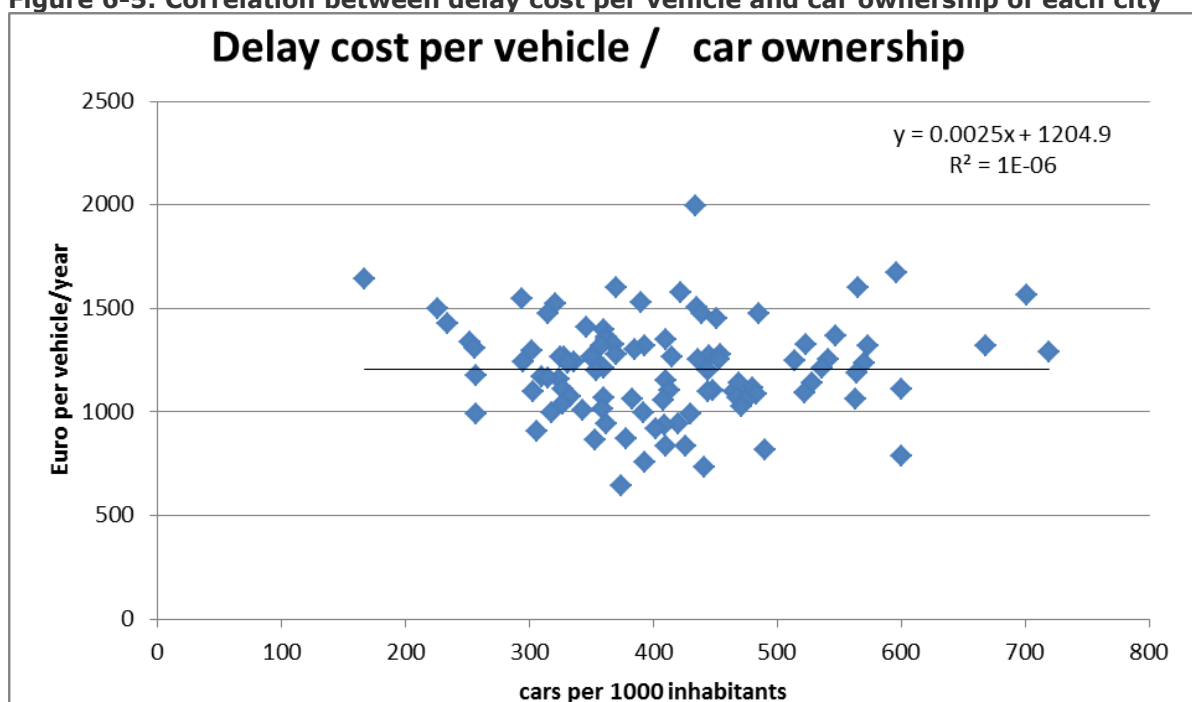

Source: TRT estimation on various data

Figure 6-4: Correlation between delay cost per vehicle and population density of the NUTS3 region where the city is located

Source: TRT estimation on various data

Figure 6-5: Correlation between delay cost per vehicle and car ownership of each city


Source: TRT estimation on various data

The only correlation found was between congestion cost per vehicle and population of the cities by class: the higher the population size class the city belongs to the lower the average congestion cost per vehicle. This correlation holds for both delay cost and deadweight loss, nevertheless, when congestion cost per capita is considered (rather
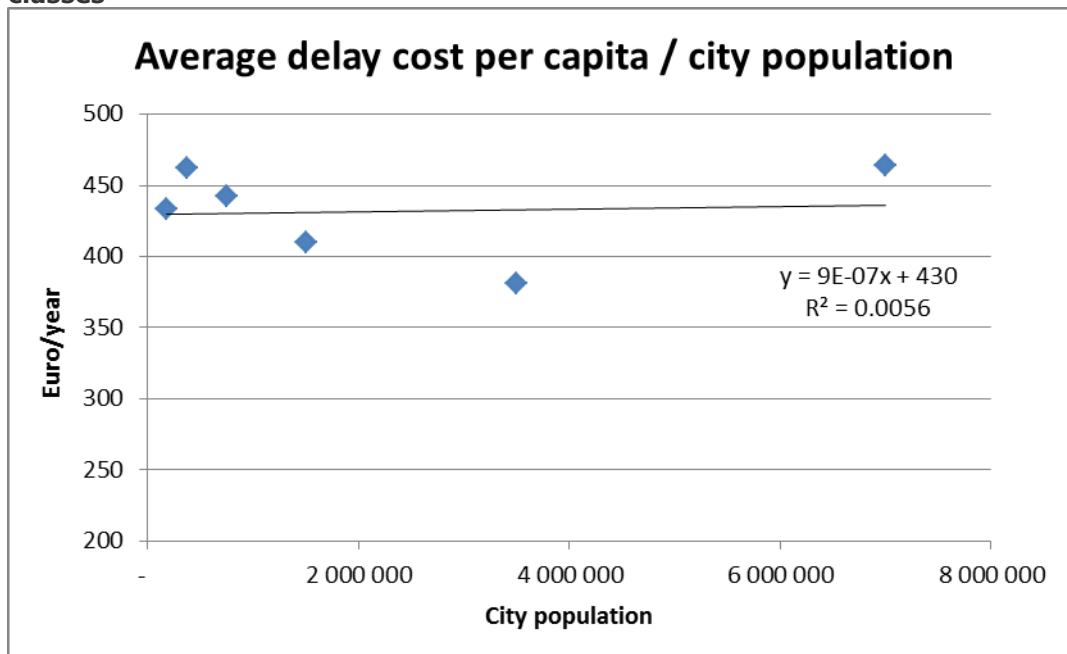
than per vehicle), the correlation is much weaker and, for delay cost, basically disappears (see Figure 6-6 and Figure 6-7).

Figure 6-6: Correlation between average deadweight loss per capita and city population size by classes
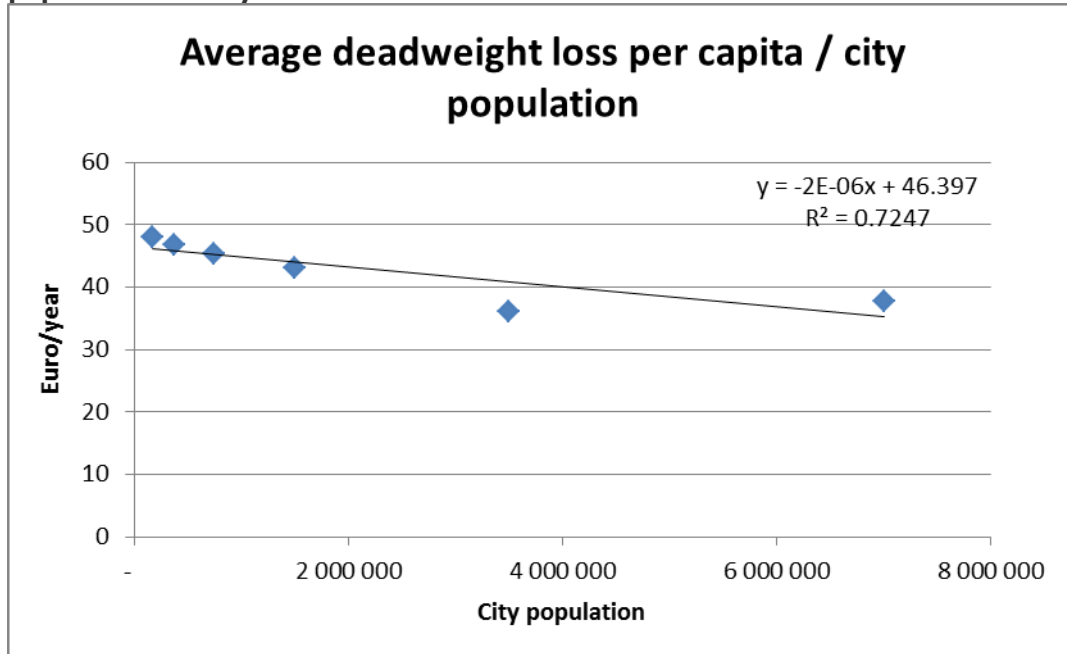
Source: TRT estimation

Figure 6-7: Correlation between delay cost per capita and city population size by classes

Source: TRT estimation

Table 6-1: Average delay cost and deadweight loss per capita and per vehicle depending on city population size: TomTom sample data (Euro/year)

City population size	Average delay cost per vehicle	Average delay cost per capita	Average Deadweight loss per vehicle	Average Deadweight loss per capita
More than 5 million	1,548	464	125.7	37.7
2 to 5 million	1,355	381	133.8	36.2
1 to 2 million	1,308	410	136.5	43.1
500,000 to 1 million	1,254	442	131.3	45.4
250,000 to 500,000	1,183	462	119.8	46.8
100,000 to 250,000	1,067	433	118.5	48.1

Source: TRT estimation on TomTom data

The results of the analysis suggest that congestion is mainly dependent on local conditions, i.e. on elements that cannot be readily recognised using simple indicators like the mode shares or the population size. In some cases it might be that the available data to describe some conditions are not up to date or accurate (e.g. car share in the EPOMM database looks sometimes questionable). However, the working conclusion of the analysis was that known attributes of cities do not help to identify homogenous clusters with similar congestion costs. Therefore, the available data has been considered a random sample (of cities above a certain size threshold, see below) and simple averages were estimated to generalise delay congestion cost estimations to the whole universe of cities. The deadweight loss instead was associated to the population size according to the values shown in Table 6-2, resulting from the regression function estimated from the sample data (see Figure 6-6). In the same table is also shown the average delay cost derived from the sample.

Table 6-2: Average delay cost and deadweight loss per capita[30] depending on city population size (Euro/year)

City population size	Average Deadweight loss per capita	Average delay cost per capita
More than 5 million	35.4	
2 to 5 million	40.5	
1 to 2 million	43.4	
500,000 to 1 million	44.5	
250,000 to 500,000	45.0	432
100,000 to 250,000	45.3	
50,000 to 100,000	45.4	
Less than 50,000	45.5	

Source: TRT estimation

The values in Table 6-2 have been obtained considering an average value of time for all cities. However, likewise the approach followed for inter-urban congestion costs,

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[30] Estimated with the regression function resulting from the sample data.

local conditions should be reflected in the values used to transform delays into monetary values. Since we are estimating congestion costs in cities, we considered not only national differences of values of time but also regional differences in terms of average income per capita. The average values reported in Table 6-2 have been scaled to considering a) the national values of time estimated from HEATCO (see Table 4-4) and b) the ratio between regional and national GDP per capita. Therefore, the estimation of urban congestion cost has been made assuming that the opportunity cost of time depends on local features and particularly economic activity.

These values of congestion cost per capita by NUTS3 region have then been applied to all related cities with at least 50,000 inhabitants[31]. The list of cities has been compiled based on information collected from different source, e.g. the website http://www.citypopulation.de/Europe.html as well as national statistical offices. The list includes 1275 cities in 30 European countries (EU28 plus Switzerland and Norway).

Table 6-3: Dataset of European urban areas within different population classes

Population of urban areas	Number of EU cities
More than 5 million	1
2 to 5 million	5
1 to 2 million	13
500,000 to 1 million	37
250,000 to 500,000	93
100,000 to 250,000	387
50,000 to 100,000	740

Source: TRT estimation on various data sources

It is reasonable to expect that some congestion occurs also in cities with less than 50,000 inhabitants, however extending the dataset to cities larger than e.g. 15,000 inhabitants would have been too complex given the number of urban areas of this size in Europe. A simplified approach was adopted to generalise urban congestion costs also to cities below the threshold of 50,000 inhabitants.

The simplified approach consisted in estimating the number of additional urban areas to consider in each NUTS3 zone. Two elements have been used for this estimation. First, the total amount of population in the NUTS3 zone compared to the amount of population in the cities with more than 50,000 inhabitants located in the same zone. Intuitively if these cities explain a large share of total population of the NUTS3 it is likely the only a few or even no cities between 15,000 and 50,000 inhabitants exist in that zone, Vice-versa, if the cities above 50,000 inhabitants explain only a limited share of total population, a higher number of smaller cities can be expected.

The second element was the typology of NUTS3 according of the classification urban / mixed / rural. In rural areas cities tend to be smaller and so a lower number of urban areas between 15,000 and 50,000 inhabitants can be expected for a given share of population not explained by the cities above 50,000 inhabitants.

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[31] Nevertheless, for the cities included in the sample with TomTom data the specific values of urban congestion cost per capita estimated with the procedure explained in chapter 4 have been used (scaled considering VOT of the related NUTS3 region).

NUTS3 population was extracted from the Eurostat database. The classification of NUTS3 regions in three categories: predominantly urban, predominantly rural, mixed is also provided by Eurostat[32].

The cities with at least 50,000 inhabitants have been associated to the NUTS3 zone they belong. Then, for each NUTS3 region, the sum of the population living in cities with at least 50,000 inhabitants has been compared to the total population of the region. Depending on the share of population living in the city/cities with more than 50,000 inhabitants in each NUTS3 region and the category of the region itself, different rules have been applied to estimate how many additional urban areas should be considered for the generalisation of urban congestion cost.

The rules have been defined on a conceptual basis and verified on a sample of European NUTS2 regions (for which comparison data on population was available) in different countries, resulting in a satisfying level of approximation.

Table 6-4: Sample of regions to verify the estimation of population in urban areas < 50,000 inhabitants

Country	Region	Observed population in cities <50,000 inhab.	Estimated population in cities <50,000 inhab.
Austria	Upper Austria (Oberösterreich)	312267	289753
Belgium	Prov. Limburg (B)	437662	234685
Switzerland	Espace Mittelland	257030	221831
Czech Republic	Karlovarský Kraj	338593	336674
Germany	Brandenburg	800155	548937
Germany	Stuttgart	4455952	4943973
Germany	Chemnitz	1833824	2194379
Denmark	Byen København	1645153	888651
Greece	Attica	3734875	3800145
Spain	Ávila	1246472	1204942
France	Paris	7970300	6624328
France	Champagne-Ardenne	362166	381574
Hungary	Közép-Dunántúl	96679	120541
Italy	Torino (NUTS3)	1316911	1022300
Italy	Piemonte)	1905863	1602458
Italy	Bari (NUTS3)	918257	527581
Italy	Puglia	2348652	1658300

Source: TRT

Table 6-5: Rules to estimate the number of urban areas < 50,000 inhabitants by NUTS3 zone – Zones with at least a city with more than 50,000 inhabitants

Share of NUTS3	NUTS3 classification

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[32] http://ec.europa.eu/eurostat/statistics-explained/index.php/Urban-rural_typology#Definition_at_the_regional_level

population living in the city/cities with more than 50,000 inhabitants	Urban	Mixed	Rural
> 70%	It is assumed that there are no other relevant urban areas in the NUTS3: only cities >50,000 inhabitants are affected by congestion cost	It is assumed that there are no other relevant urban areas in the NUTS3: only cities >50,000 inhabitants are affected by congestion cost	It is assumed that there are no other relevant urban areas in the NUTS3: only cities >50,000 inhabitants are affected by congestion cost
50% - 70%	It is assumed that there is one other relevant urban area of about 25,000 inhabitants in the NUTS3: inhabitants of this urban area are affected by congestion cost together with population of the cities >50,000 inhabitants		
25% - 50%	It is assumed that there are two other relevant urban areas of about 25,000 inhabitants in the NUTS3: inhabitants of these urban areas are affected by congestion cost together with population of the cities >50,000 inhabitants	It is assumed that there is one other relevant urban area of about 25,000 inhabitants in the NUTS3: inhabitants of this urban area are affected by congestion cost together with population of the cities >50,000 inhabitants	
< 25%	It is assumed that the region is mostly a sort of large metropolitan area even if separated in several municipalities. So the congestion cost for the whole NUTS3 is computed using the cost/inhabitant of the largest size class applied to the 80% of the total population of the NUTS3 (not 100% because the definition of urban zone is that no more than 20% of population lives in rural areas).	It is assumed that there are two other relevant urban areas of about 25,000 inhabitants in the NUTS3: inhabitants of these urban areas are affected by congestion cost together with population of the cities >50,000 inhabitants	

Source: TRT

Table 6-6: Rules to estimate the number of urban areas < 50,000 inhabitants by NUTS3 zone – Zones without cities with more than 50,000 inhabitants

NUTS3 population	NUTS3 classification		
	Urban	Mixed	Rural
> 250,000 inhabitants	It is assumed that there are three urban areas of about 25,000 inhabitants in the NUTS3: inhabitants of these urban areas are affected by congestion cost	It is assumed that there is one urban area of about 25,000 inhabitants in the NUTS3: inhabitants of these urban areas are affected by congestion cost	It is assumed that there are no relevant urban areas in the NUTS3. So the congestion cost is zero
150,000 – 250,000 inhabitants	It is assumed that there are two urban areas of about 25,000 inhabitants in the NUTS3: inhabitants of these urban areas are affected by congestion cost		
75,000 – 150,000 inhabitants	It is assumed that there is one urban area of about 25,000 inhabitants in the NUTS3: inhabitants of these urban areas are affected by congestion cost	It is assumed that there are no relevant urban areas in the NUTS3. So the congestion cost is zero	
< 75,000 inhabitants	It is assumed that there are no relevant urban areas in the NUTS3. So the congestion cost is zero		

Source: TRT

6.1.2 Estimating urban congestion costs by NUTS3 region

Using the rules reported in the tables, the number of urban areas for which computing congestion costs have been estimated for each NUTS3 in Europe. Using the average congestion costs per city related to passenger cars in a NUTS3 region (see paragraph 6.1.1), total urban congestion cost by NUTS3 region was quantified. An additional assumption made has been that in cities with less than 50,000 inhabitants congestion occurs only in the peak period of the day. According to the cost values estimated with the procedure explained in section 4, considering only peak time means retaining some 80% to 85% of total urban congestion costs.

The result of the process has been the urban congestion cost (both in terms of delay cost and in terms of deadweight loss) related to passenger cars on a NUTS3 basis at European level. Figure 6-8 shows the value of passenger car urban congestion costs in each NUTS3.

Figure 6-8: Yearly urban delay cost by NUTS3 region in 2014
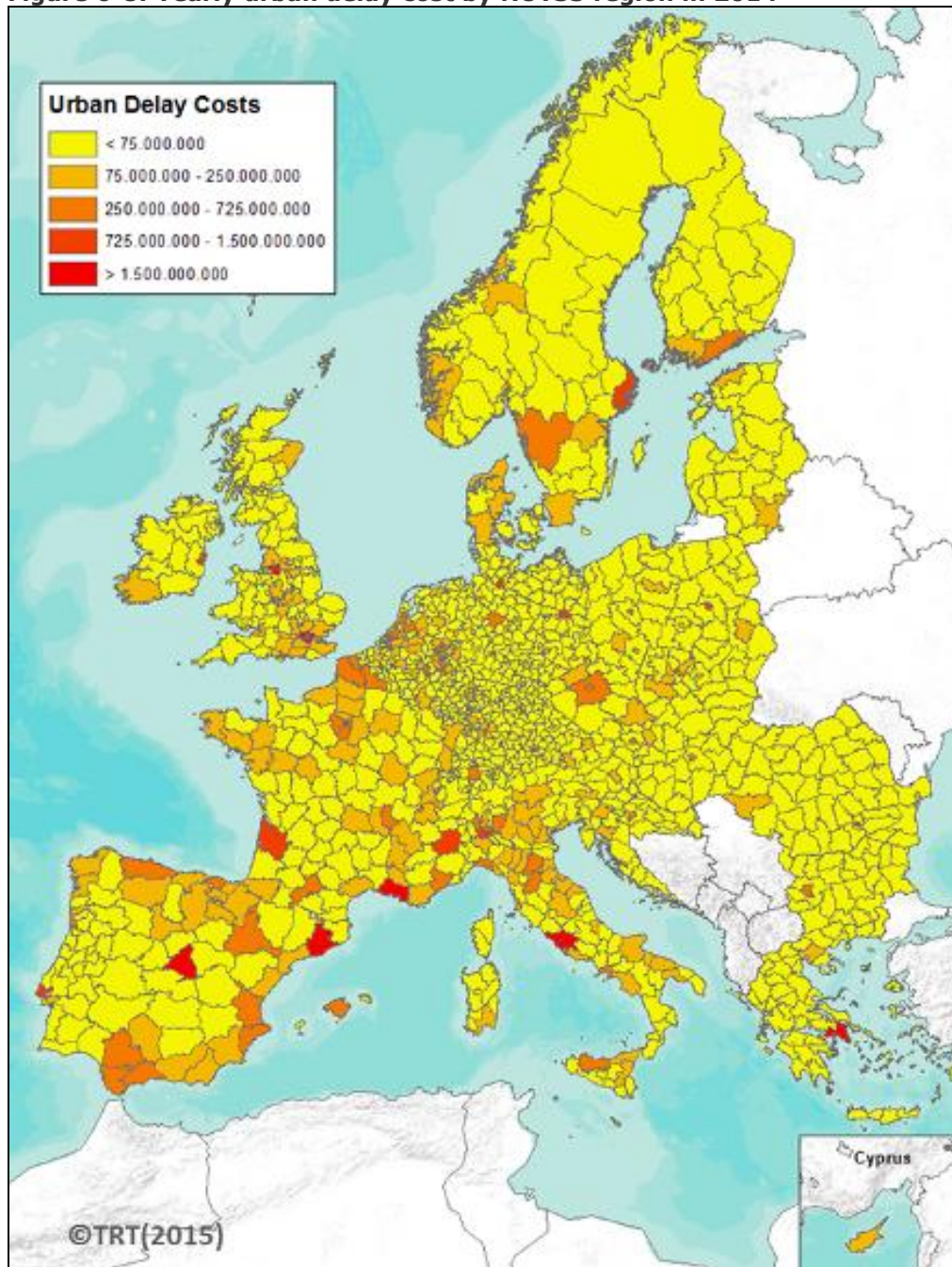
The values in Figure 6-8 are not immediately comparable among countries because regions are of different size and because values of travel time also differ. In Figure 6-9 and Figure 6-10, congestion costs are expressed in terms of yearly cost per capita. It can be appreciated that several zones have a relatively small total congestion cost but a higher cost per capita (these regions are generally characterised by one main urban area where a large share of population is concentrated whereas in zones where populations is more distributed in medium cities the cost per capita is generally lower.

Figure 6-11 presents the ratio between urban congestion cost related to passenger cars and regional GDP. Using this ratio, the picture of urban congestion cost in Europe changes significantly. While in absolute terms and per capita, higher costs are

generally found in Western European regions, when congestion costs are compared to GDP, many Eastern Europe regions reach the top of the ranking. This result has been obtained despite using values of time adjusted by country and so lower in Eastern Europe countries.

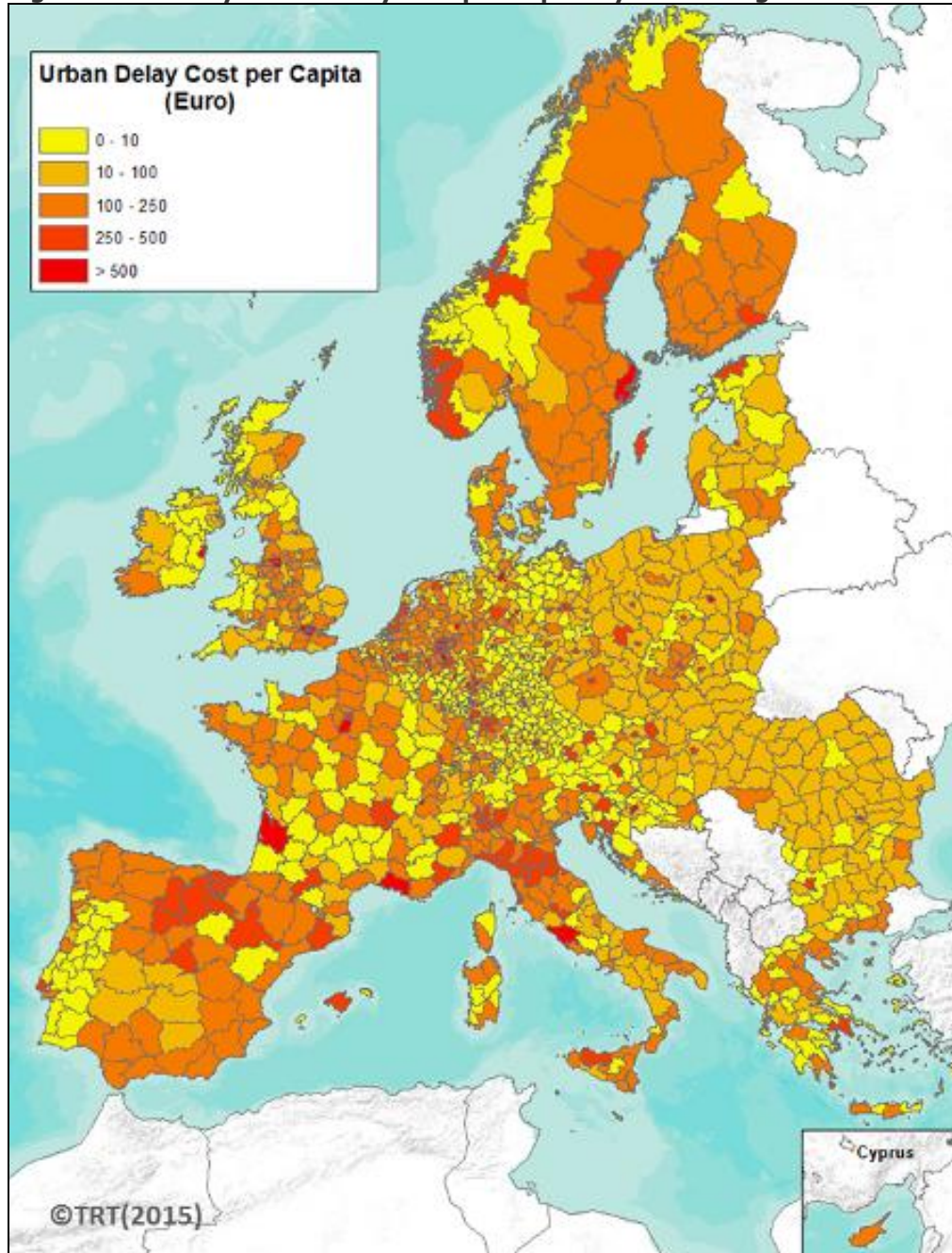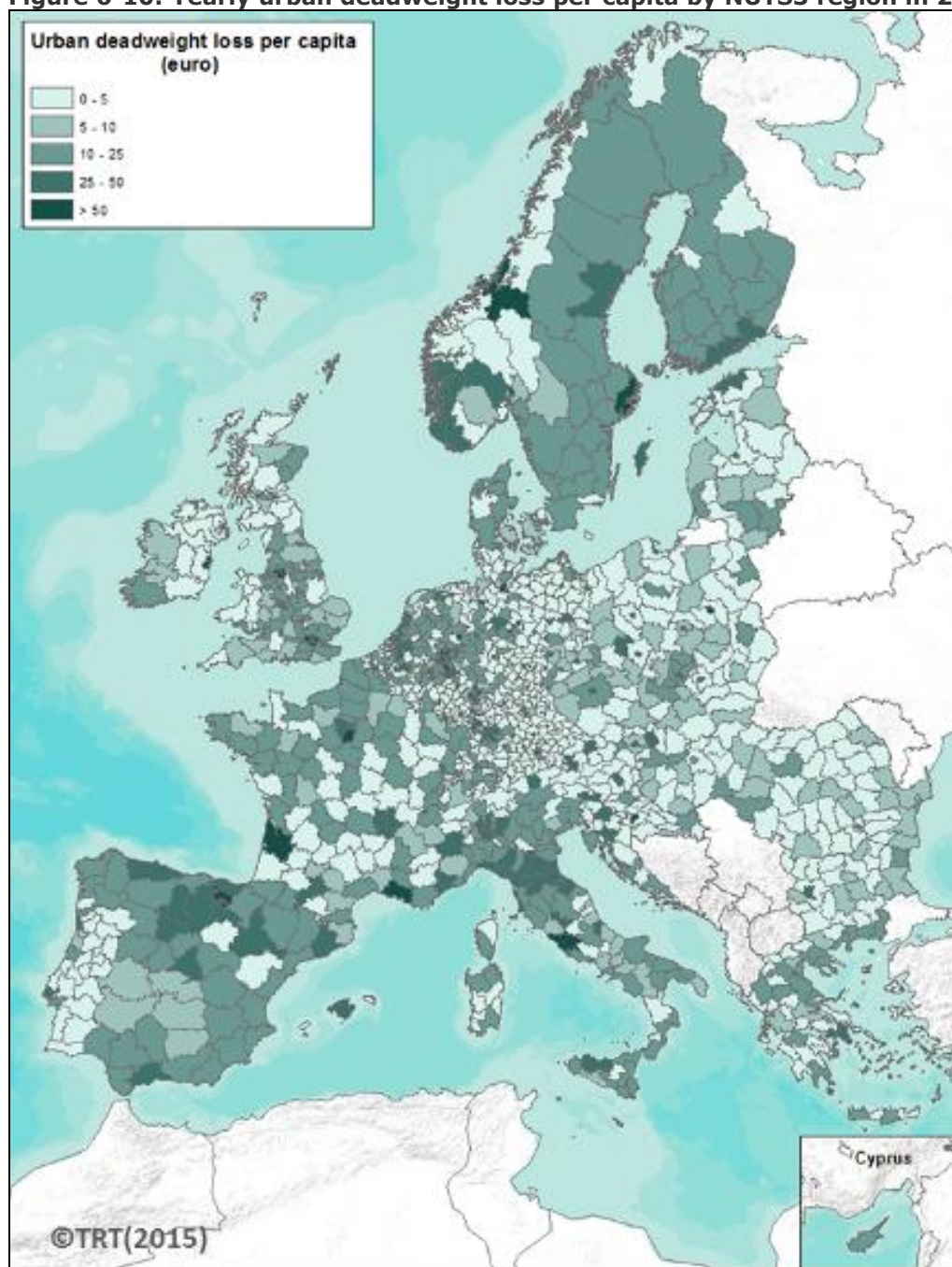**Figure 6-9: Yearly urban delay cost per capita by NUTS3 region in 2014**

Figure 6-10: Yearly urban deadweight loss per capita by NUTS3 region in 2014
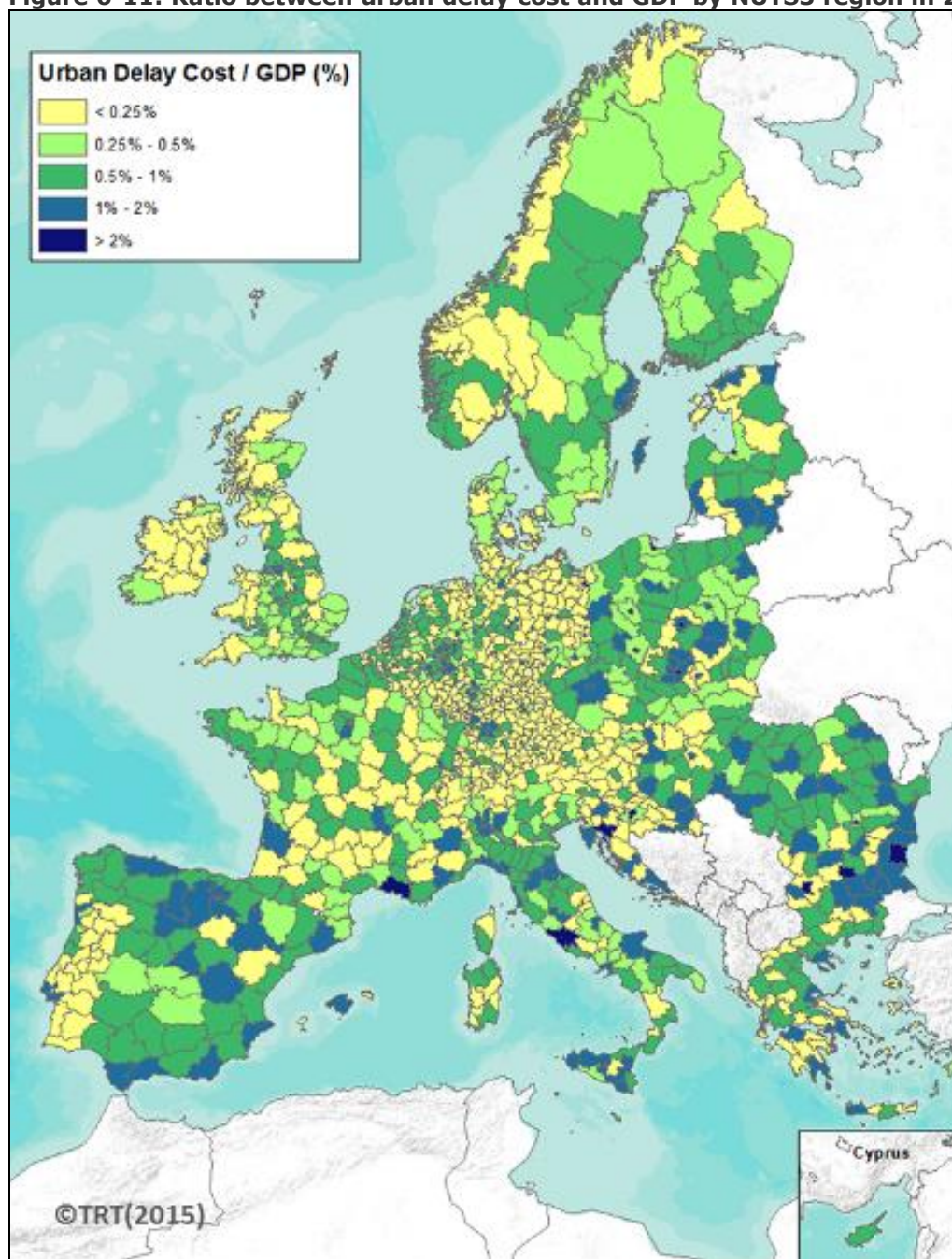
Figure 6-11: Ratio between urban delay cost and GDP by NUTS3 region in 2014

Table 6-7 reports the total urban congestion costs related to passenger cars estimated by country (both in terms of delay cost and in terms of deadweight loss). According to our estimates, at European level (EU28), urban congestion costs account for more than 110 billion Euros/year in terms of delay cost and about 10.9 billion Euros/year in terms of deadweight loss, These two figures are equivalent to about 0.8% and, respectively, 0.1% of GDP.

As we demonstrated in section 4.3, the estimates of congestion cost are sensitive to different assumptions regarding some parameters and some input data used for the estimations. Namely, if demand is assumed to be more elastic and if steeper speed-flow curves are used, deadweight loss (external cost) could be significantly higher up

to twice the reference estimate. At the same time, if average delays proposed by INRIX are used instead of TomTom data, delay congestion costs could result lower.

In absolute terms, larger countries explain the largest part of this cost, while in terms of cost per unit of GDP Eastern European countries are above the EU average.

Table 6-7: Yearly urban congestion cost by country

Country	Yearly urban delay cost (million Euro/year)	Urban delay cost: share of GDP (%)	Yearly urban deadweight loss (million Euro/year)	Urban deadweight loss: share of GDP (%)
Austria	1,179	0.39%	125	0.04%
Belgium	2,208	0.60%	220	0.06%
Bulgaria	697	1.81%	71	0.18%
Croatia	766	1.73%	79	0.18%
Cyprus	143	0.80%	15	0.08%
Czech Republic	1,387	0.89%	149	0.10%
Denmark	865	0.37%	91	0.04%
Estonia	181	1.12%	19	0.12%
Finland	932	0.49%	104	0.05%
France	14,210	0.71%	1,447	0.07%
Germany	18,400	0.71%	2,045	0.08%
Greece	2,547	1.22%	253	0.12%
Hungary	1,098	1.11%	81	0.08%
Ireland	1,281	0.79%	107	0.07%
Italy	14,921	0.95%	1,444	0.09%
Latvia	291	1.44%	30	0.15%
Lithuania	340	1.10%	35	0.11%
Luxembourg	109	0.25%	10	0.02%
Malta	33	0.50%	3	0.05%
Netherlands	3,391	0.57%	362	0.06%
Norway	1,375	0.51%	136	0.05%
Poland	4,457	1.20%	455	0.12%
Portugal	1,703	1.00%	171	0.10%
Romania	1,837	1.40%	157	0.12%
Slovakia	404	0.59%	39	0.06%
Slovenia	220	0.61%	23	0.06%
Spain	10,049	0.96%	1,092	0.10%
Sweden	2,610	0.68%	274	0.07%
Switzerland	1,108	0.23%	107	0.02%
United Kingdom	23,862	0.71%	2,071	0.06%
EU28	110,120	0.77%	10,972	0.08%

Source: TRT estimation

6.2 Total congestion cost

The estimation of overall congestion costs related to passenger cars is the result of the contribution of urban and inter-urban congestion, as described in the chapter above. We present total congestion cost for passenger demand only because we could not estimate urban cost for freight. In fact, TomTom urban congestion data refers to passenger commuting trips (e.g. assuming a trip of certain duration) and it cannot be transferred to the freight case without additional information on urban freight transport patterns. As shown in the previous section freight inter-urban costs are a share of passenger costs. The following tables report the estimated total congestion costs by country for passengers. At the European level (EU28), delay congestion cost (internal cost) for passenger accounts to nearly 140 billion euro/year (Table 6-8). Estimated deadweight loss (external cost) amounts to some 15.7 billion euro/year (Table 6-9). The value of delay cost corresponds to about 1% of EU GDP. This is a not negligible cost for European drivers even though one should always keep in mind that, as discussed in section 2.4, it is an estimation of the monetary equivalent of additional travel time rather than a financial cost actually borne by individuals.

Of course, the absolute value of congestion cost is higher in bigger Western countries (e.g. United Kingdom, France, Germany and Italy). However, when analysed as percentage of GDP, Eastern countries are more often above the EU average, with Bulgaria at the top of the ranking (more than 2% of GDP) and also Poland and Romania above 1.5%of GDP. On the other end of the ranking there are countries like Austria and Luxembourg where passengers delay cost is estimated to half percentage point of GDP or even less. This does not necessarily mean that in these countries congestion is very limited: at least in part the result depends on the high GDP level.

Table 6-8: Yearly total delay congestion cost per country (passengers)

Country	Yearly total congestion cost (million Euro/year)	Share of GDP (%)	Yearly inter-urban delay cost (million Euro/year)	Yearly urban delay cost (million Euro/year)
Austria	1,529	0.51%	350	1,179
Belgium	3,985	1.08%	1777	2,208
Bulgaria	871	2.26%	174	697
Croatia	798	1.80%	32	766
Cyprus	143	0.80%	n.a.	143
Czech Republic	1,671	1.07%	284	1,387
Denmark	1,327	0.57%	462	865
Estonia	196	1.21%	15	181
Finland	1,086	0.58%	154	932
France	21,294	1.06%	7084	14,210
Germany	20,904	0.80%	2504	18,400
Greece	2,817	1.35%	270	2,547
Hungary	1,254	1.27%	156	1,098
Ireland	1,648	1.01%	367	1,281
Italy	19,300	1.22%	4379	14,921
Latvia	318	1.58%	27	291
Lithuania	401	1.30%	61	340
Luxembourg	190	0.44%	81	109
Malta	33	0.50%	n.a.	33
Netherlands	4,936	0.83%	1545	3,391
Norway	1,473	0.55%	98	1,375
Poland	6,402	1.73%	1945	4,457
Portugal	2,336	1.37%	633	1,703
Romania	2,187	1.66%	350	1,837
Slovakia	562	0.81%	158	404
Slovenia	262	0.72%	42	220
Spain	12,499	1.20%	2450	10,049
Sweden	2,925	0.76%	315	2,610
Switzerland	1,705	0.36%	597	1,108
United Kingdom	28,101	0.83%	4239	23,862
EU28	139,974,	0.98%	29,854,	110,120,

* only urban cost for Cyprus and Malta
Source: TRT estimation

Table 6-9: Yearly total deadweight loss (external cost) per country (passengers)

Country	Yearly total deadweight loss (million Euro/year)	Share of GDP (%)	Yearly inter-urban deadweight loss (million Euro/year)	Yearly urban deadweight loss (million Euro/year)
Austria	181	0.06%	56	125
Belgium	504	0.14%	284	220
Bulgaria	99	0.26%	28	71
Croatia	84	0.19%	5	79
Cyprus	15	0.08%	n.a.	15
Czech Republic	194	0.12%	45	149
Denmark	165	0.07%	74	91
Estonia	21	0.13%	2	19
Finland	129	0.07%	25	104
France	2,580	0.13%	1133	1,447
Germany	2,446	0.09%	401	2,045
Greece	296	0.14%	43	253
Hungary	106	0.11%	25	81
Ireland	166	0.10%	59	107
Italy	2,145	0.14%	701	1,444
Latvia	34	0.17%	4	30
Lithuania	45	0.15%	10	35
Luxembourg	23	0.05%	13	10
Malta	3	0.05%	n.a.	3
Netherlands	609	0.10%	247	362
Norway	152	0.06%	16	136
Poland	766	0.21%	311	455
Portugal	272	0.16%	101	171
Romania	213	0.16%	56	157
Slovakia	64	0.09%	25	39
Slovenia	30	0.08%	7	23
Spain	1,484	0.14%	392	1,092
Sweden	324	0.08%	50	274
Switzerland	202	0.04%	95	107
United Kingdom	2,749	0.08%	678	2,071
EU28	15,747	0.11%	4,775	10,972

* only urban cost for Cyprus and Malta
Source: TRT estimation

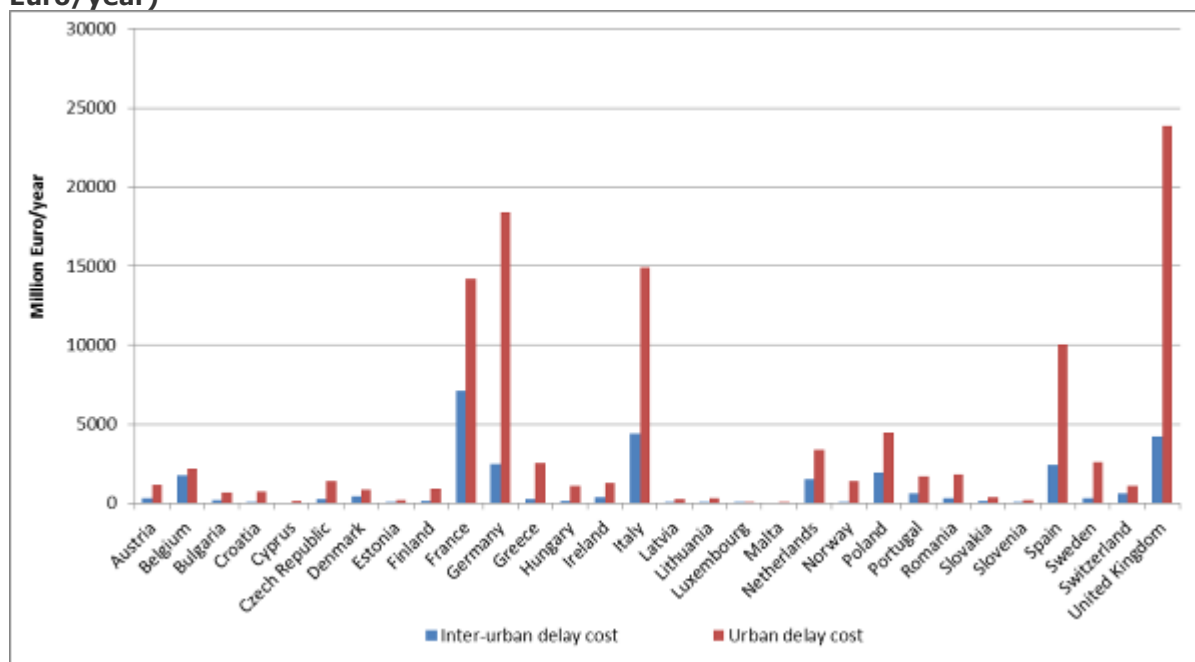**Figure 6-12: Urban and inter-urban delay cost for passenger cars by country (Million Euro/year)**
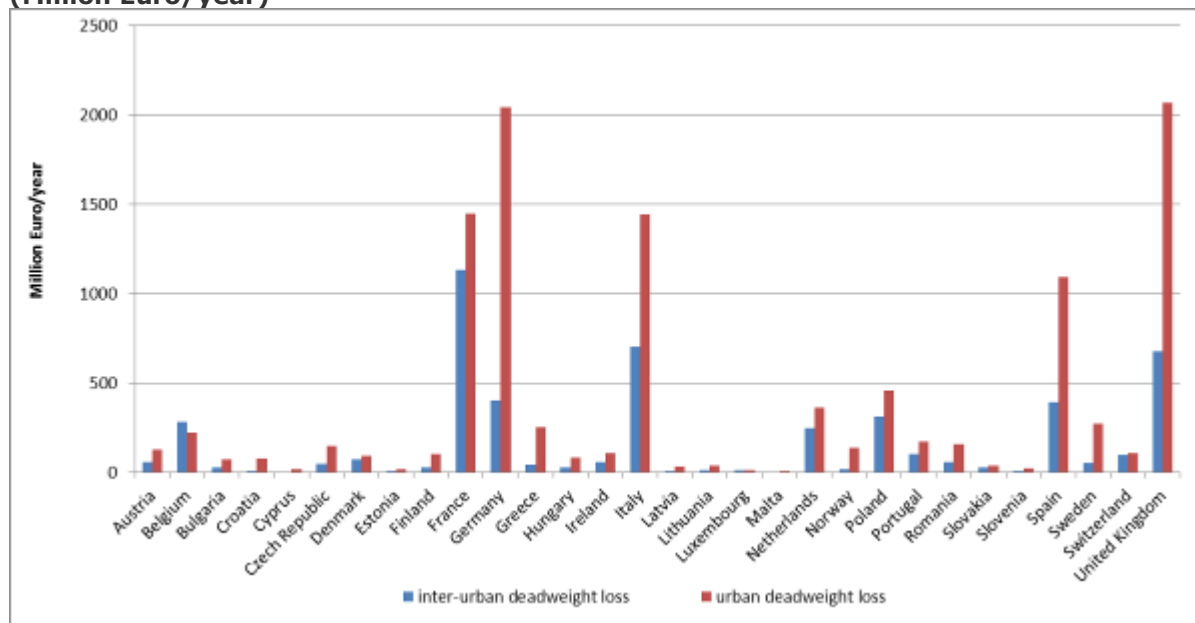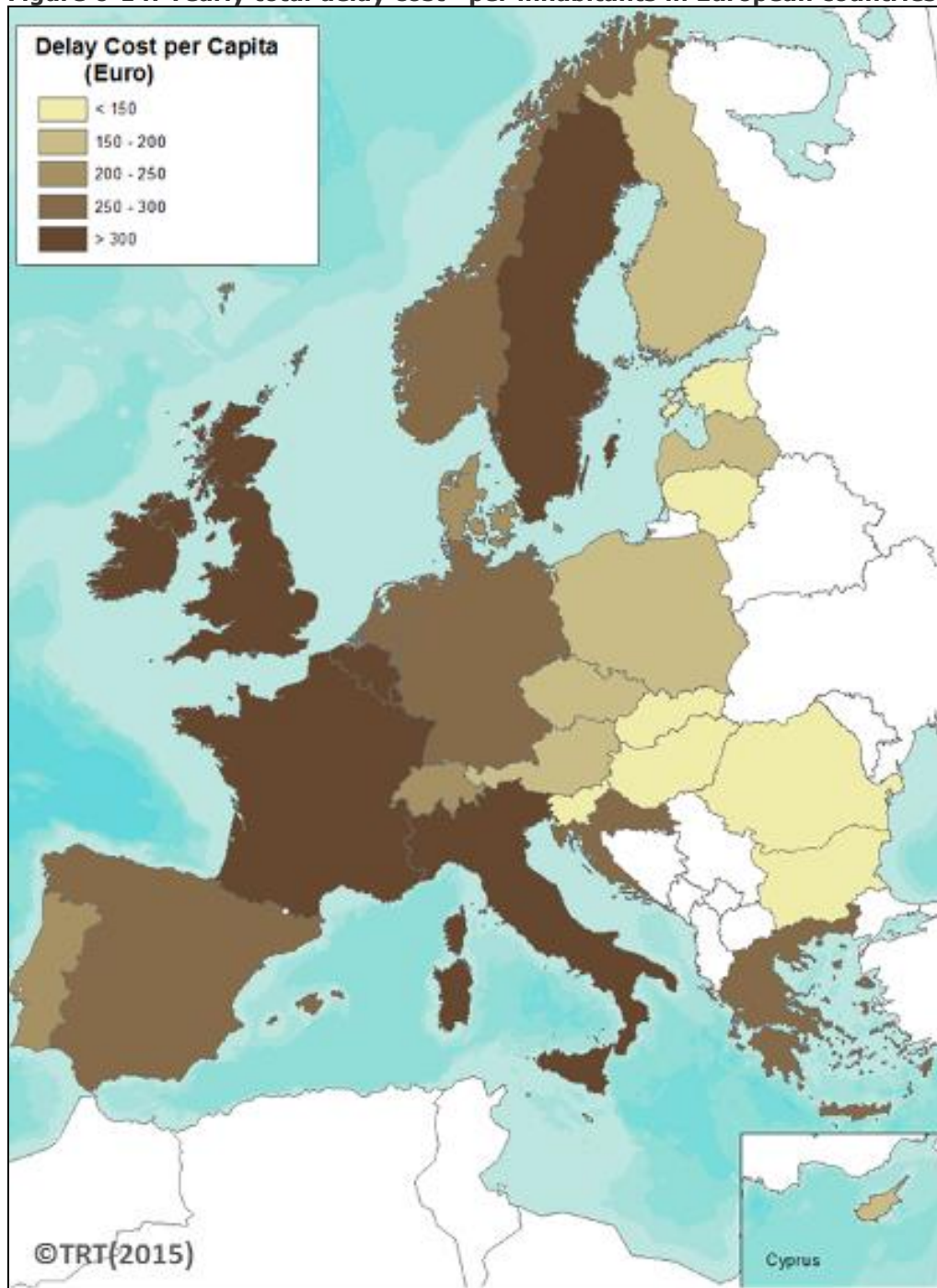

Figure 6-13: Urban and inter-urban deadweight loss for passenger cars by country (Million Euro/year)
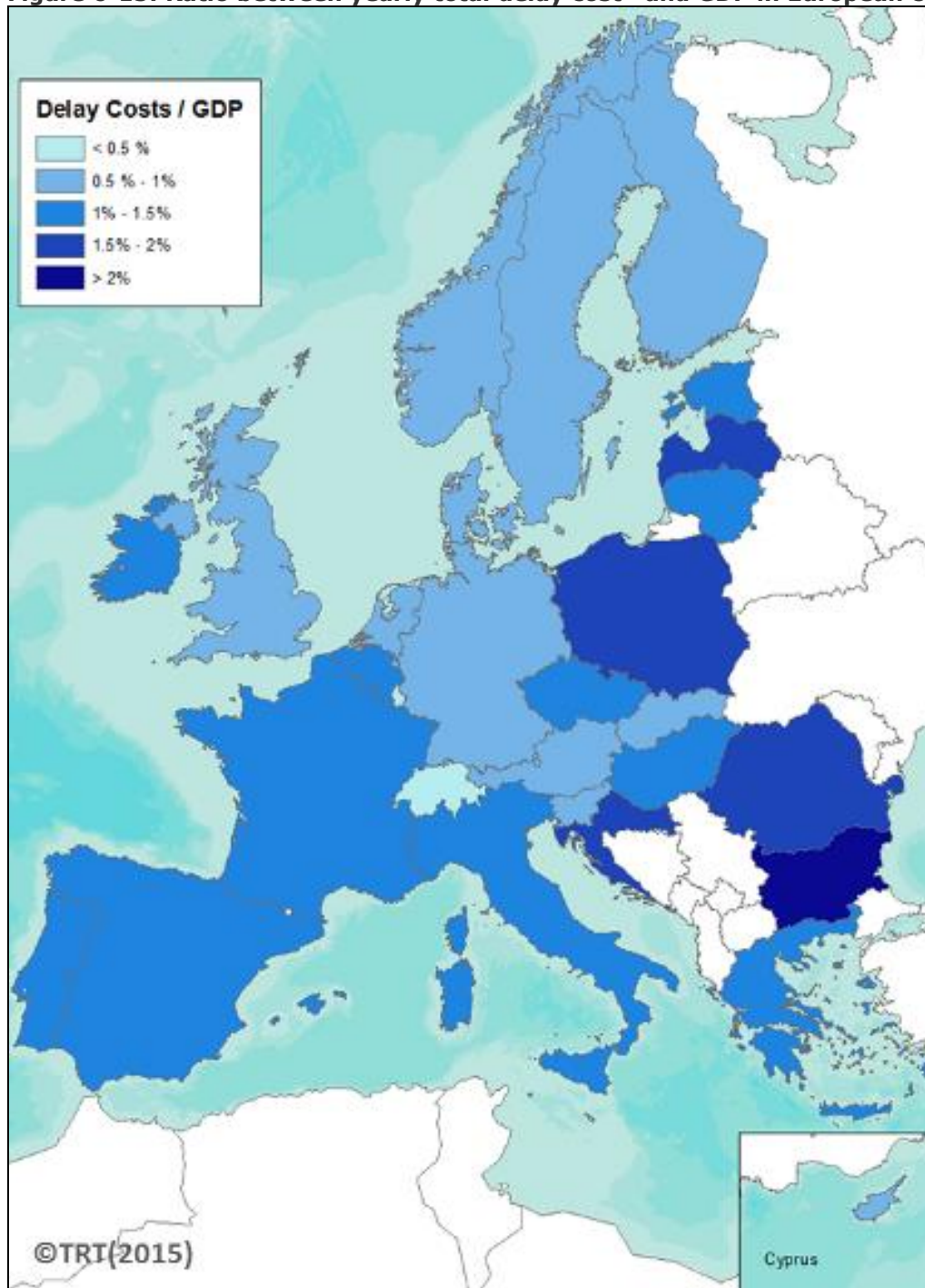

The following figures show the amount of yearly total delay cost per inhabitants in European countries and its ratio with GDP.

Figure 6-14: Yearly total delay cost* per inhabitants in European countries

* only urban cost for Cyprus and Malta

Figure 6-15: Ratio between yearly total delay cost* and GDP in European countries

* only urban cost for Cyprus and Malta

6.3 Comparison with literature

The result estimated in the previous paragraph has been compared to available studies at the country level and at the European level in order to assess whether the estimations obtained are consistent with previous values.

A first comparison concerning three European countries is summarised in Table 6-10. According to Cebr-INRIX (2012) direct cost (delay and fuel) of congestion in the Large

Urban Zones of **United Kingdom, France** and **Germany** are estimated as much as 3.6 billion Euro/year, 3.9 billion Euro/year and, respectively, 5.6 billion Euro/year. In these countries our estimations of delay costs are significantly higher: 28.1 billion Euro/year in United Kingdom, 21.3 billion Euro/year in France and 20.9 billion Euro/year in Germany. Even if we take into account only congestion at urban level, our estimation remains much larger: 23.8 billion euro/year in UK, 14.2 billion euro/year in France and 18.4 billion euro/year in Germany.

It is not surprising that our results exceed the estimates of the Cebr-INRIX study. First of all our methodology takes into account a larger number of urban areas and not only those defined as Large Urban Zones. Second, our methodology is more comprehensive also because we consider off-peak congestion and inter-urban congestion. Third, as discussed above (see paragraph 4.2.1), wasted time during peak time used in Cebr-INRIX is lower than that reported by TomTom and used as the basis of our analysis of urban congestion. Furthermore, there is also a difference when estimates based on daily wasted time are expanded to the year as the number of working days considered is not the same.

Table 6-10: Total congestion cost (Million Euro/year): comparison with Cebr-INRIX study

Source	United Kingdom	France	Germany
Cebr-INRIX (2012): Direct cost (delay and fuel)	3,620	3,883	5,647
TRT estimation: Total delay cost *(Of which Urban delay cost)*	28,101 *(23,800)*	21,294 *(14,210)*	20,904 *(18,400)*

A second comparison (Table 6-11) can be made for the estimation of the cost at the EU level (27 European countries). CE Delft et al. (2011) report an aggregate yearly delay costs for passenger cars in a range between 98.4 to 161.3 billion euro/year, while estimated deadweight loss is between 15.9 and 26.0 billion euro/year. This data refers to both urban and inter-urban congestion. These estimates amount to about 0.7% to 1.2% of EU GDP in the year 2008 (delay cost) and, respectively 0.12% to 0.19% (deadweight loss).

Our estimate of yearly total delay cost for passenger cars is as much as 140.0 billion euro/year in EU28 while our estimate of deadweight loss is of about 15.7 billion Euro/year. Compared to current EU GDP these values correspond to about 1% of GDP (delay cost) and, respectively 0.1% of GDP (deadweight loss). Our estimation of congestion costs is therefore much in line with the comparable data.

When considering freight road transport, the CE Delft report estimates congestion costs in a range between 26.7 and 42.7 billion euro/year for Heavy Duty Vehicles (HDVs) in terms of delay cost and between 4.3 and 6.9 billion euro/year in terms of deadweight loss. Our methodology could be applied only to inter-urban congestion costs. We obtained an estimate of about 2.4 billion euro/year in terms of delay cost and 0.4 billion euro/year in terms of deadweight loss. Our results are therefore lower in comparison to CE-Delft results. Since we are considering only inter-urban congestion our estimate is necessarily lower. We noticed when presenting the results that on average inter-urban congestion costs explain some 20% of total costs (and it can be expected that inter-urban traffic is more relevant for freight than for passengers). Since our estimate is lower than 20% of the CE-Delft value, the

difference is hardly explained only by the reduced scope of the analysis. There can be various methodological reasons behind the difference, in particular, the estimates are significantly affected by the assumption made on value of time and load factors of road freight vehicles.

Table 6-11: Total congestion cost: comparison with CE Delft study

| Source	EU Delay cost	EU Deadweight loss
CE Delft et al. (2011): passenger cars HDV	98,416 to 161,331 26,695 to 42,660	15,891 to 26,015 4,311 to 6,880
TRT estimation: passenger cars HDV*	139,974 2,404	15,747 392

Only inter-urban congestion

A third comparison we present is with the data reported in a JRC study (Christidis and Ibáñez, 2012). According to this study, covering twenty European countries, the annual cost of road congestion (delay cost) for passenger and freight transport was about 111.3 billion Euro/year, i.e. about 1% of GDP in 2009.

Taking into account the same twenty countries, our estimation of delay costs for passenger cars in 2014 is about 131.2 billion Euro/year (133.6 billion euro/year including also inter-urban cost for trucks). Our estimate is therefore much in line with the term of comparison. The JRC study was based on the same data regarding observed delays, but this data has been used in our methodology in quite a different way and only for inter-urban costs. Therefore the good match between the two sources is not an artefact.

If we look at single countries, the comparison is also very good even though some differences occur from country to country, as shown in Figure 6-16. In most of the countries our methodology provides higher costs, while for a few countries (e.g. Germany, Finland, and Lithuania) we obtained slightly lower congestion costs.

Figure 6-16: Total congestion delay cost: comparison with JRC study
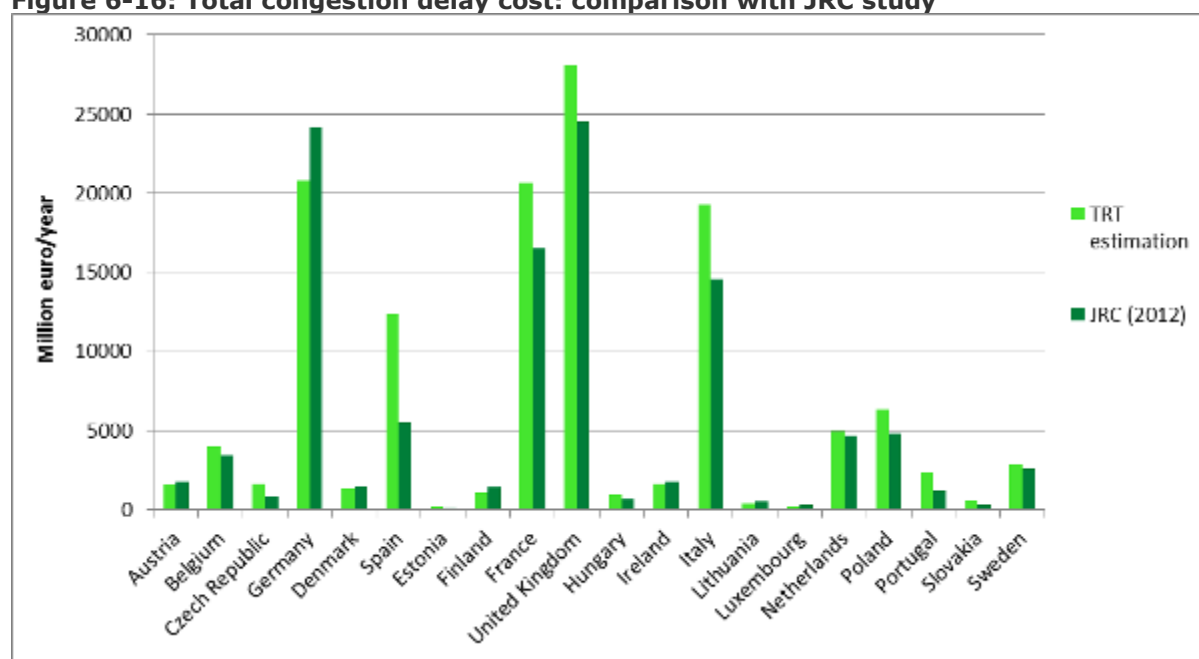
7 Conclusions

This report has presented our estimates of road congestion costs in EU, focusing on time losses (i.e. excluding other costs such as cost of fuel, environmental externalities, and indirect costs for consumers). Building on a theoretical discussion we have identified two different definitions of congestion cost based on alternative interpretations of impacts that traffic generates: delay cost and deadweight loss. Using a range of available information and tools we have developed a methodology to provide a quantification of congestion costs under both definitions. The methodology is sometimes complex, the estimations of urban and inter-urban costs are based on different procedures and data and several assumptions have been needed to obtain results. Results are related to congestion experienced by passenger cars at both urban and inter-urban level, while for the freight case only the inter-urban dimension has been considered (due to lack of data). At urban level it has been assumed that the opportunity cost of time depends on local features and particularly economic activity, therefore applying values of time parameters by NUTS3 region, while at inter-urban level the national value of time has been applied. We have demonstrated with some sensitivity analysis that different assumptions on key parameters can lead to significantly different values at least for urban congestion cost measured in terms of deadweight loss.

However, even considering these sources of uncertainty, the order of magnitude of the estimates is basically confirmed. Measured in terms of delay cost related to passenger cars, the monetary value of congestion in the EU is slightly more than 140 billion Euro per year, equivalent to some 1% of the GDP in the same area. Deadweight loss amounts to some 10% - 15% of this figure. In the theoretical analysis we have underlined that this is a monetary equivalent of time wasted rather than an actual expenditure.

Delay cost and deadweight loss provide two alternative measures of congestion costs. Using one or another of the two estimations is a matter of perspective. Actually, as we noted introducing the theoretical concepts, a level of transport demand below the intersection between supply curve (social costs curve) and demand curve is inefficient, despite some congestion can still be observed. In other words, total cost of congestion can fairly be measured by delay cost, but at least assuming the perspective of welfare economics, part of this cost reflects the willingness of individuals to move even at a reduced speed and so it is not a real cost. Only the inefficient part of congestion, when the monetary cost of delays exceeds individual preferences, should be removed.

All in all, if one wants to answer the questions "what is the cost of road congestion?" we think that she should make reference to the delay costs. However, if one wants to compare the costs of policy interventions aimed at alleviate congestion (e.g. infrastructure investments) with the potential benefit achievable, deadweight loss is a more meaningful measure because it takes into account of willingness to pay of individuals.

Congestion affects all European countries with some differences. In absolute terms passenger congestion costs are higher in bigger countries in Western Europe, but if compared to GDP most Eastern Europe countries suffer for higher costs. A large proportion of these costs depend on urban congestion, which explains on average

some 80% of total costs (but more in many Eastern Europe countries). Inter-urban passenger costs are more relevant especially in rich countries in the middle of Europe where probably the inhabitants of cities can use more efficient urban transport systems.

Our analysis has not unveiled any significant correlation between the estimated passenger car congestion cost (delay cost and deadweight loss) and variables representing the features of the cities (e.g. population size, car mode share, public transport mode share). The only minor correlation found was between deadweight loss per capita and population of the cities: the higher the population size the lower the average congestion cost per capita. Therefore, congestion costs at urban level seems mainly related to local conditions of each specific city.

The methodology used for the estimation makes use of real traffic data in various forms. As the availability of this data is expected to grow in the future, the methodology could be replicated and refined (e.g. with larger sets of delay data) to update the estimates and monitor the trend of congestion costs over time.

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