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UNITE

UNIfication of accounts and marginal costs for Transport Efficiency

UNITE Case Studies 7E: Brussels Urban Transport

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UNITE Case Studies 7A to 7D - Inter-urban road user costs

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Executive Summary

The EU DG TREN UNITE project is aiming to quantify the full marginal social costs of transport in Europe in a variety of settings. This paper reports the outputs of one particular case study carried out during the project, which has the implementation of the assignment model SATURN in Brussels to estimate the costs of congestion in this city.

In this study, we estimated that for the morning peak of 2005, the level of the internalising congestion charge should be 0.09 € per pcu.kilometre. This is based on a value of time of 4.30 €/hour per vehicle.

The methodology used in this case study could be generalised to other urban region. This would however require the implementation of the transport network model for the region to be analysed.

1 Context of the case study

The road congestion can be easily explained as follows: when the volume of vehicles on a road infrastructure is higher that a certain level, vehicles are disturbing each other. Their speed is diminishing. The travel time spent to achieve the trip is increasing and the cost of the trip is increasing too. As a consequence, congestion has a cost.

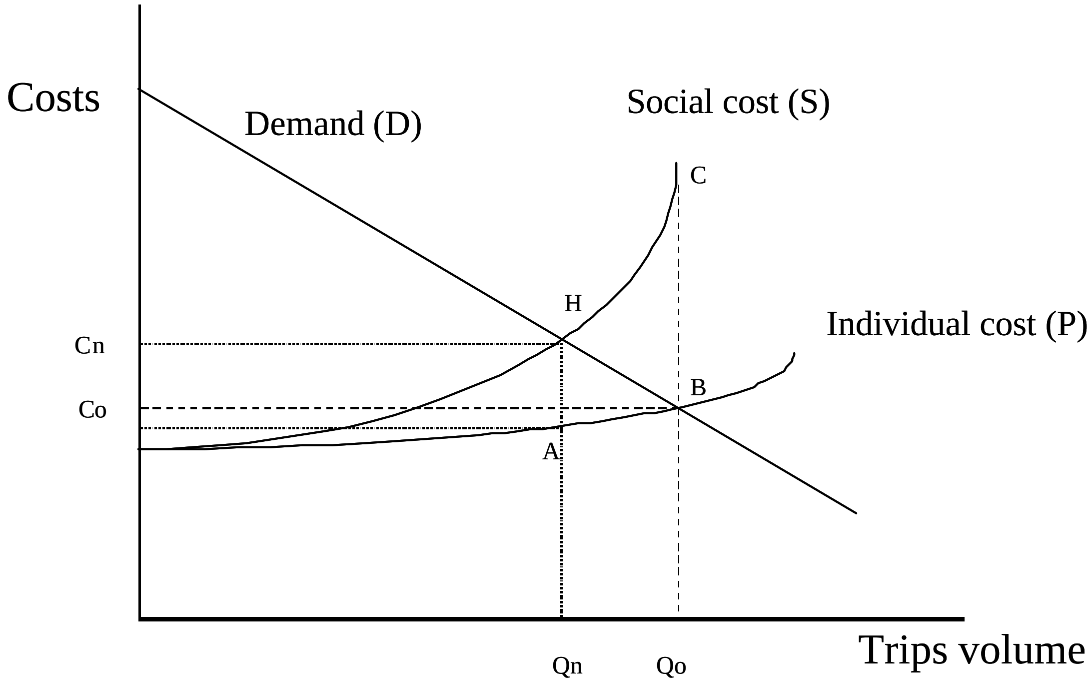
Engineers and economists have been analysing the congestion phenomena. Traffic engineers have shown the relation between the numbers of vehicles on the road and their speed and between the flow of vehicles on the road and their speed. The economists have identified the congestion problem as a problem of externalities. When vehicles are disturbing each other, the marginal driver induces a cost to the rest of the society because all other vehicles are getting slower. He does not pay anything for this cost that he is producing: he is then generating a negative externality. Hence this uncorrected market is bringing too many vehicles on the road.

Figure 1 provides the classical economic analysis. The demand curve (D) shows the trips demand in vehicle*km for a typical road depending on the generalised cost (usually time and distance cost). The marginal individual cost curve (P), which can be considered as the supply curve, represents the individual cost supported by one vehicle related to the trips volume.

When the level of trips volume is low, this cost equals the vehicle operating cost and the cost of the travel time with a high speed. When the level of trips volume is increasing, the speed is diminishing, the travel time cost and the operating cost are increasing and the slope of the "marginal private cost curve" too. The market equilibrium is located in the intersection of the demand curve (D) and the supply curve (P) with a trip volume of Qo. At this point the driver is supporting a cost equal to the benefit of his trip. Further, he is supporting a cost higher than his benefit and does not realise the trip.

Unfortunately, this equilibrium is not optimum from the point of view of the society. This is easily understandable by considering the marginal social cost curve (S), which represents the social cost induced by a vehicle depending on the level of trips volume. This cost equal the individual cost increased by the cost of the time losses endured by all the other vehicles. The intersection point of the demand curve (D) and the marginal social cost curve (S) defines the optimum situation from the point of view of the society and corresponds to a trips volume Qn. Further, and for example in Qo, the society gains QoB for one additional trip and loses QoC for this trip.

Figure 1: Individual and social cost of transport



It is important to note that:

- The internalising tax is equal to AH, at the optimum level of traffic Qn and not at the equilibrium point Qo;
- The internalising tax AH cannot be defined considering only congestion. The other externalities have to be taken into account (operating, pollution, noise, accidents marginal cost non considered in the insurance premium) and the level of taxes already paid by the vehicle and included in the curves P and S.

If a general agreement exists concerning the analysis of the congestion and of the measures to be taken to reduce it, there is not yet a unique theory concerning the way to measure it and to estimate its cost.

The definition of the congestion induces the comparison between the congestion scenario and a reference scenario. The congestion scenario is quite easy to define: in this scenario, the congestion cost has to be measured. The difficulty is the assumptions to be taken in the reference scenario. Three definitions can be envisaged:

- the most common one: the most frequently proposed and used one is the free flow situation: there is quite no vehicle on the road; this definition is not realistic because it would induce non-acceptable road capacity investment road are not build to be empty!
- the engineer's one which correspond to the maximum flow of the road; this definition is also critical because it completely ignores the trips demand curve: it is independent of the user utility;
- the economist's one which has been defined above before and which is illustrated at the figure 1. The total congestion cost is here the cost that would be avoided if the congestion were reduced at its optimal level. It seems to be the most satisfying one: this cost is related to the transport demand, to the capacity of infrastructure, to the speed flow curve and to the value of time of the users.

This paper presents an estimation of the congestion cost based on the third definition of the reference scenario for the Brussels urban area.

This case study addresses car users marginal cost in term of congestion time, pollutant emissions and accidents taking into account modal shift between modes due to modification of global demand.

2 Brussels' model description

The "model" used to calculate the marginal cost of congestion in the Brussels area is composed of two main components:

- the Brussels demand model, which provides the volume of car trips to be considered on the network according to the level of total volume of trips;
- the Brussels road network model which provides indicator of speed; vehicle*hours, vehicle*km, etc. according to the volume of car trips to be considered.

2.1 The Brussels demand model

The demand model is a STRATEC home made procedure that was computed for the IRIS Brussels Master Plan in 1993. It consist of a classical four step model:

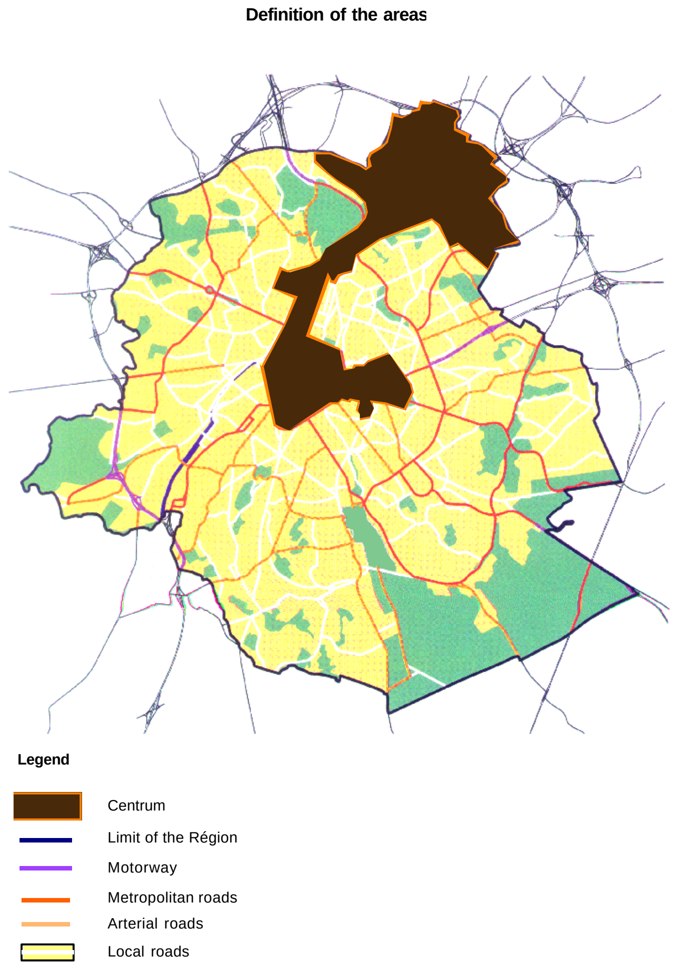
- the emission attraction sub-model provide the peak hours number of trips respectively from each origin zone and to each destination zone related to the location of the household, job and commercial activity;
- the distribution procedure which enables to distribute the trips from each origin zone to each destination zone;
- the modal split sub-model is based on logit models calibrated by trip purpose and mainly related to car travel time, public transport travel time, travel distance and car ownership rate;
- the road traffic and public transport assignment sub-models:
  - the road traffic assignment model is a SATURN 8.3 assignment model of the Brussels area, its periphery and the rest of Belgium which provides the car travel times from each origin zone to each destination zone according to the volume of car determined by the modal choice model;
  - the public transport assignment model is a TRIP assignment model of the Brussels area, its periphery and the rest of Belgium which provides the travel times by public transport from each origin zone to each destination zone related to the definition of the public transport supply.

The STRATEC demand model is covering all trips to Brussels. The geographical subdivision in zone is composed of 184 zones covering the whole country of which 101 zones covering the Brussels-Capital Region, 66 covering its periphery and 17 covering the rest of Belgium.

The STRATEC demand model has been calibrated on household survey carried out in 1991 for the IRIS Brussels Master Plan and on the 1981 National Census.

The modal split sub-model and the road traffic assignment modal are iterative: for a given total demand scenario, the modal split model provides the road traffic demand matrix and the public transport demand matrix, notably depending on the travel time by car and public transport. The road traffic demand is assigned on the SATURN 8.3 road network model, which provides the resulting origin-destination time matrix by car. This origin-destination time matrix is introduced in the modal split model, which generates new demand matrix, etc. The iterative procedure is stopped at the convergence level.

Figure 2: The Brussels geographical areas



2.2 The Brussels road network model

External cost of congestion and interaction between congestion and other externalities have been estimated using the SATURN 9.5 simulation model of Brussels-Capital Region.

The Brussels-Capital simulation model has been build and calibrated by STRATEC in 1997 on behalf on the Ministry of the Brussels-Capital Region. It considers the main Brussels-Capital network. The main road network is composed of four different hierarchical levels of road: motorway, metropolitan road, arterial streets and local streets. The rest of Belgium has been defined as an assignment model except the main intersections, which have a sensitive impact on the Brussels-Capital network operation: these ones have been incorporated in the simulation model. The public transport (bus and tram) bicycles and pedestrians are also taken in account.

The Brussels-Capital model includes 5305 links and 2032 intersections (1169 priority intersections and 575 traffic light intersections, 99 roundabouts and 189 intersections external of the limits of the dynamic model). Figure 2 hereafter provides the definition of the geographical areas used in the model.

The implementation of the Brussels SATURN model explicitly describes each junction. SATURN-Brussels thus provides for each node the maximum capacity for each lane and combination of directions, as a function of factors such as traffic light cycles or the type of crossroads or roundabout. The capacity of the network is thus determined by the capacity of the junctions, not by speed-flow relations on the links.

3 Database and assumptions

3.1 Definition of the scenarios

Demand scenarios have been built by increasing/reducing the global transport demand uniformly. The 2005 planning scenario of the IRIS Brussels Master Plan has been considered as the reference.

Uniform increase/decrease of the reference global demand matrix from 75% to 125% have been tested:

- in a first step, impacts on modal shift between cars and public transport have been carried out using the Brussels demand model as described in section 2.1. The output of this procedure was the car matrix resulting from uniform increase/decrease from 75% to 125% of the planning global IRIS Master Plan origin-destination matrix; the demand elasticity is thus a result of the model.
- in a second step, impact in term of marginal congestion cost, environmental cost and pollution cost have been calculated.

3.2 Assumptions

3.2.1 Marginal congestion cost

The Wardrop Equilibrium default assignment procedure within SATURN is based on Wardrop's Principle of traffic equilibrium, which may be stated as: Traffic arranges itself on congested networks such that the cost of travel on all routes used between origin-destination pair is equal to the minimum cost of travel and all unused routes have equal or greater cost. It seeks to minimise the travel cost of each individual driver.

The SATURN assignment procedure also allows a "system optimal" assignment option, which minimises the total cost of travel in a network, in contrast to the Wardrop Equilibrium (or user optimum) assignment.

The marginal congestion cost appears as the difference between the marginal social cost resulting from the "system optimal" assignment and the marginal private cost resulting from the "Wardrop Equilibrium" assignment.

As far as convergence problems can happen when using the "system optimal" assignment with a SATURN simulation model, the SATURN 9.5 Brussels simulation model has been converted in an assignment model, for the need of this case study.

Impacts in term of congestion loss of time have been be provided by the model in term of time cost. The value of time which has been used to estimate the monetary value of the congestion time is the one which has been estimated in the ESTEEM – TRACE projects concerning the trips travelled inside or to the Brussels Region: 4.30 EURO/h per vehicle. This value of time has been calculated for a similar geographical zone (Brussels and its periphery) and is considering a similar segment of trips (trips to Brussels at the morning peak hours): the same distribution of traveller by trip purpose and socio economic sub-segment can be assumed.

3.2.2 Environmental cost

Environmental cost are based on the IRIS Master Plan calculation hypothesis taking into account emissions costs related to the avoidance cost by type of road

3.2.3 Accident cost

Accidents have been estimated from the distribution of vehicles by hierarchical level of road using accident rate by hierarchical level of road. Accident costs are based on the calculation hypothesis of the IRIS Brussels Master Plan taking into account:

- the accident rate by type of road
- the respective rate of accident related to material damage and corporal damage
- the frequency of the different level of corporal damage
- the average cost of each type and level of damage

4 Results

Curves have been drawn, representing the responses in term of marginal congestion costs, environmental costs and accidents costs to modifications of the traffic level.

4.1 Marginal congestion cost

The figures hereafter provide the impacts resulting of increasing/reducing the global transport demand in term of marginal congestion cost. These results are expressed in term euro per pcu.kilometre, with a value of time of 4.30 EURO/h in the study zone (source ESTEEM).

Figure 3: Marginal congestion cost by geographical area

	Marginal cost (€ / pcu.kilometre)			
Demand variation	**Centrum**	**Rest of the Region**	**Out of the Region**	**Total**
75%	0.05	0.04	0.04	**0.04**
80%	0.06	0.05	0.05	**0.05**
85%	0.08	0.06	0.06	**0.06**
90%	0.09	0.08	0.07	**0.07**
95%	0.10	0.09	0.07	**0.08**
100%	0.12	0.10	0.08	**0.09**
105%	0.13	0.11	0.09	**0.10**
110%	0.14	0.12	0.10	**0.11**
115%	0.16	0.13	0.11	**0.12**
120%	0.17	0.14	0.12	**0.13**
125%	0.19	0.15	0.12	**0.14**

Source: STRATEC

At the 100% level, i.e. at the expected level of demand in the morning peak in 2005, marginal congestion cost is 0.09 € per pcu.kilometre. If we refer to Figure 1 of this report, this is the internalising charge (AH) that should be applied to reach the optimal traffic volume (Qn).

Figure 3 provides a breakdown of marginal cost by zone. It increases as we move towards the centre of the urban area. Relatively to the city centre, it remains relatively high in the external, less urbanised part. The reason for this is that this zone includes all the major highways leading to Brussels, where a lot of congestion occurs each morning.

Figure 4 provides a breakdown of the marginal cost per type of road. The most congested roads (i.e. the one with the highest marginal cost) are not the highways, which stop at edge of the city, but the urban roads (both main and local roads). It is thus on that network that additional traffic would cause the highest additional delays.

Figure 4: Marginal congestion cost by road type

	Marginal cost (€ / pcu.kilometre)			
Demand variation	**Motorway**	**Main network**	**Local roads**	**Total**
75%	0.04	0.05	0.05	**0.04**
80%	0.05	0.06	0.06	**0.05**
85%	0.06	0.07	0.07	**0.06**
90%	0.06	0.08	0.08	**0.07**
95%	0.07	0.09	0.09	**0.08**
100%	0.08	0.11	0.10	**0.09**
105%	0.09	0.12	0.12	**0.10**
110%	0.10	0.13	0.13	**0.11**
115%	0.11	0.15	0.14	**0.12**
120%	0.11	0.16	0.15	**0.13**
125%	0.12	0.17	0.16	**0.14**

Source: STRATEC

4.2 Environmental cost

Figure 5 provides the marginal environmental costs (in euro per km) per geographical zone (and total) as a function of increasing/reducing transport demand. At the level of 100% (reference demand for 2005), this marginal cost is around €18 per 1,000 km. This is low when compared to congestion costs or to accident costs.

Figure 5: Pollution cost by geographical sector (in € / 1,000 km)

Demand variation (%)	Centrum	Rest of the Region	Out of the Region	Regional average
75	19.32	19.27	16.90	17.97
80	19.32	19.27	16.90	17.97
85	19.32	19.28	16.90	17.97
90	19.31	19.28	16.90	17.98
95	19.32	19.28	16.90	17.98
100	19.32	19.28	16.90	17.98
105	19.32	19.28	16.90	17.99
110	19.31	19.28	16.90	17.99
115	19.32	19.29	16.90	17.99
120	19.31	19.29	16.90	18.00
125	19.31	19.29	16.90	18.00

Source: STRATEC

Environmental marginal costs are similar in the city centre and the rest of the Brussels region. It only declines in the outer suburbs, but only a small amount (from €19.3 to €16.9 per 1,000 km).

4.3 Accident cost

Figure 6 provides the marginal accident costs (in euro per pcu.km) for each geographical zone and the average across all zones, as a function of increasing/reducing transport demand. At the level of 100% (reference demand for 2005), this marginal cost is around €0.385 per pcu.km.

Accident marginal costs are at €0.57 per pcu.km in the city centre, and €0.65 in the inner suburbs. Traffic is dense in both area, and accident costs is thus much higher than in the outer suburbs (€0.18 per pcu.km), where traffic is less dense.

Figure 6: Accident cost by geographical sector (in € / pcu.km)

Demand variation (%)	Centrum	Rest of the Region	Out of the Region	Regional average
75	0.558	0.642	0.178	0.378
80	0.559	0.644	0.178	0.379
85	0.563	0.646	0.178	0.381
90	0.564	0.648	0.178	0.383
95	0.566	0.650	0.178	0.384
100	0.569	0.652	0.178	0.385
105	0.572	0.655	0.178	0.387
110	0.572	0.657	0.178	0.388
115	0.574	0.659	0.178	0.390
120	0.575	0.661	0.178	0.391
125	0.577	0.663	0.178	0.392

Source: STRATEC

5 Generalisation

The methodology used in this case study could be applied to other urban region. This however requires the use of a transport network model for the region to be analysed. The work involved in building the network and an origin/destination matrix is important. If the model does not already exist for the region to be analysed, this might be a significant hurdle to the application of this methodology.

In terms of costs calculation, some parameters might have to be adapted.

For congestion costs, the value of time is generally considered to be proportional to disposable income. It should thus be adapted to the local average revenue.

For environmental costs, emission factors will depend on the structure of the fleet, in terms of vehicle size and fuel used, but mostly in terms of the penetration of new technologies (share of pre-Euro and Euro 1/2/3/4/5 vehicles in the fleet). These shares vary rapidly over time, and this improvement of the emission performance of the fleet should be taken into account in future use of this methodology.

Accidents costs are a function of health costs and accident rates. Health costs will differ from country to country, as they are a function of the average revenue per capita. They also depend on the organisation of the health system in each country, an area where strong differences exist in Europe. The accident rate per kilometre driven varies strongly across countries. Finally, the share of accident with corporal damages, and the share of accidents with severe or only light corporal damages, can also differ from country to country.

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Appendix: Variations of Marginal User Costs by Area

Table 1: Marginal congestion cost by trip kilometre by type of roads (euro/vkm)

Demand variation	Motorway	Main network	Local roads	Region average
75	0,0412	0,0486	0,0499	**0,0446**
80	0,0478	0,0589	0,0597	**0,0527**
85	0,0554	0,0703	0,0695	**0,0616**
90	0,0630	0,0829	0,0813	**0,0712**
95	0,0716	0,0940	0,0930	**0,0810**
100	0,0807	0,1072	0,1047	**0,0916**
105	0,0885	0,1170	0,1192	**0,1012**
110	0,0970	0,1328	0,1309	**0,1120**
115	0,1058	0,1466	0,1425	**0,1225**
120	0,1131	0,1561	0,1533	**0,1311**
125	0,1212	0,1729	0,1627	**0,1414**

Table 2: Marginal congestion cost by trip kilometre by geographical sector (euro/vkm)

Demand variation	Centrum	Rest of the Region	Out of the Region	Total
75	0,0538	0,0448	0,0429	**0,0446**
80	0,0647	0,0541	0,0497	**0,0527**
85	0,0762	0,0640	0,0575	**0,0616**
90	0,0884	0,0758	0,0652	**0,0712**
95	0,1013	0,0864	0,0740	**0,0810**
100	0,1154	0,0981	0,0833	**0,0916**
105	0,1285	0,1095	0,0912	**0,1012**
110	0,1445	0,1226	0,0995	**0,1120**
115	0,1611	0,1338	0,1086	**0,1225**
120	0,1717	0,1437	0,1159	**0,1311**
125	0,1930	0,1548	0,1239	**0,1414**

Table 3: Pollution cost by trip kilometre by type of roads (euro/vkm)

Demand variation (%)	Motorway	Main network	Local roads	Region average
75	0,0169	0,0194	0,0194	0,0180
80	0,0169	0,0194	0,0194	0,0180
85	0,0169	0,0194	0,0194	0,0180
90	0,0169	0,0194	0,0194	0,0180
95	0,0169	0,0194	0,0194	0,0180
100	0,0169	0,0194	0,0194	0,0180
105	0,0169	0,0194	0,0194	0,0180
110	0,0169	0,0194	0,0194	0,0180
115	0,0169	0,0194	0,0194	0,0180
120	0,0169	0,0194	0,0194	0,0180
125	0,0169	0,0194	0,0194	0,0180

Table 4: Pollution cost by trip kilometer by geographical sector (euro/vkm)

Demand variation (%)	Centrum	Rest of the Region	Out of the Region	Total
75	0,0193	0,0193	0,0169	0,0180
80	0,0193	0,0193	0,0169	0,0180
85	0,0193	0,0193	0,0169	0,0180
90	0,0193	0,0193	0,0169	0,0180
95	0,0193	0,0193	0,0169	0,0180
100	0,0193	0,0193	0,0169	0,0180
105	0,0193	0,0193	0,0169	0,0180
110	0,0193	0,0193	0,0169	0,0180
115	0,0193	0,0193	0,0169	0,0180
120	0,0193	0,0193	0,0169	0,0180
125	0,0193	0,0193	0,0169	0,0180